# Cyclopedia

*of*

# Applied Electricity

*A General Reference Work on*

DIRECT-CURRENT GENERATORS AND MOTORS, STORAGE BATTERIES, ELECTROCHEMISTRY, WELDING, ELECTRIC WIRING, METERS, ELECTRIC LIGHTING, ELECTRIC RAILWAYS, POWER STATIONS, SWITCHBOARDS, POWER TRANSMISSION, ALTERNATING-CURRENT MACHINERY, TELEGRAPHY, ETC.

*Prepared by a Corps of*

ELECTRICAL EXPERTS, ENGINEERS, AND DESIGNERS OF THE HIGHEST PROFESSIONAL STANDING

*Illustrated with over Two Thousand Engravings*

SEVEN VOLUMES

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THE editors have freely consulted the standard technical literature of America and Europe in the preparation of these volumes.* They desire to express their indebtedness, particularly to the following eminent authorities, whose well-known works should be in the library of every electrician and engineer.

Grateful acknowledgment is here made also for the invaluable co-operation of the foremost engineering firms and manufacturers in making these volumes thoroughly representative of the very best and latest practice in the design, construction, and operation of electrical machinery and instruments; also for the valuable drawings, data, suggestions, criticisms, and other courtesies.

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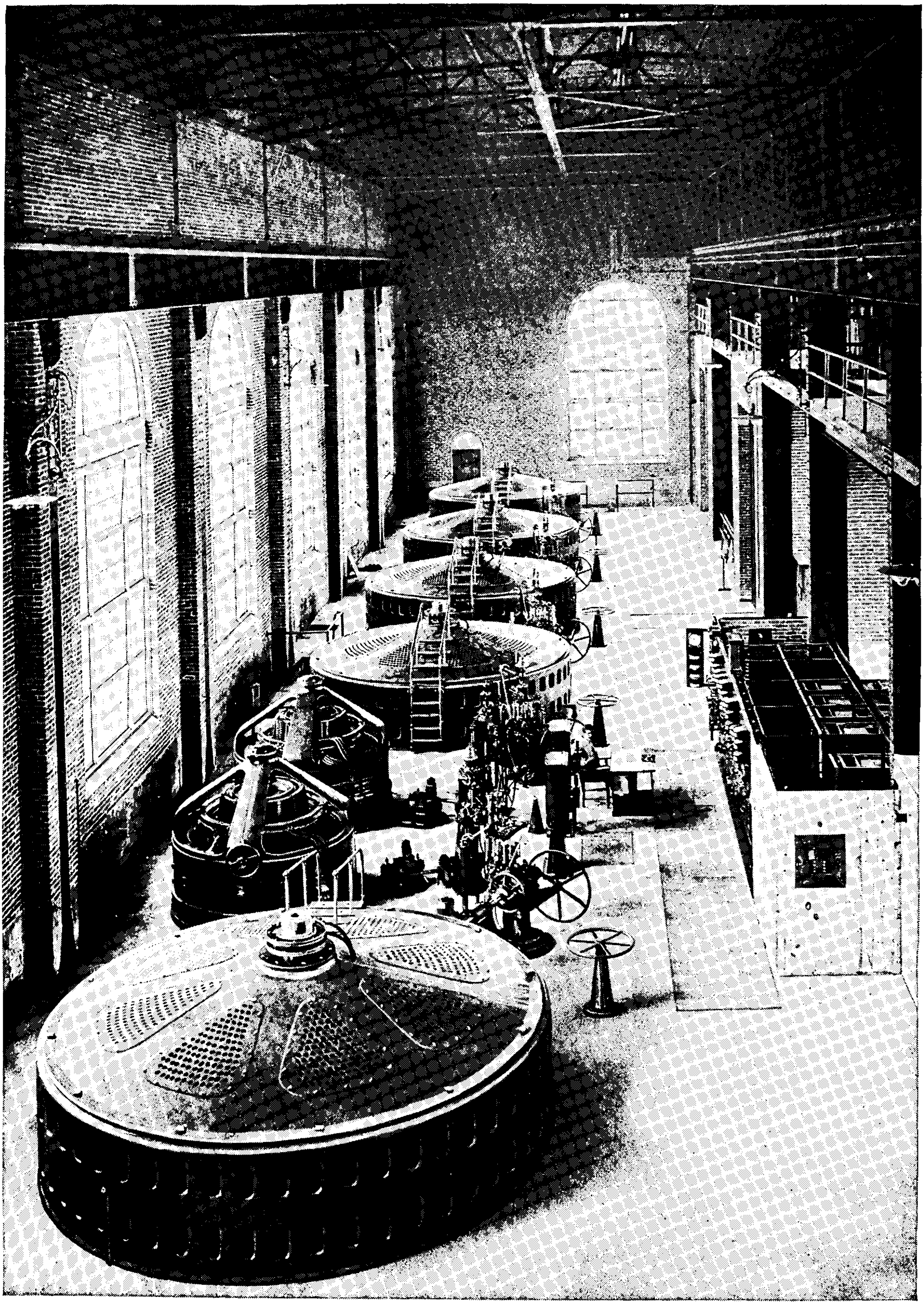

2500-K.W. 3-PHASE 2300-VOLT WATER-WHEEL-DRIVEN ALTERNATORS AND EXCITERS, CONNECTICUT RIVER POWER COMPANY, VERNON, VERMONT

*Courtesy of General Electric Company*

ONE of the simplest acts in modern life is switching on the electric current that gives light or power, or that makes possible communication between distant points. A child can perform that act as effectively as a man, so thoroughly has electricity been broken to the harness of the world's work; but behind that simple act stand a hundred years of struggle and achievement, and the untiring labors of thousands of the century's greatest scientists. To compact the results of these labors into the compass of a practical reference work is the achievement that has been attempted — and it is believed accomplished—in this latest edition of the Cyclopedia of Applied Electricity.

¶ Books on electrical topics are almost as many as the subjects of which they treat, and all of them, if gathered into a great common library, would contain so many duplicate pages that their use would entail an appalling waste of time upon the man who is trying to keep up with electrical progress. To overcome this difficulty the publishers of this Cyclopedia went direct to the original sources, and secured as writers of the various sections, men of wide practical experience and thorough technical training, each an acknowledged authority in his work; and these contributions have been correlated by our Board of Editors into a logical and unified whole.

¶ The Cyclopedia is, therefore, a complete and practical working treatise on the generation and application of electric power.

It covers the known principles and laws of Electricity, its generation by dynamos operated by steam, gas, and water power; its transmission and storage; and its commercial application for purposes of power, light, transportation, and communication. It includes the construction as well as the operation of all plants and instruments involved in its use; and it is exhaustive in its treatment of operating "troubles" and their remedies.

¶ The Cyclopedia is as thoroughly scientific as any work could be; but its treatment is as free as possible from abstruse mathematics and unnecessary technical phrasing, while it gives particular attention to the careful explanation of involved but necessary formulas. Diagrams, curves, and practical examples are used wherever they may be helpful in explaining the subject under discussion.

¶ The Cyclopedia is a compilation of many of the most valuable Instruction Books of the American School of Correspondence, and the method adopted in its preparation has been found to be the best devised for the education of the busy, practical man.

¶ A glossary of the electrical terms used in this Cyclopedia will be found in Volume VII. The definitions are given in simple language and, where it was thought desirable, reference has been made to the volume and page where the reader may find added matter on the topic sought.

¶ Attention is directed to a bibliography of the best literature in Electrical Engineering, in Volume VII. No attempt has been made to exhaust the sources but merely to provide the names, authors, and publishers of books which would appeal to the widest circle of readers.

In conclusion, grateful acknowledgment is due to the staff of authors and collaborators, without whose hearty co-operation this work would have been impossible.

## VOLUME II



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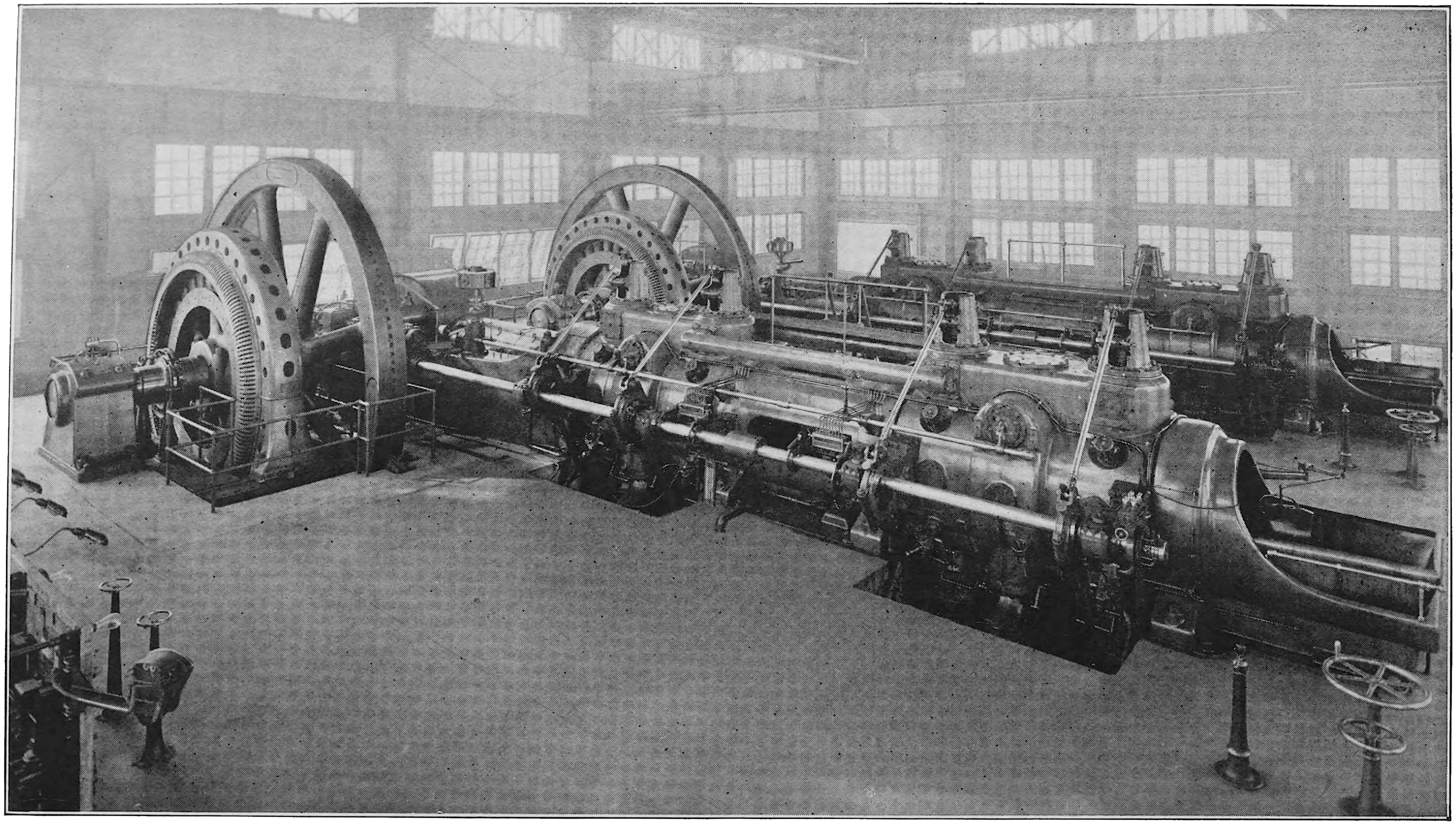
* For page numbers, see foot of pages.

† For professional standing of authors, see list of Authors and Collaborators at front of volume.



VIEW OF POWER PLANT OF THE SOUTHWESTERN STATES PORTLAND CEMENT CO., SHOWING TWO 750-Kw. GENERATORS DIRECT COUPLED TO TANDEM COMPOUND GAS ENGINES

Courtesy of *Allis-Chalmers Company, Milwaukee, Wis.*

# DIRECT-CURRENT DYNAMOS

## PART I

## PRINCIPLES

### INTRODUCTION

In order that the student who wishes to go further into the subject of Dynamo-Electric Machinery may be familiar with the various symbols employed in the different standard reference books, the authors have adopted the same conventions and have also utilized in various places the C. G. S. (centimeter-gram-second) or *absolute* units.

### UNITS*

**Dyne.** The dyne, the *unit of force*, is that force capable, after acting for 1 second on a mass of 1 gram, of giving it a velocity of 1 centimeter per second. It is equal to $\frac{1}{981}$ of a gram or $\frac{1}{28000}$ of an ounce.

**Erg.** The erg, the *unit of work*, is the work or energy due to one dyne of force acting through a distance of one centimeter.

The *international units of electricity* are defined as follows:

**Resistance.** The unit of resistance shall be what is known as the *international ohm*, which is substantially equal to one thousand million ($10^9$) units of resistance of the centimeter-gram-second system of electromagnetic units, and is represented by the resistance offered to an unvarying electric current by a column of mercury at the temperature of melting ice, fourteen and four thousand five hundred and twenty-one ten-thousandths (14.4521) grams in mass, of a constant cross-sectional area, and of the length of one hundred and six and three-tenths (106.3) centimeters.

**Current.** The unit of current shall be what is known as the *international ampere*, which is one-tenth ($10^{-1}$) of the unit of cur-

*Act of U. S. Congress July 12, 1894.

rent of the centimeter-gram-second system of electromagnetic units, and is the practical equivalent of the unvarying current, which, when passed through a solution of nitrate of silver in water in accordance with standard specifications, deposits silver at the rate of one thousand one hundred and eighteen millionths (.001118) of a gram per second.

**Electromotive Force.** The unit of electromotive force shall be what is known as the *international volt,* which is the electromotive force that, steadily applied to a conductor whose resistance is one international ohm, will produce a current of an international ampere, and is practically equivalent to $\frac{1000}{1434}$ of the electromotive force between the poles or electrodes of the voltaic cell, known as *Clark's cell,* at a temperature of fifteen degrees Centigrade and prepared in the manner described in the standard specifications. The volt is equal to one hundred million ($10^8$) units of electromotive force of the centimeter-gram, second system of units.

**Quantity.** The unit of quantity shall be what is known as the *international coulomb,* which is the quantity of electricity transferred by a current of one international ampere in one second.

**Capacity.** The unit of capacity shall be what is known as the *international farad,* which is the capacity of a condenser charged to a potential of one international volt by one international coulomb of electricity.

**Work.** The unit of work shall be the *joule,* which is equal to ten million ergs, and which is practically equivalent to the energy expended in one second by an international ampere in an international ohm.

**Power.** The unit of power shall be the *watt,* which is equal to ten million units of power in the centimeter-gram-second system, and is equivalent to the work done at the rate of one joule per second.

**Inductance.** The unit of inductance shall be the *henry,* which is the induction in a circuit when the electromotive force induced in this circuit is one international volt, while the inducing current varies at the rate of one ampere per second.

$L$ –Coefficient of self-induction, or inductance in henrys
$l$ –Length of magnetic circuit in cm.
$\lambda$ –(lambda) Angle of lead of brushes
$M$ –Volts per revolution per second (induction factor)
$\mu$ –(mu) Magnetic permeability
$N$ –Revolutions per minute; $n$–Revolutions per second
$\nu$ –(nu) Coefficient of magnetic dispersion or leakage coefficient
$p$ –Pairs of poles
$\pi$ –(pi) Used to represent the number 3.1416
$R$ –Resistance of external circuit, in ohms
$r_a$ –Total resistance of armature coils, in ohms
$r_b$ –Resistance of brush contacts, in ohms
$r$ –Total resistance of armature circuit, in ohms ($r = r_a + r_b$)
$r_{sh}$ –Resistance of shunt field exciting coils, in ohms
$r_{se}$ –Resistance of series field exciting coils, in ohms
r.p.m.–Revolutions per minute
$\rho$ –(rho) Specific resistance
$\psi$ –(psi) Angle of pole span
$\Sigma$ –(sigma) Used to designate a summation
$T_{sh}$ –Number of field exciting turns in shunt with armature
$T_{se}$ –Number of field exciting turns in series with armature
$T$ –Number of turns
$t$ –Time in seconds
$\Phi$ –(phi) Flux per pole
$V$ –Volts at terminals of a generator
$v$ –Velocity in feet per second
$W$ –Power in watts
$\omega$ –(omega) Angular velocity in radians per second
$y$ –Winding pitch
$y_{av}$ –Average pitch
$y_b$ –Backward winding pitch
$y_f$ –Forward winding pitch
$y_k$ –Winding pitch at the commutator
$y_r$ –Resultant pitch
$Z$ –Number of conductors on the armature counting all around the periphery
$>$ –Mathematical symbol, to read "greater than"
$<$ –Mathematical symbol, to read "less than"

## DYNAMO-ELECTRIC MACHINES

A *dynamo-electric machine* is one which converts mechanical energy into electrical energy, or *vice versâ*, by means of the relative motion of a conductor carrying an electric current, and an interlinked magnetic field. When the conversion is from mechanical to electrical energy, the machine is called a *generator;* and when the conversion is from electrical to mechanical energy, the machine is called a *motor.* In order fully to understand the design and construction of these machines, it will be necessary to consider the principles which govern their action.

### MAGNETIC PRINCIPLES

**Magnetic Field.** It was early found that pieces of a certain kind of iron ore were capable of attracting bits of iron. From the name of the country in which this peculiar oxide of iron was first found, came the name of articles made of it—*i. e., magnets,* from "Magnesia," in Asia. This oxide of iron is commonly called *magnetite.*

It was also found that if pieces of the steel came in contact with such a natural magnet, called a *lodestone,* they became magnets without any loss of magnetic strength in the original. A magnet produced by touching a natural one is sometimes called an *artificial* magnet. When pieces of soft iron are acted upon magnetically, they become magnets, or are *magnetized;* but when no longer under this influence the magnetism disappears. This is called *temporary* magnetism, while the magnetism of steel which is retained is called *permanent.*

When a magnet in the form of a bar is suspended by a thread, it sets itself in a position so as to point nearly north and south and if disturbed it will swing back and forth, ultimately returning to its original position. Such a pivoted magnet is commonly known as a *compass.* No matter how often mechanically disturbed, the same pole of the magnet will always point to the north and this is called the *north, positive,* or *plus* (+) pole, while the other end is designated the *south, negative,* or *minus* (−) pole.

*Force between Magnetic Poles.* If two magnets are brought together, it will be observed that their like poles repel each other, while their unlike poles attract. In other words, there is in the first case, a force exerted between the two poles tending to push them further apart while, in the second instance, the force acts to bring them together. Coulomb, a French scientist, first measured the action between two magnet poles, and found this force to be inversely proportional to the square of the distance between the poles. He also found if another similar magnet was placed on one of the two already in use, thus doubling its strength, that the force exerted was also doubled. The force may be expressed by the equation

$$F=\frac{m_1m_2}{d^2}$$

where $F$ = the force exerted on each pole by the other; $m_1$ = the strength of one pole; $m_2$ = the strength of the other pole; and $d$ = the distance between the poles.

If Coulomb's law is expressed in this form, by choosing the units of force and length, the definition of unit pole strength can be derived.

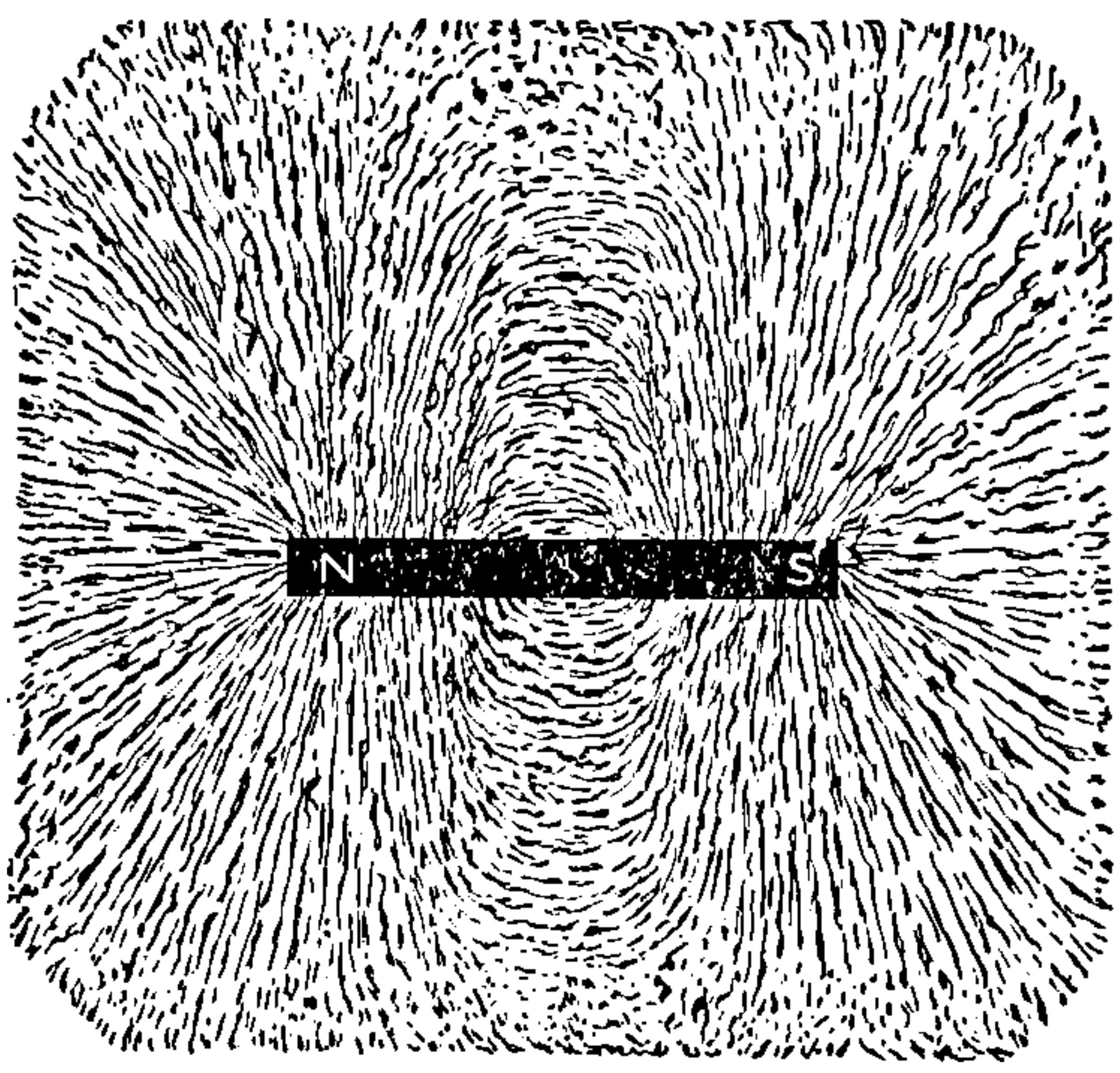



Fig. 1. Field of Force about a Bar Magnet

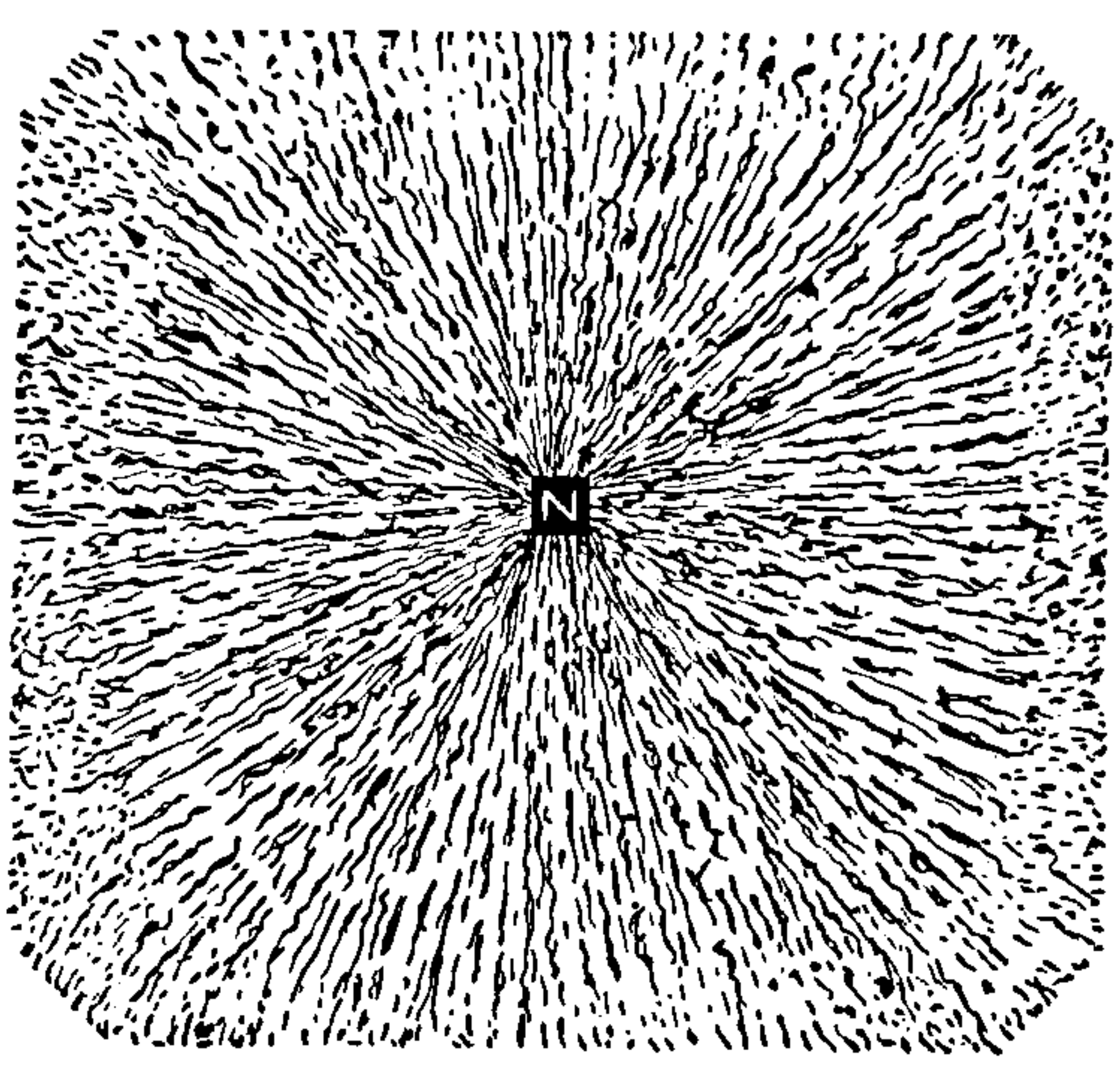



Fig. 2. Field of Force about a Single Pole

Let the unit of length be the centimeter, and the unit of force the dyne; then a unit pole may be defined as one which exerts a force of one dyne on a similar pole at a distance of one centimeter. The strength of any pole or quantity of magnetism is, therefore, measured by the force it exerts upon a pole of unit strength at a distance of one centimeter.

If a magnet shaped as a straight bar is held under a piece of cardboard upon which iron filings are sprinkled, it will be found that the filings settle down in curved lines forming a magnetic figure, the general form of which is shown in Fig. 1. Should only one of the poles of the magnet be held toward the cardboard, the filings will arrange themselves as shown in Fig. 2.

The iron filings become magnetized by their proximity to the magnet and acting as magnetic needles arrange themselves with their axes along the direction of the magnetic force and form the curved lines of the figure. These curves indicate the direction of the magnetic forces and are called *lines of force.* It is assumed that they proceed from the north pole, through the surrounding medium to the south pole, and a compass needle would set itself with its axis tangential to the line of force, its north pole pointing along the positive direction of the line.

These experiments show that the medium in the neighborhood of a magnet is in a state of stress and the space so affected is called a *magnetic field.* The influence of a magnet is supposed to extend in all directions indefinitely; but as *the force varies inversely as the square of the distance from the magnet,* the effect is rendered practically negligible beyond a comparatively limited area.

*Lines of Force.* A line of force is essentially nothing more than the direction of the magnetic force, and has no real existence. It is, however, usual in dealing with magnetic problems to refer to them as though lines of force actually did exist, as this enables us to express the strength of a magnetic field in a very convenient way.

The lines of force emanating from a single pole do not all lie in the same plane, but radiate into space in all directions. Assume a number of concentric spheres at whose center is placed a unit pole, then the lines of force leaving the pole will pass through all of the spheres in succession. But since the surface of a sphere increases as the square of its radius, the number of lines of force per unit area must decrease as the square of the radius increases. This further shows why in the equation on page 6, the force varies inversely as the square of the distance.

A field of unit strength must by definition have one line of force per square centimeter. Accordingly when a unit pole is placed at the center of a sphere of one centimeter radius, there will be $4\pi$ lines of force, since the surface area of a sphere is $4\pi r^2$ and in this case $4\pi$ square centimeters. Thus a unit pole radiates $4\pi$ lines of force and a pole of strength $m$ will likewise radiate $4\pi m$ lines of force.

The total number of lines of force crossing any surface is called the *total flux* over that area and the number of lines per square centimeter is called the *flux density.*

*Field about a Conductor Bearing a Current.* When a conductor carrying a current of electricity is passed through a piece of cardboard with iron filings sprinkled on the board as before, it is seen, Fig. 3, that the filings arrange themselves in curved lines similar to those of Fig. 2; while, if the return circuit of the conductor be also passed

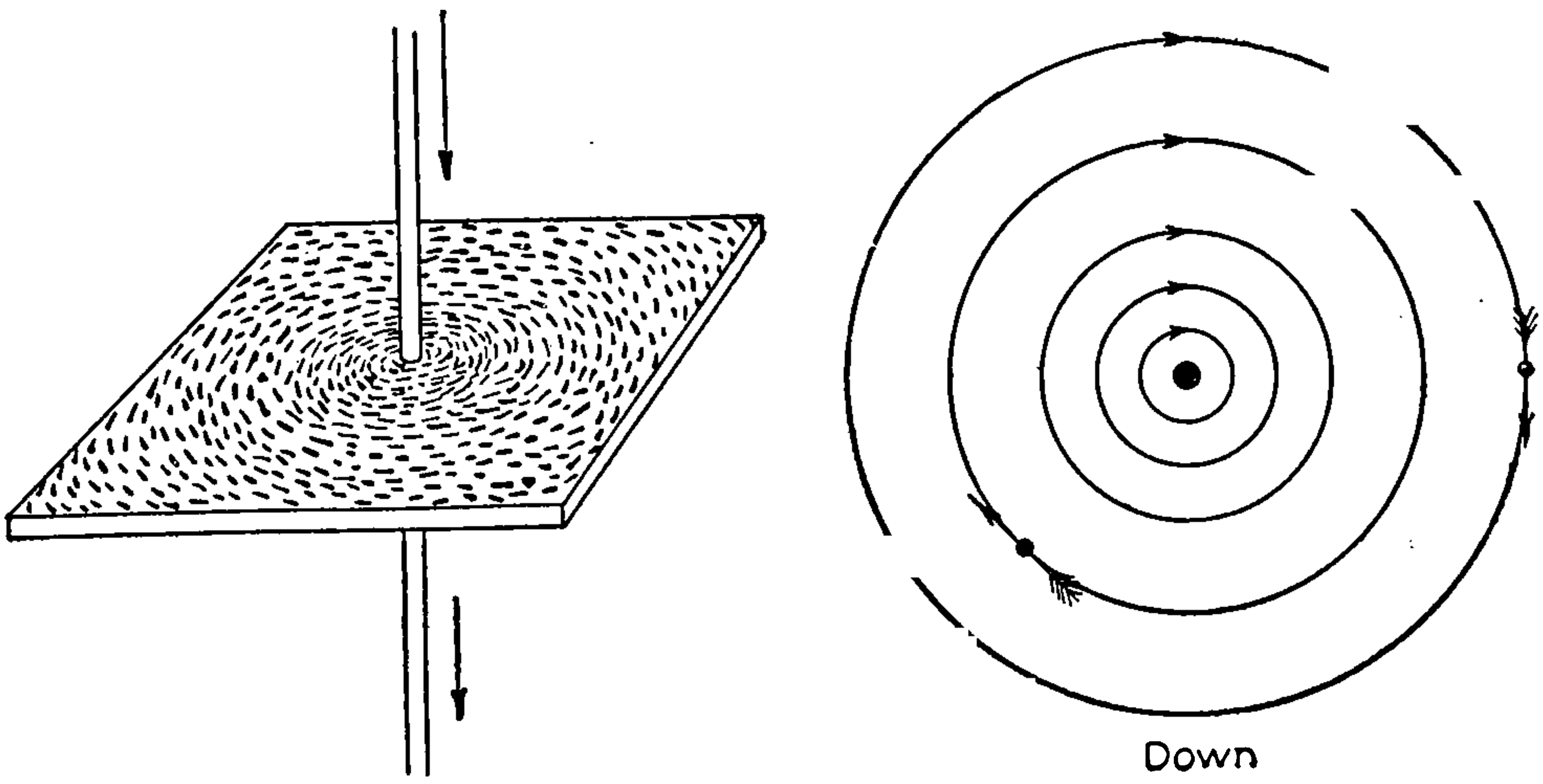



Fig. 3. Field about a Conductor Carrying a Current

through the card, the filings assume the alignment shown in Fig. 4. From the similarity of the phenomena, it may be concluded that a conductor carrying an electric current is surrounded by a magnetic field whose strength depends upon that of the current. This was first noted by Oersted, who, in 1820, observed that a compass needle was deflected when placed near a conductor carrying a current of electricity, the direction of motion of the needle depending upon the direction of flow of the current.

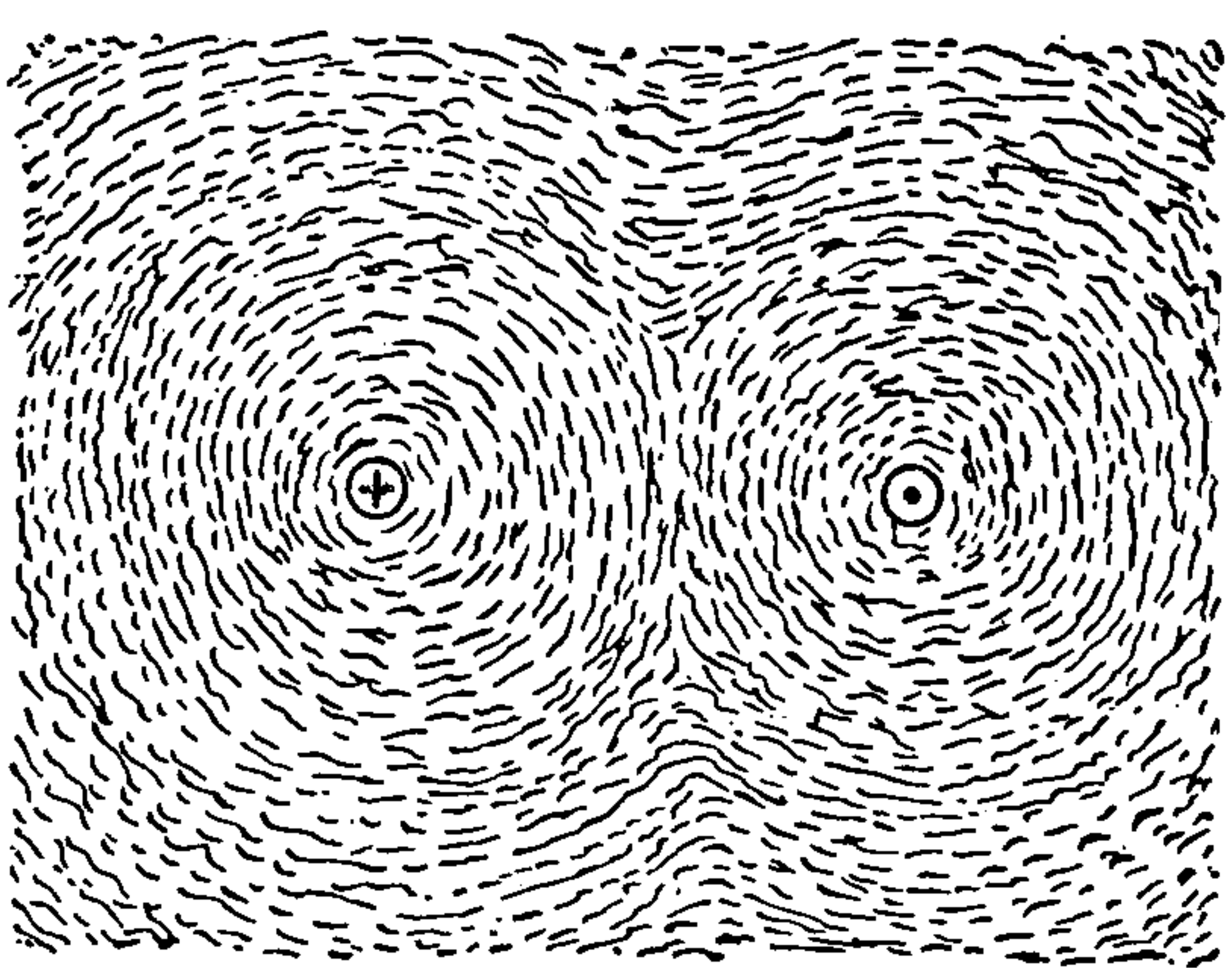


Fig. 4. Field about a Coil

From Fig. 3 and Fig. 4 it is seen that the lines of force produced by the current in the conductor are concentric circles and their direction may be determined by exploring the field with a compass. Maxwell expressed the relation between current and field directions as follows:

The direction of the current and that of the resulting magnetic force are related to one another, as the travel and rotation of an ordinary (*i. e.*, right-handed) screw, Fig. 5.

This fact may also be expressed as follows:

Grasp the conductor with the right hand, the fingers being bent around the wire; then the fingers point in direction along the lines of force while the thumb, extended, points in the direction of flow of the current, Fig. 6.

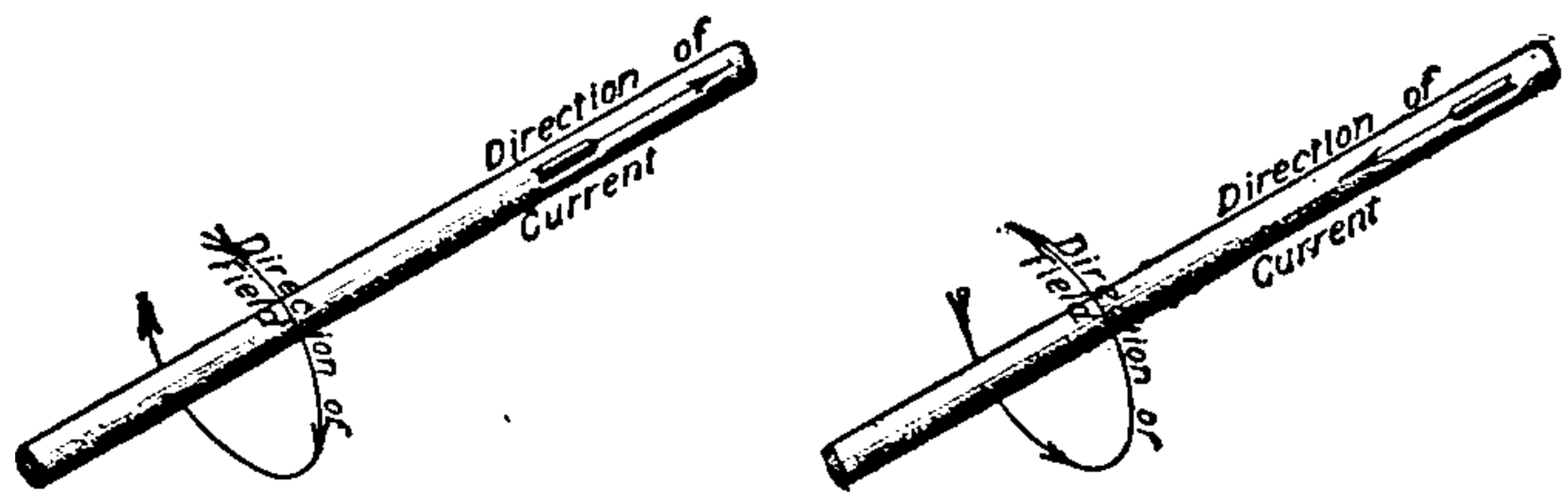



Fig. 5. Direction of Magnetic Lines about a Conductor

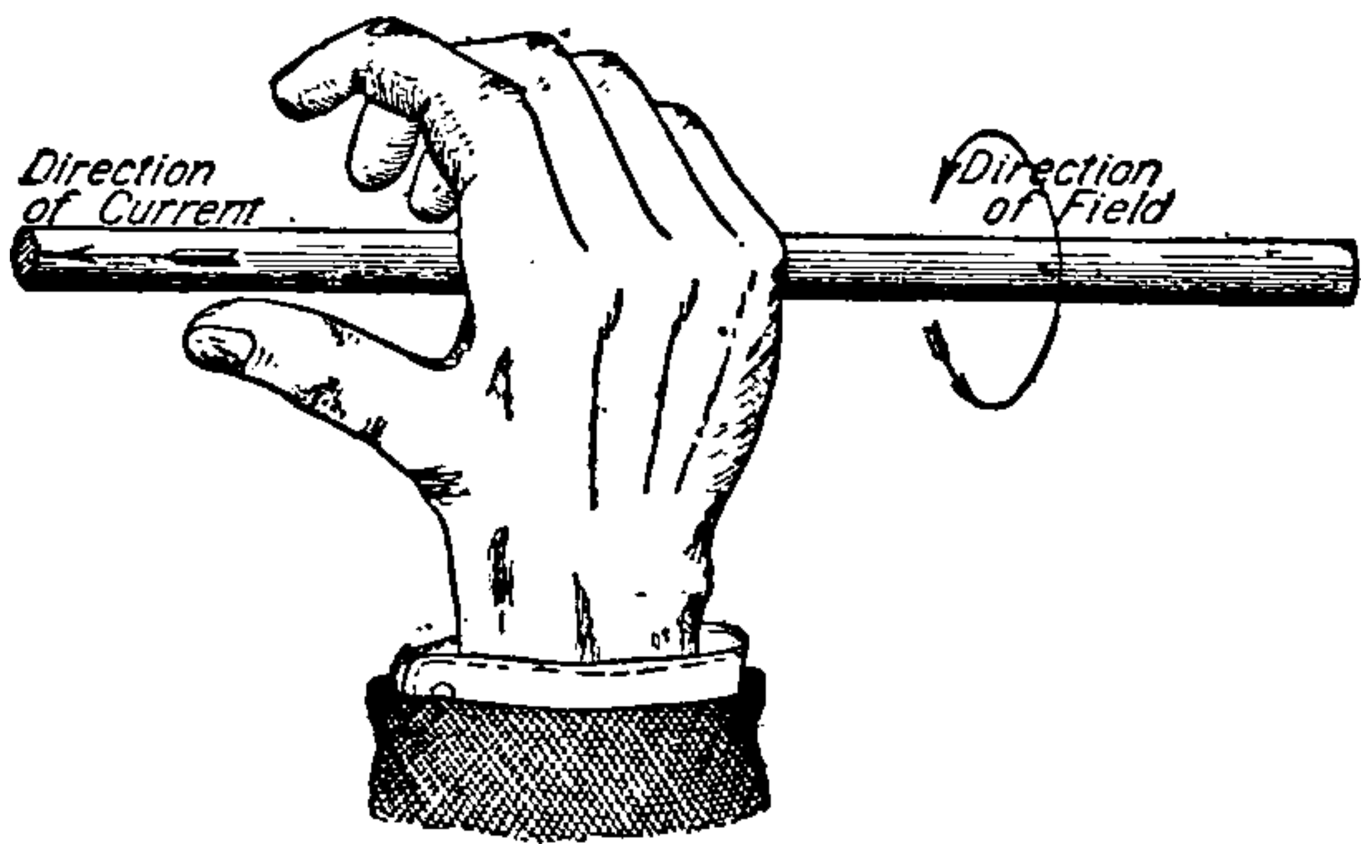



Fig. 6. Right-Hand Rule

**Solenoid.** Now, suppose that a wire is bent in the form of a circular loop, Fig. 7, and furthermore suppose that a current is traversing the conductor in the direction indicated. Then, according to the rules given, the lines of magnetic force would surround the loop in the manner shown. The field of such a loop, on being explored with a compass needle or filings, will be seen to retain the general character of the field surrounding a straight conductor; and consequently all the lines will leave by one face and return by the other, the entire number passing through the loop. Hence, one face of the loop will be equivalent to the north pole of a magnet, and the opposite face will correspond to the south pole. In fact, the loop will act exactly as if it were a thin disk magnetized perpendicularly to its plane.

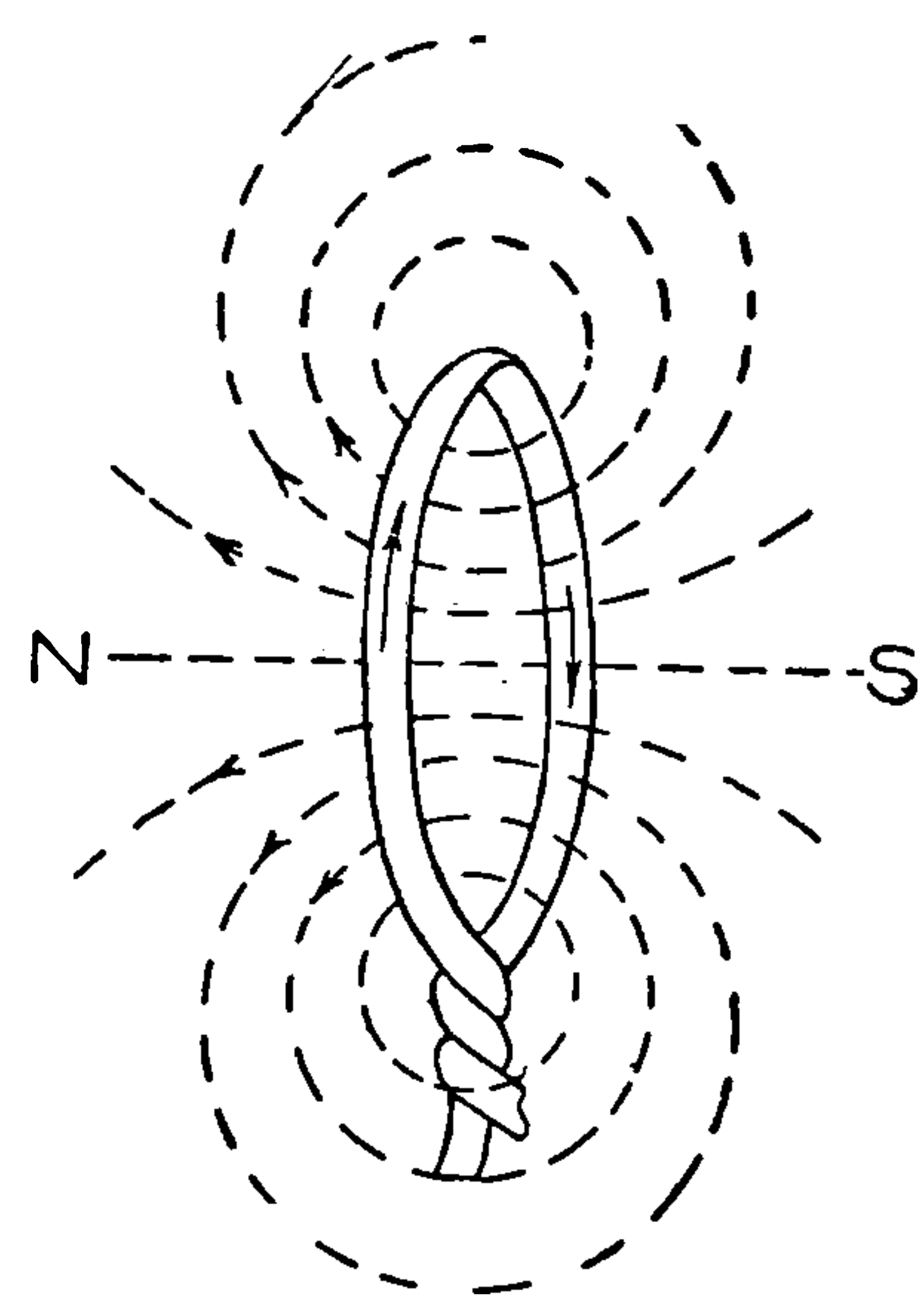



Fig. 7. Magnetic Field about a Single Loop

By placing side by side several of these current loops, with their transverse axes in the same straight line, there is formed a *solenoid*, Fig. 8. Exploration of the resulting magnetic field by any of the above methods shows that the lines of force pass right through the interior of the solenoid, leaving by one end and returning by the opposite end. A cylinder of soft iron inserted in the space within the solenoid will be found to act strongly as a magnet when the current flows around the solenoid; but if the current is interrupted, the magnetic effect almost disappears. Reversal of the current will be found to reverse the polarity of the core, while increasing the current augments the magnetic strength of the coil. The cylinder of soft iron with its

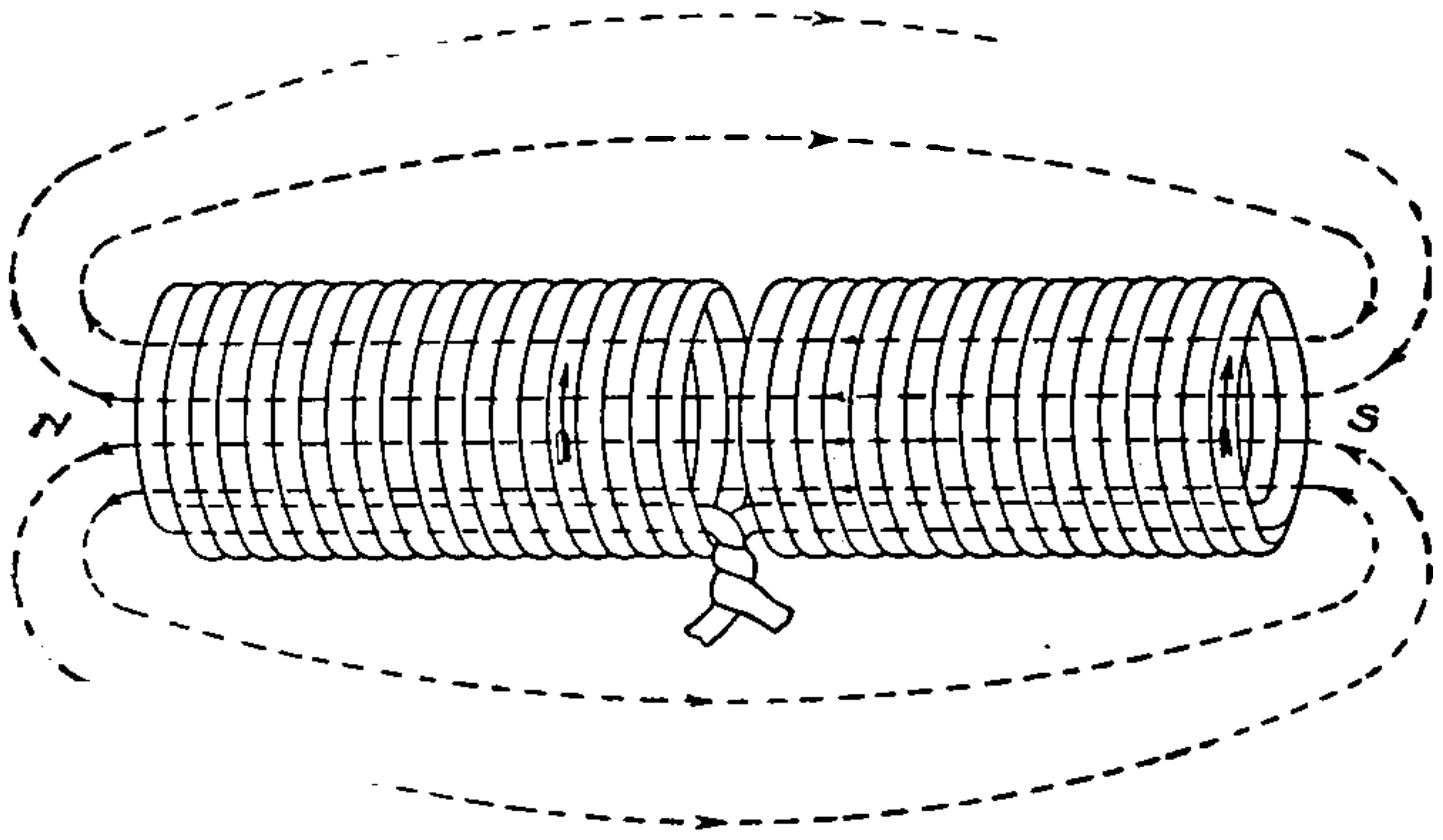



Fig. 8. Magnetic Field about a Solenoid

winding is called an *electromagnet* since it depends for its magnetism upon an electric current.

**Toroid.** Bend the solenoid around until its ends meet; or produce the same winding by turning insulated wire around an endless ring core of circular cross-section, as in Fig. 10. The arrangement thus produced will be a *toroid,* commonly called *Faraday's ring;* and if the wires are wound closely and uniformly over the whole periphery, the lines of force will be closed curves whose paths lie entirely within the turns; consequently there are no external poles—a unique electromagnetic condition.

**Magneto-Electric Induction.** Faraday, in 1832, discovered that electric currents could be induced in a closed circuit by moving magnets near it or by moving the circuit across a magnetic field. Connect a copper wire to a sensitive galvanometer—*i. e.*, an instrument which will measure electric currents—and move the wire quickly downward past a pole of a bar magnet; the needle of the galvanometer will deflect to one side of the zero position and immediately return after the motion stops. If the conductor had been moved upward the deflection of the galvanometer needle would have been reversed. This indicates that there was a momentary current

be such that the plane of the coil is perpendicular to the lines of force emanating from the end or pole of the solenoid. If the coil be placed so that its plane is parallel to the lines of force, there will be no induced current set up as the field is varied and the galvanometer needle will not be deflected. In the first case a maximum number of lines of force passed through the coil, while in the second case no lines interlinked with the coil. When the plane of the coil takes any position between these limiting ones the induced current will depend upon the effective area presented by the coil to the lines of force, or, in other words, the strength of the induced current depends upon the number of lines of force passed through the coil.

The induction effects may be summed up as follows:

Whenever the flux interlinked with a circuit is varying, there is an e. m. f. acting around the circuit proportional to the time rate of change of the flux, the positive direction of the e. m. f. and the positive direction of the flux passing through the circuit being related to each other as are the rotation and travel of a right-handed screw. That is, if a circular loop is moved in the field of a magnet in such a way that it does not enclose the same amount of flux at any two successive instants, then there is induced in the loop an e. m. f. whose value is proportional to the change of enclosed flux per unit time. A similar effect will be obtained by keeping the loop fixed and moving the magnet.

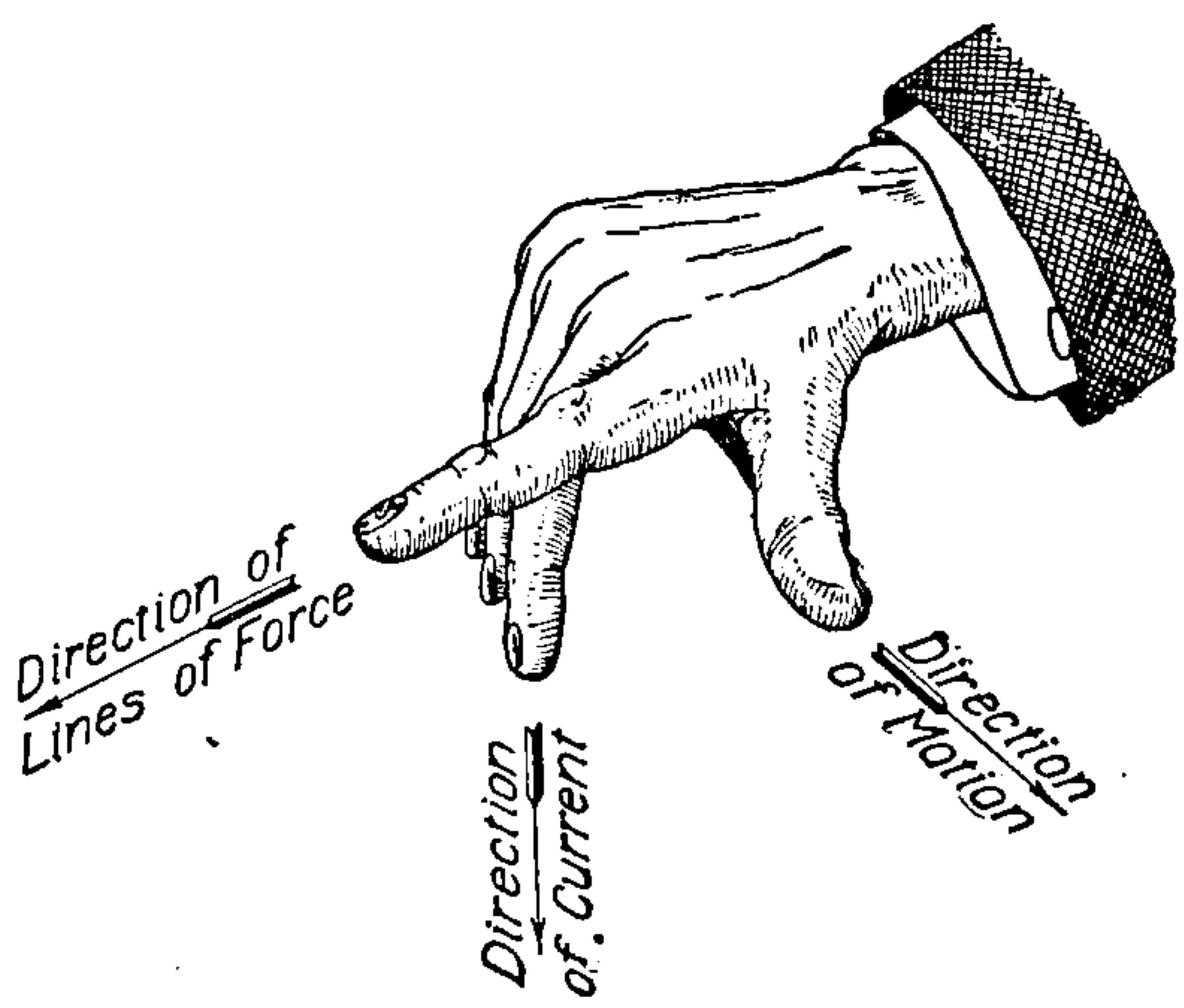



Fig. 9. Dynamo Rule

Another rule expressing the relation between the direction of flux, motion, and induced current is as follows:

If the forefinger of the right hand points in the direction of the lines of force and the thumb in the direction of motion, then the middle finger bent at right angles to both thumb and forefinger will point in the direction of the induced current, Fig. 9.

**Magnetomotive Force.** It has already been shown that, when a current circulates about the windings of a solenoid, it becomes magnetized and lines of force pass through the interior, leaving at one end and returning by the other. The current thus flowing sets up a force which drives the magnetic flux around the magnetic circuit, just as an electromotive force causes a current of electricity to flow around an electric circuit. This magnetizing force, due to the current, is called the *magnetomotive force,* or m. m. f. As the current is increased, the magnetizing force and the flux are also increased. It may be shown experimentally that, if twice the current is allowed to flow around the solenoid windings, both the magnetizing force exerted by the current and the flux are doubled. Likewise, if the same current is allowed to flow through coils having a different number of turns, the magnetic flux is found to increase with an increase in the number of turns of wire. These points may be summed up thus: *The magnetomotive force is directly proportional to the current flowing and also to the number of turns through which the current passes.*

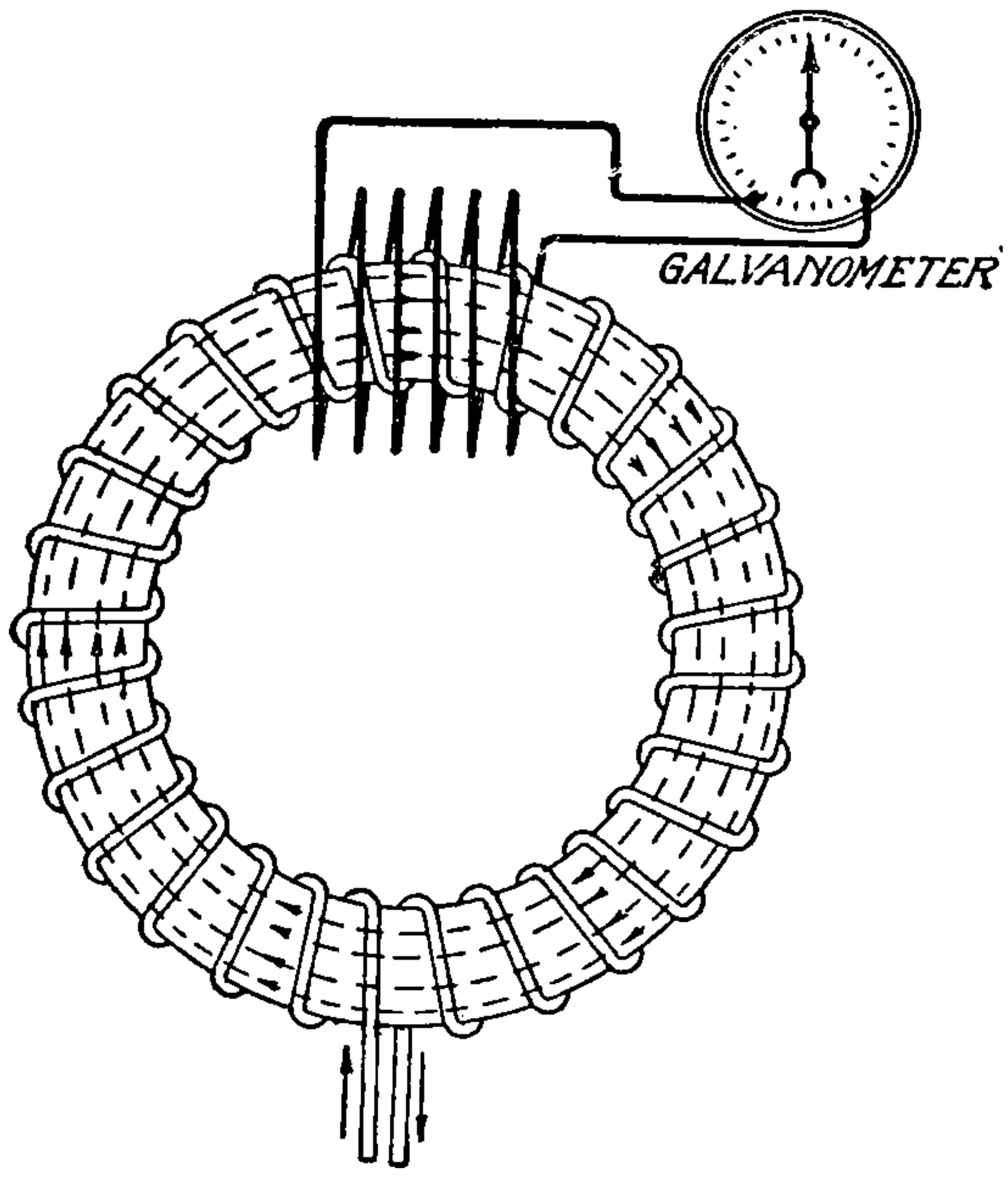


Fig. 10. Toroid and Exploring Coil

If $T$ represents the number of turns and $I$ the current in amperes passing through the turns, the magnetomotive force will vary directly as $IT$. This product, $IT$, is known as the *ampere-turns,* and experiment would show that the same magnetomotive force is obtained with a current of 100 amperes flowing around 1 turn, 25 amperes circulating in 4 turns, or 1 ampere passing through 100 turns. In each case there are 100 ampere-turns.

To calculate the value of the magnetomotive force in the absolute or C. G. S. units, in which system magnetic calculations are usually expressed, it becomes necessary to multiply the ampere-turns by $\frac{4}{10}\pi$, or by 1.257, giving for the magnetomotive force

$$\text{m. m. f.} = \tfrac{4}{10}\pi \, IT = 1.257 \, IT \tag{1}$$

**Reluctance.** Now take a number of wooden rings all of the same cross-section, but of different diameters, and wind upon each the same number of turns of wire evenly distributed, as in Fig. 10. If an exploring coil is placed upon each ring to measure the flux produced by suddenly allowing currents of the same strength to circulate through the turns, it will be found that the amount of flux varies inversely as the length of the magnetic path; *i. e.*, with the same number of ampere-turns, the greater the length of magnetic path the smaller will be the amount of flux. Experiments using rings of equal mean diameters but of varying cross-section would show that for the same number of ampere-turns and the same length of magnetic circuit, *the flux produced will vary directly as the area or cross-section,* that is, the larger the cross-section, the greater the flux produced.

It has now been shown that flux varies directly as the magnetomotive force; also, if this force be constant that the flux varies directly as the cross-section of the magnetic path and inversely as the length. These relations may be expressed as follows:

$$\Phi = \frac{1.257\ ITA}{l} \tag{2}$$

where $\Phi$ = the flux in lines of force; $A$ = the area or cross-section of magnetic path in sq. cm.; and $l$ = length of magnetic circuit in cm. This equation may, however, be written

$$\Phi = \frac{1.257\ IT}{\frac{l}{A}} \tag{3}$$

The expression $\frac{l}{A}$ is known as the *reluctance* and corresponds to the resistance of an electrical circuit. Therefore, by substitution

$$\Phi = \frac{\text{m. m. f.}}{\text{reluctance}} \tag{4}$$

which gives us an expression similar to Ohm's law where

$$\text{current} = \frac{\text{e. m. f.}}{\text{resistance}}$$

**Intensity of Magnetic Field.** If in the equation (1) for magnetomotive force both sides of the equation were divided by $l$, the result would then express the force in ampere-turns per centimeter length of magnetic circuit. This quantity is represented by the letter **H.**

$$\frac{\text{m. m. f.}}{l} = \frac{1.257 IT}{l} = \mathbf{H} \tag{5}$$

It is customary in magnetic calculations to so express the magnetic force. If the length of the magnetic path and the desired number of lines of force are known, the total number of lines may be obtained by multiplying **H** by $l$.

Further, divide each side of equation (2) by $A$; whence

$$\frac{\Phi}{A} = \frac{1.257IT}{l} = \mathrm{B} \tag{6}$$

The expression $\frac{\Phi}{A}$ represents the number of lines per square centimeter and is, therefore, the *flux density*. It is also termed the *magnetic induction* and is usually designated by the letter **B**.

Equation (1) may now be expressed in the form

$$\mathbf{B} = \mathbf{H}, \quad \text{or } \frac{\mathbf{B}}{\mathbf{H}} = 1 \tag{7}$$

Accordingly, if the magnetizing force is given in ampere-turns per cm. length and the flux density in lines of force per sq. cm., the two are numerically equal. *This equation holds only for non-magnetic materials as air, wood, copper, etc.*

**Relation between Magnetizing Force and Magnetic Induction.** In the earliest of Faraday's experiments with solenoids, he found that the flux through any of these was much greater when iron was inserted than when air or wood was enclosed by the coils of wire. He ascribed this peculiar circumstance to the greater *conducting power of the magnetic medium for lines of force.* Lord Kelvin introduced the phrase *magnetic permeability* for this property of magnetic materials, and it is defined as the ratio between the magnetic induction **B** produced in the medium and the magnetizing force **H** to which that induction is due; *i. e.*,

$$\mu = \frac{\mathbf{B}}{\mathbf{H}} \tag{8}$$

**Magnetic Permeability.** The precise notion now attached to this term is that of a numerical coefficient, and it is analogous to electrical conductivity. Its value is dependent upon the character of the substance and the magnetizing force or m. m. f. applied to the substance. For vacuum, its value is unity; for air, it is practically unity; for magnetic materials it is greater than 1 and may reach 3,000 for soft iron; while for diamagnetic materials it is slightly less than 1. The permeability of such non-magnetic materials as silk, cotton, and other insulators, also of brass, copper, and other non-magnetic metals, is taken as unity, being practically the same as for air.

The permeability of iron, however, *varies very greatly with the degree to which it has been magnetized.* In all kinds of iron (after passing the initial stage mentioned below), the magnetizability of the material becomes diminished as the actual magnetization is pushed further; in fact, there is a tendency to magnetic saturation. In other words, when the piece of iron has been magnetized up to a certain degree, it becomes less and less subject to further magnetization. Actual saturation is never reached, though there is a limit beyond which the magnetization cannot be increased with practical advantage. This is shown in Fig. 11, which represents the permeability curve of a sample of good iron or steel as used in generator field-magnet construction. The practical limit of the flux-density B in good wrought iron and in mild steel is about 20,000 lines of magnetic induction per sq. cm., or about 125,000 to 130,000 lines per sq. in., while in cast iron about 12,000 lines per sq. cm., or 70,000 lines per sq. in., are used.

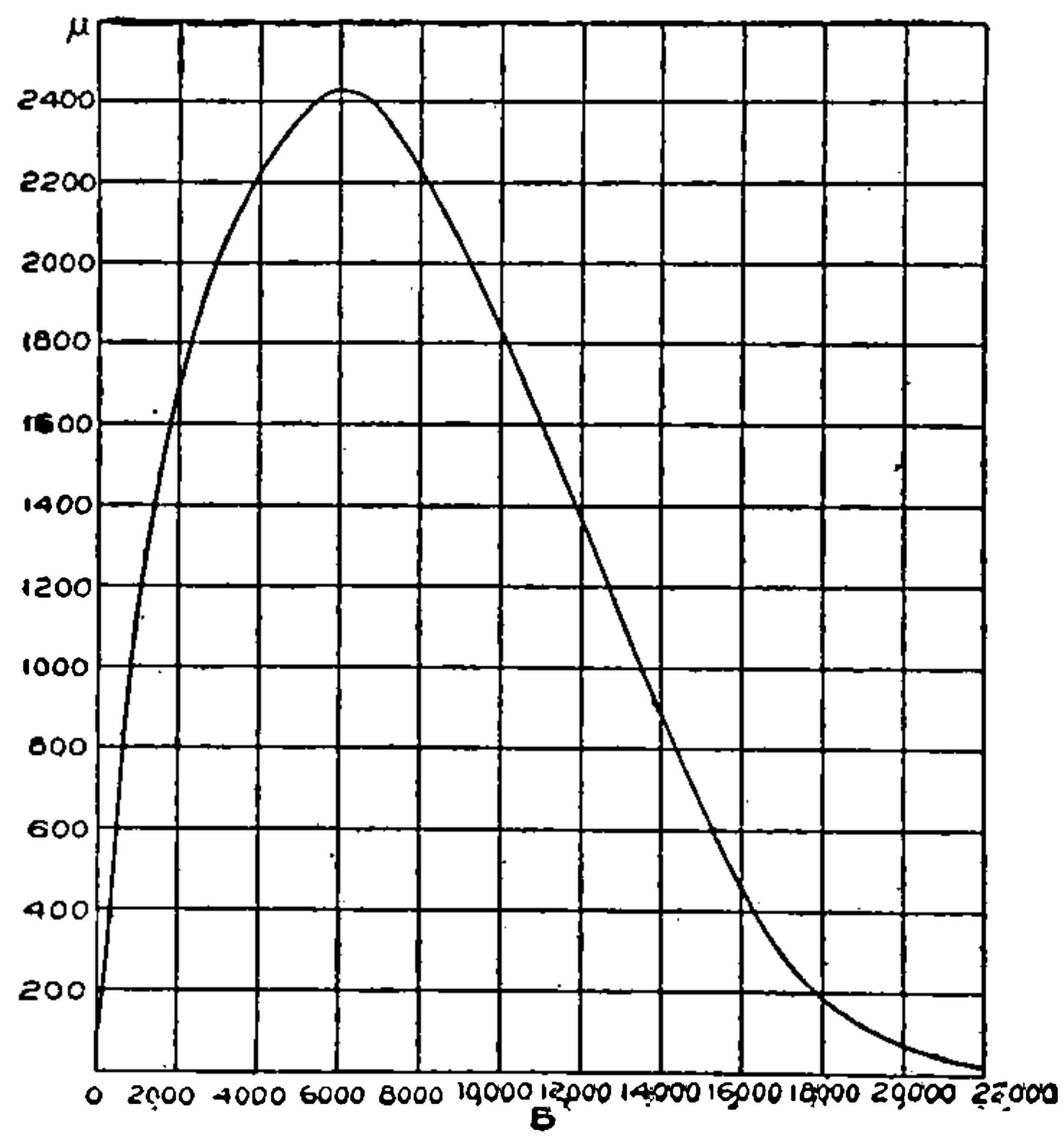


Fig. 11. Permeability Curve

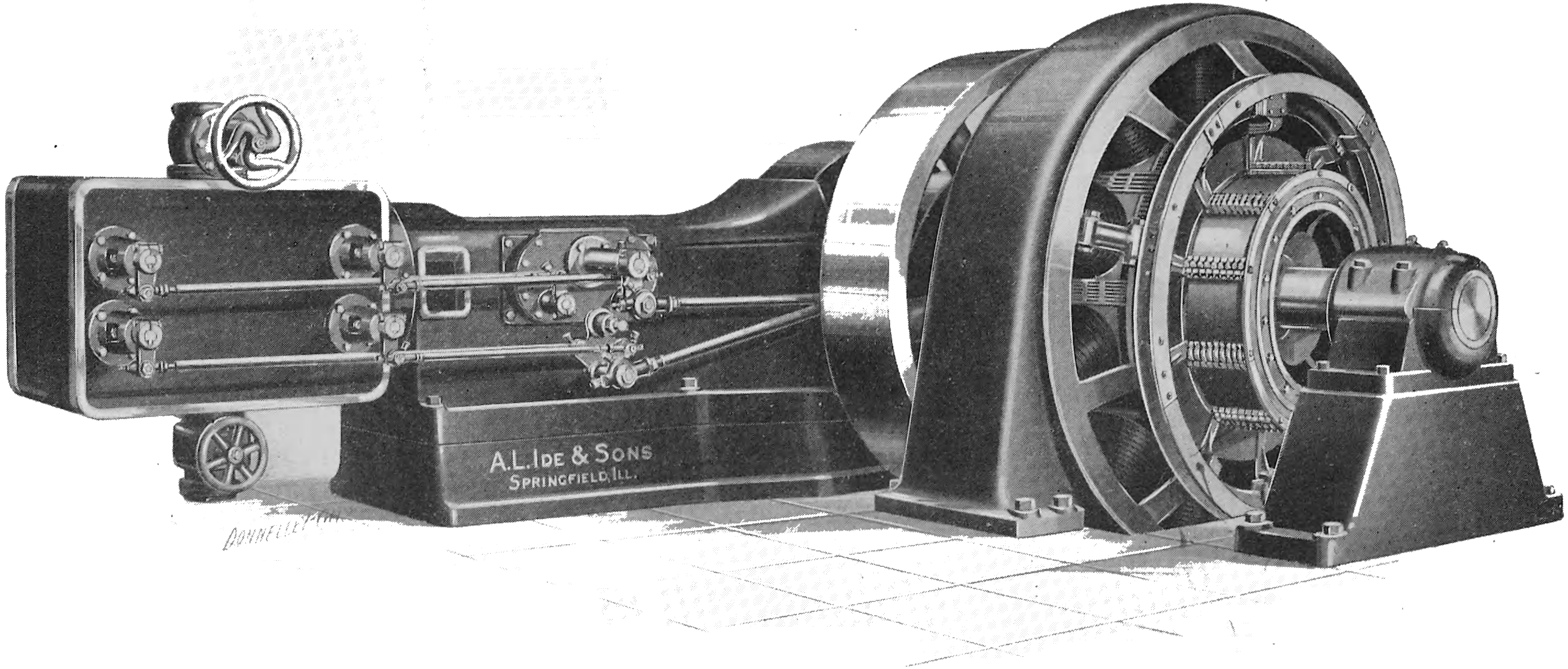
The preceding equations are for materials where the value of $\mu$ was 1. For iron and other magnetic materials where $\mu$ has a value other than 1, equations (2), (3), and (6) take the following general forms, respectively,

$$\Phi = \frac{1.257ITA\,\mu}{l} \qquad (9)$$

$$\Phi = \frac{1.257IT}{\dfrac{l}{\mu A}} \qquad (10)$$

$$\frac{\Phi}{A} = \text{B} = \frac{1.257IT\mu}{l} \qquad (11)$$

$$\text{Reluctance} = \frac{l}{\mu A}$$




IDEAL CORLISS VALVE ENGINE DIRECT CONNECTED TO GENERATOR
*Courtesy of A. L. Ide and Sons*

wrought iron or mild steel. In addition, it will usually be noted that the curves for fresh pieces of iron or steel present, at the lowest part of the curve near the origin, a small concavity, Fig. 12, showing that under certain magnetizing forces the permeability is greater than at the initial stage. While this concavity is more pronounced in the case of hard iron and steel than in the case of soft iron, the curves for different specimens of the same kind of iron will be found to differ in detail.

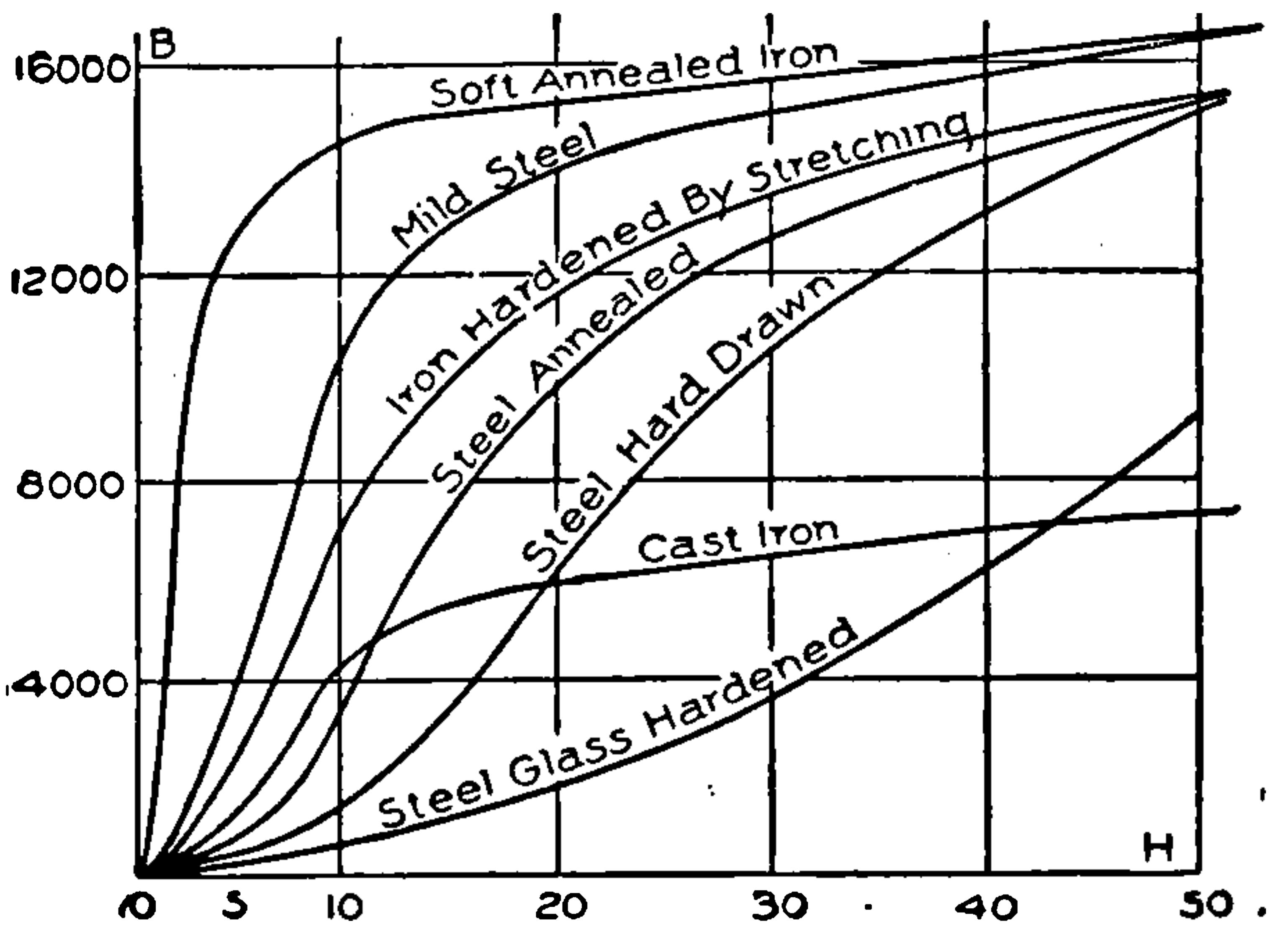



Fig. 13. Magnetization Curve for Iron and Steel

A comparative idea of the magnetic properties of various irons and steels used in electrical machinery is given in Fig. 13.

**Effect of Air Gap in Magnetic Circuit.** Thus far the magnetic circuit has been considered as made up of a solid, endless ring of iron. But suppose it to be built up partly of iron and partly of some non-magnetic material, as air or copper. Then the total reluctance of the magnetic circuit is the sum of the reluctances of its various parts. For example, if a ring is made up of $l_i$ centimeters of iron and $l_a$ centimeters of air, the reluctance of this magnetic circuit would be

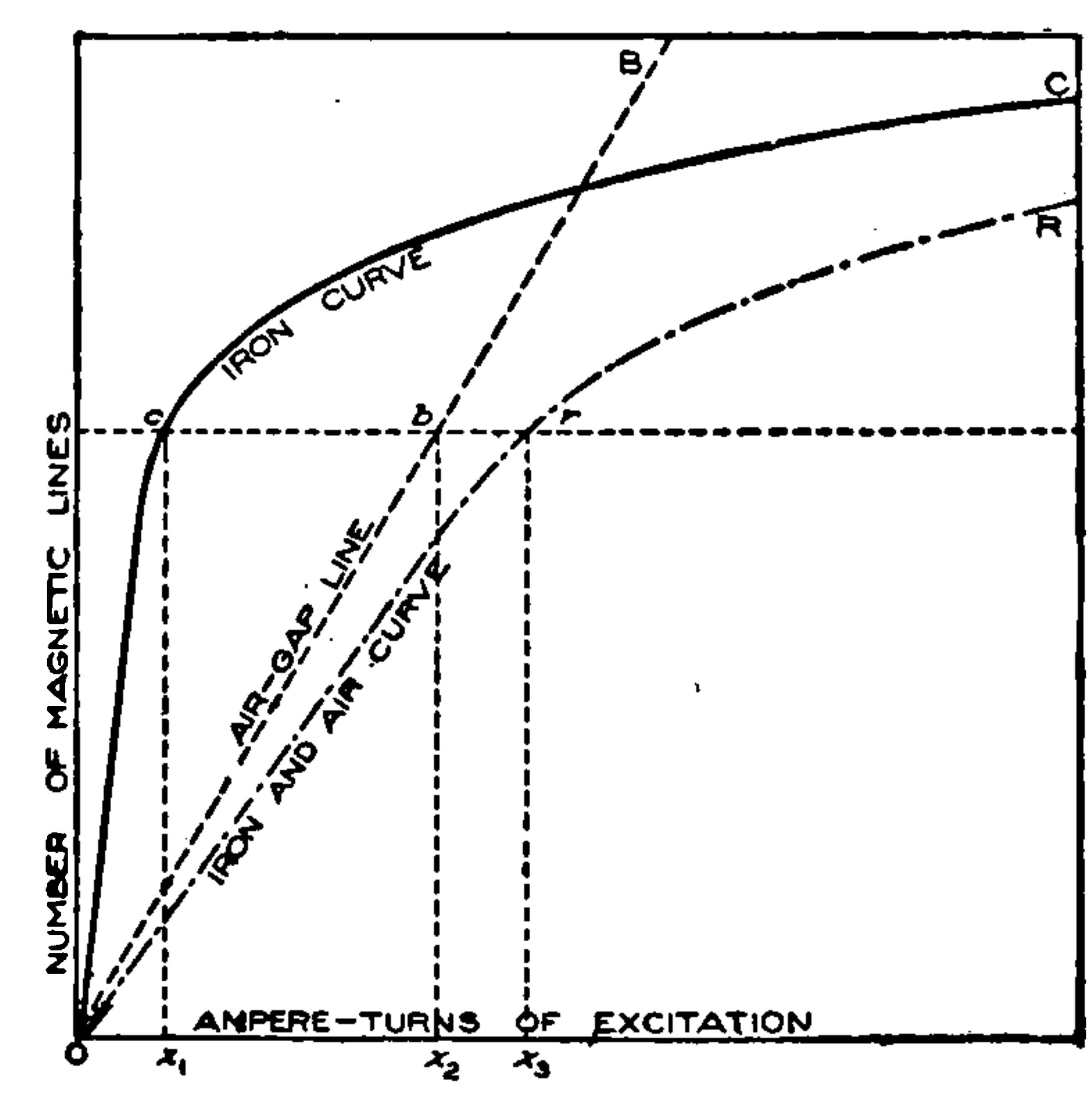



Fig. 14. Effect of Air Gap on Magnetization

$$R = \frac{l_i}{\mu_i A_i} + \frac{l_a}{\mu_a A_a}$$

in which $\mu$ and $A$ are, respectively, the permeability and the cross-sectional area of the materials denoted by the subscripts. If $I\,T$ represents the ampere-turns, the total flux of such a circuit is

$$\Phi = \frac{1.257IT}{\dfrac{l_i}{\mu_i A_i} + \dfrac{l_a}{\mu_a A_a}}$$

Since the magnetic permeability of air is constant and practically equal to unity, it is seen that an air gap, or its equivalent, introduced into a magnetic circuit previously consisting of iron, will increase the m. m. f. required to produce the same flux as before, due to the inferior permeability of the non-magnetic portion.

**Effect of Joints in Magnetic Circuit.** Ewing* tried the effect under different magnetizing forces of varying the number of joints in the iron of a magnetic circuit. His results, Fig. 15, refer to a bar of wrought iron cut across, first into two, then into four, and finally into eight pieces. He also found that when the faces of a cut were carefully surfaced up to true planes, the disadvantageous effects of the cut were considerably reduced, and under considerable mechanical pressure they almost vanished. An ordinary joint is equivalent to an air gap of about .005 cm. = .002 in.

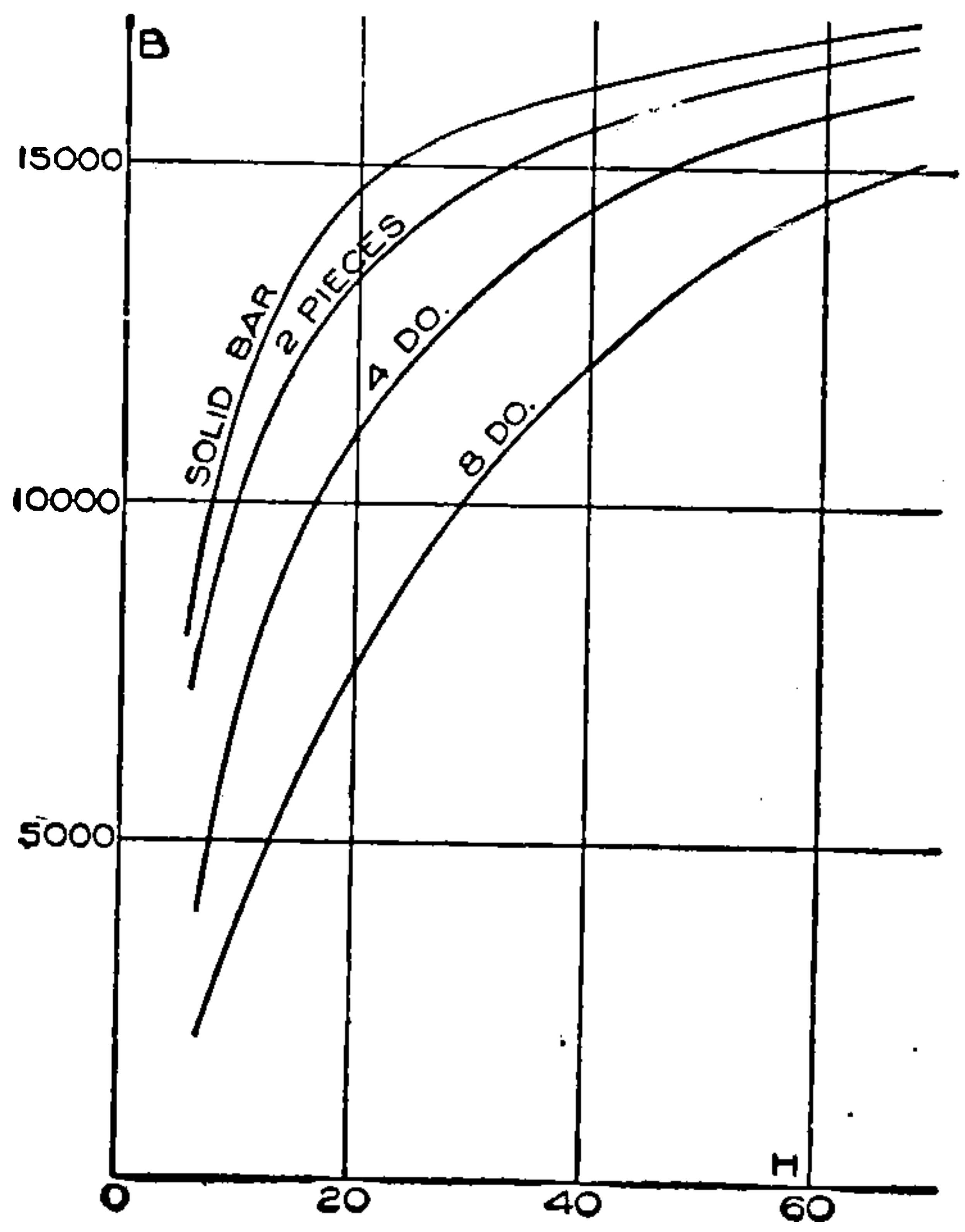



Fig. 15. Effect of Joints on Magnetization

**Residual Magnetism.** It has been found, when the magnetizing forces have been removed from a specimen of iron, that it retains some magnetism. This *residual* magnetism depends for its magnitude upon the character of the iron or steel, being greater in the harder than in the softer grades.

Referring to Fig. 12, it will be seen that when a specimen of wrought iron was magnetized to a high flux-density, and then the m. m. f. reduced to zero, the flux-density diminished to about 9,000 lines per square centimeter, the descending curve of magnetization being above the ascending one. The number of lines per square centimeter remaining under these conditions is called *remanence.* In order to remove this remanence, it is necessary to apply a certain negative magnetizing force, termed by Hopkinson the *coercive force,* which varies in magnitude from 2 units for soft wrought iron, to about 80 units or more for hard steel.

* "Magnetic Induction in Iron and Other Metals," London, 1892, Pages 208-273.

**Effects of Cycles of Magnetization.** This tendency of the magnetic effects to lag behind the forces producing them has been named by Ewing *hysteresis,* and is best studied by subjecting the iron specimen to one or more complete cycles of magnetization. For instance, suppose the m. m. f. applied to a piece of iron to be increased gradually from zero to a maximum value, then decreased through zero to an equal negative maximum, and finally to reverse and return through zero to the positive maximum value. The magnetic changes

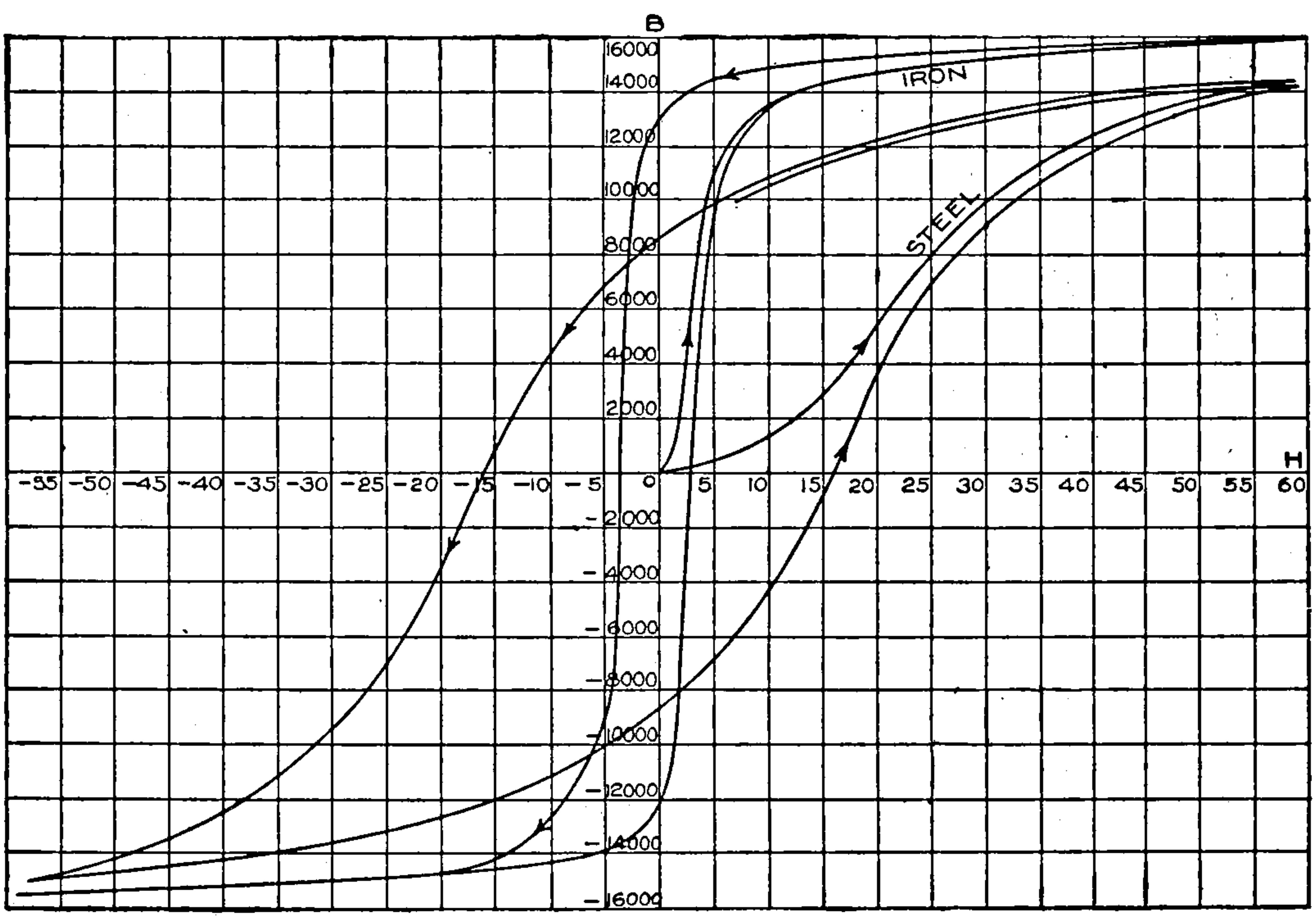



Fig. 16. Hysteresis Curve

for such a complete cycle for specimens of iron and steel are shown in Fig. 16.

The process, as shown by the diagram, is started with the flux-density and m. m. f. at zero. The latter is then increased to about 60 units, in the case of the piece of iron, the resulting flux-density being 16,000. The m. m. f. is then reduced to zero, the flux-density only decreasing to 13,000. At an m. m. f. of −3, the flux-density is brought to zero; that is, −3 is the coercive force, and 13,000 the remanence. With an m. m. f. of −60, the flux-density is −15,500; and varying the m. m. f. from this point to zero, leaves the specimen with a flux-density of −12,000. Further increasing the m. m. f. until the flux-density becomes zero, the final m. m. f.

is found to be + 3. From this point the m. m. f. is increased to its former maximum value, this ascending curve differing a little from the first. Thus it is seen that when a specimen of magnetic material is put through a complete magnetic cycle, the coincident values of the m. m. f. and the flux-density form a closed curve. The area thus enclosed has been shown by Warburg and Ewing to represent the energy wasted as heat in the material, when the specimen is put through a complete cycle; and its value depends upon both the character of the material and the degree of magnetization, being greater for hard steel than for soft iron with the same range of magnetization.

Iron, when placed in an alternating magnetic field, is not only subjected to the hysteresis phenomena above considered, but since the iron is an electrical conductor and the magnetic field about it changes in strength, it also becomes subjected to a set of local electrical currents. These tend further to heat the iron, and are called *Foucault* or *eddy currents;* their path, by Maxwell's law, is perpendicular to the direction of the flux. Their value may be lessened by increasing the resistance of their path—that is, by *laminating the iron, in a direction parallel to the direction of the flux and perpendicular to the path of these currents,* each sheet of iron being insulated from its neighbors. In practice, these laminæ vary from about 14 to 25 mils (0.014 inch to 0.025 inch) in thickness.

*Calculation of Heat Waste in Iron Cores.* From consideration of a great many tests of hysteretic losses, Dr. C. P. Steinmetz proposed the following law connecting the hysteresis loss *h* in ergs per cubic centimeter per cycle and the maximum flux-density B attained

**TABLE I**

**Hysteretic Constants for Samples of Iron and Steel**

| Material | Hysteretic Constant $\eta_h$ | Material | Hysteretic Constant $\eta_h$ |
|---|---|---|---|
| Very thin soft sheet iron .. | .0024 | Soft annealed cast steel.... | .008 |
| Thin good sheet iron ...... | .003 | Soft machine steel ........ | .0094 |
| Thick sheet iron.......... | .0033 | Cast steel ............... | .012 |
| Most ordinary sheet iron .. | .004 | Cast iron ................ | .016 |

during a cycle

$$h = \eta_h \mathbf{B}^{1.6}$$

wherein $\eta_h$ is a coefficient called the *hysteretic constant,* depending for its value upon the quality of the material. Some of these constants for ordinary frequencies are given in Table I. This law is practically true for all cycles up to 200 per second.

By applying the proper transformation factors to express the loss in watts per cubic inch, the Steinmetz formula reduces to

$$w_h = 0.83 \times \eta_h \times f \times \mathbf{B}^{1.6} \times 10^{-7}$$

wherein

$w_h$ = Hysteresis loss in watts per cubic inch of iron;

$f$ = Frequency or cycles of magnetization per second;

B = Maximum flux-density in lines per square inch.

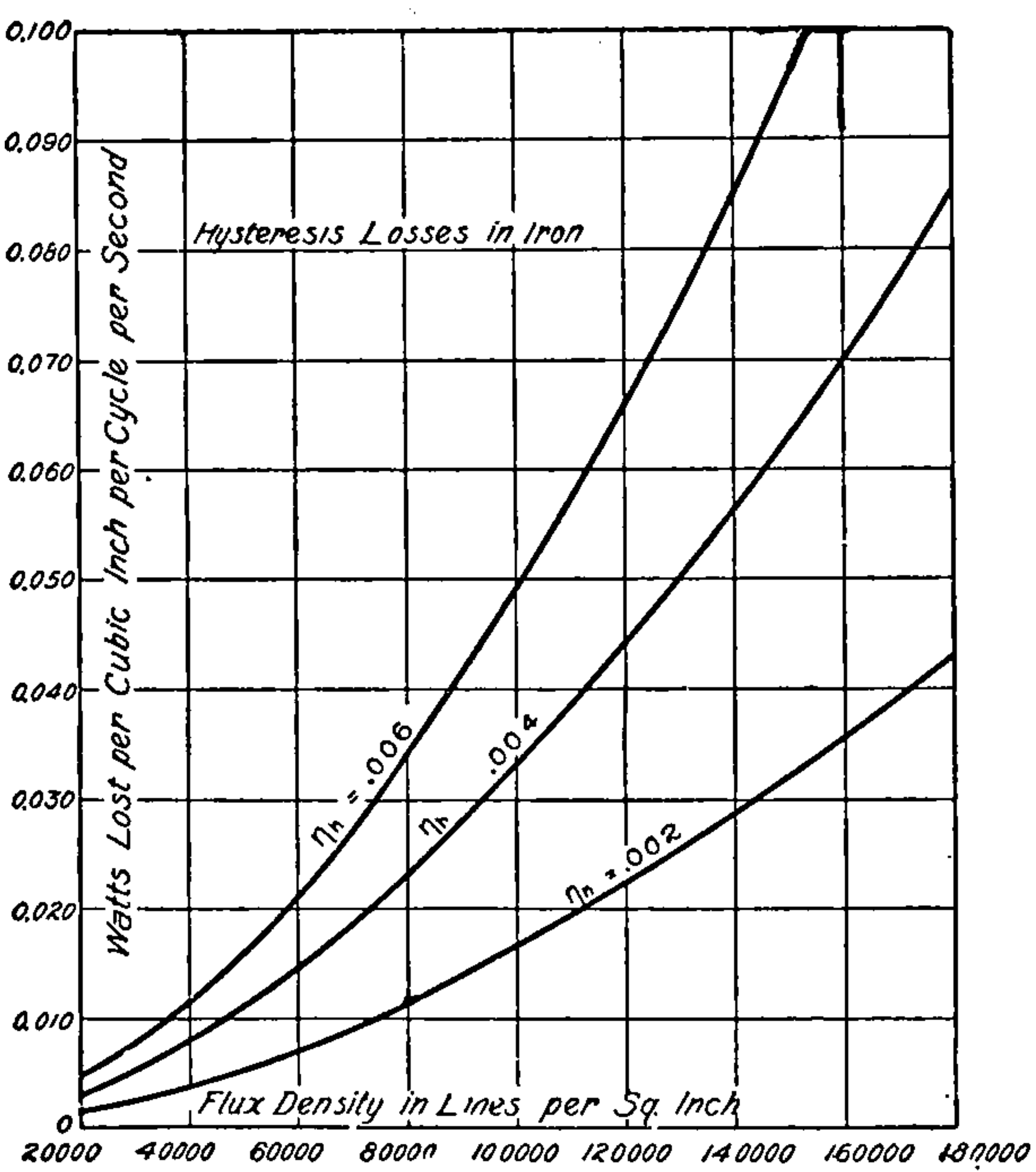



Fig. 17. Hysteresis Losses in Iron

In Fig. 17 are given graphically the hysteresis losses in watts per cubic inch of iron per cycle per second, with various hysteretic constants.

The eddy-current loss in iron cores varies directly as the square of the thickness of the iron laminæ, as the square of the maximum flux-density, and as the square of the frequency. The formula obtained by calculation and found to agree closely with values obtained by test is

$$w_e = 40.6 \times t_p^2 \times \mathbf{B}^2 \times f^2 \times 10^{-12}$$

wherein

$w_e$ = Watts loss due to eddy currents per cubic inch of iron;

$t_p$ = Thickness of the iron plates, in inches; and the other symbols have the meanings previously assigned.

Fig. 18 exhibits values of $w_e$ graphically for various thicknesses of iron over wide ranges of flux-density at one cycle per second.

The sum of these losses ($w_h + w_e$) for any electrical machine is called for brevity the *iron-losses* of that machine. Calculations for actual machines will be given later.

*Retardation of Magnetization.* It has long been known that, owing to the eddy-currents produced in the iron cores of electro-magnets, the magnetism of the inner part builds up less rapidly than that of the outer parts. Similarly, when the m. m. f. is cut off, the inner part of the core retains its magnetism longer than the outer parts. In dynamos with large field-magnets, especially when solid cores are employed, several minutes may elapse before the field will build up or change. Hopkinson has shown that the retardation varies as the square of the linear dimensions of the core. This, however, does not hold if laminated cores are used.

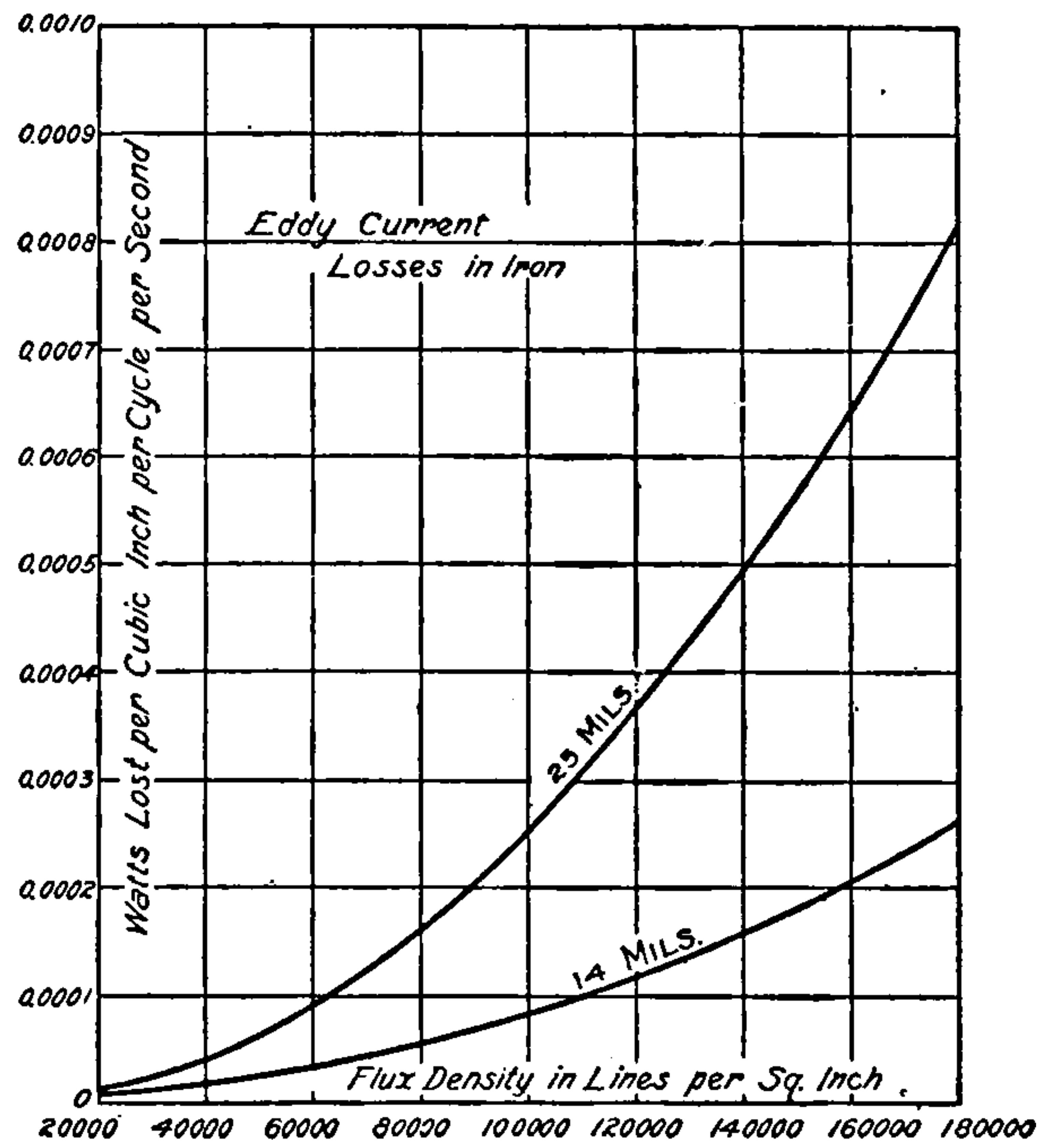


Fig. 18. Eddy-Current Losses in Iron

*Magnetic Dampers.* If a magnetic flux, whether in air or iron, be surrounded by a closed electrical circuit, any change in the value of the flux will induce an e. m. f. in that metallic circuit, tending to oppose the flux change. It has suggested itself, therefore, to builders of dynamos, to surround the magnet-poles with copper bands in order to reduce the possibility of sudden field fluctuations. This feature is employed extensively in alternating-current generators, synchronous motors, and rotary converters, under the name of *dampers* or *damping rings.*

## INDUCED CURRENTS

**Generation of E. M. F. by Cutting Flux.** Whenever lines of magnetic flux are cut by a conductor, an e. m. f. is produced in that conductor, and the value thereof is one volt when 100,000,000, or $10^8$ lines of force are cut per second. That is, the e. m. f. depends solely upon the *time rate* of cutting, so that one volt would also be set up if $10^6$ lines were cut in one-hundredth of a second. In both cases the rate of cutting is supposed to be uniform throughout the given time.

The generation of e. m. f. is absolutely certain, no matter when or by what process the lines are cut. A *current,* however, will flow only when there is a closed electrical circuit. A straight bar of copper, for example, cutting across a magnetic field, would have a potential difference established between its ends; but, excepting a slight displacement current at the start, no current would flow until the electrical circuit was completed. A distinction should be made, therefore, between the generation of an e. m. f. and the flow of a current. Thus, it may happen that two or more opposing voltages neutralize each other, so that no current whatsoever flows, even though the electrical circuit is complete. This is the case when a copper ring is moved in its own plane across a uniform field; the two halves cut an equal number of lines, and the e. m. f. produced in one half is exactly equal but opposite to that produced in the other half of the ring, making the current-flow zero. This explains the fact that the flux in a coil of wire must be varied in order to permit a current to flow; or, in other words, the coil must be filled with, and emptied of, lines of magnetic induction, in which case an alternating current is produced. This is often stated so broadly, however, that it seems to mean that an e. m. f. cannot be obtained in a uniform field, whereas an e. m. f. *must* be produced whenever magnetic lines are cut, though a flow of current may not result.

**Elementary Generator.** The simplest form of generator consists of a loop of wire arranged to rotate in a uniform magnetic field, Fig. 19. The generation of e. m. f. in such a dynamo will be as follows: Assume the loop with its plane parallel to the direction of the flux. If, then, the loop be rotated counter-clockwise about its axis $XY$, the sides $AB$ and $CD$, which cut lines of magnetic induction, will have an e. m. f. induced in them that will tend to cause a current flow in the directions indicated by the arrows. The value of this e. m. f. will depend upon the speed or *time rate* of cutting; and since this rate is greatest when the plane of the loop is parallel to the direction of the flux, *i. e.*, when the motion of the loop is at right angles to the line of force, the e. m. f. developed at the instant represented in Fig. 19 will be a maximum. As the loop approaches the 90°, or

ment, except that the loop has two turns instead of one. Against this commutator, at diametrically opposite points, press a pair of

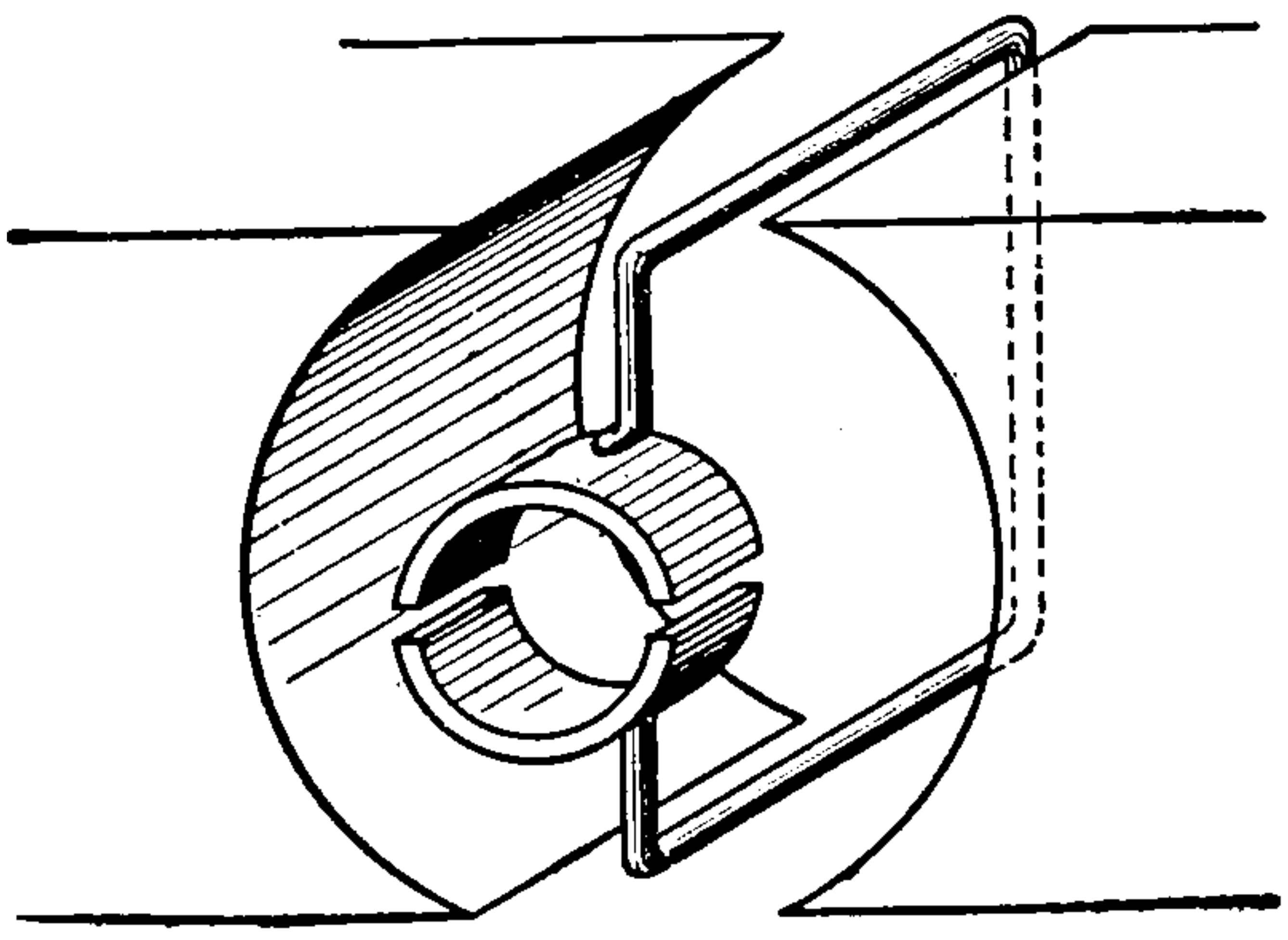


Fig. 21. Commutator with Simple Turn

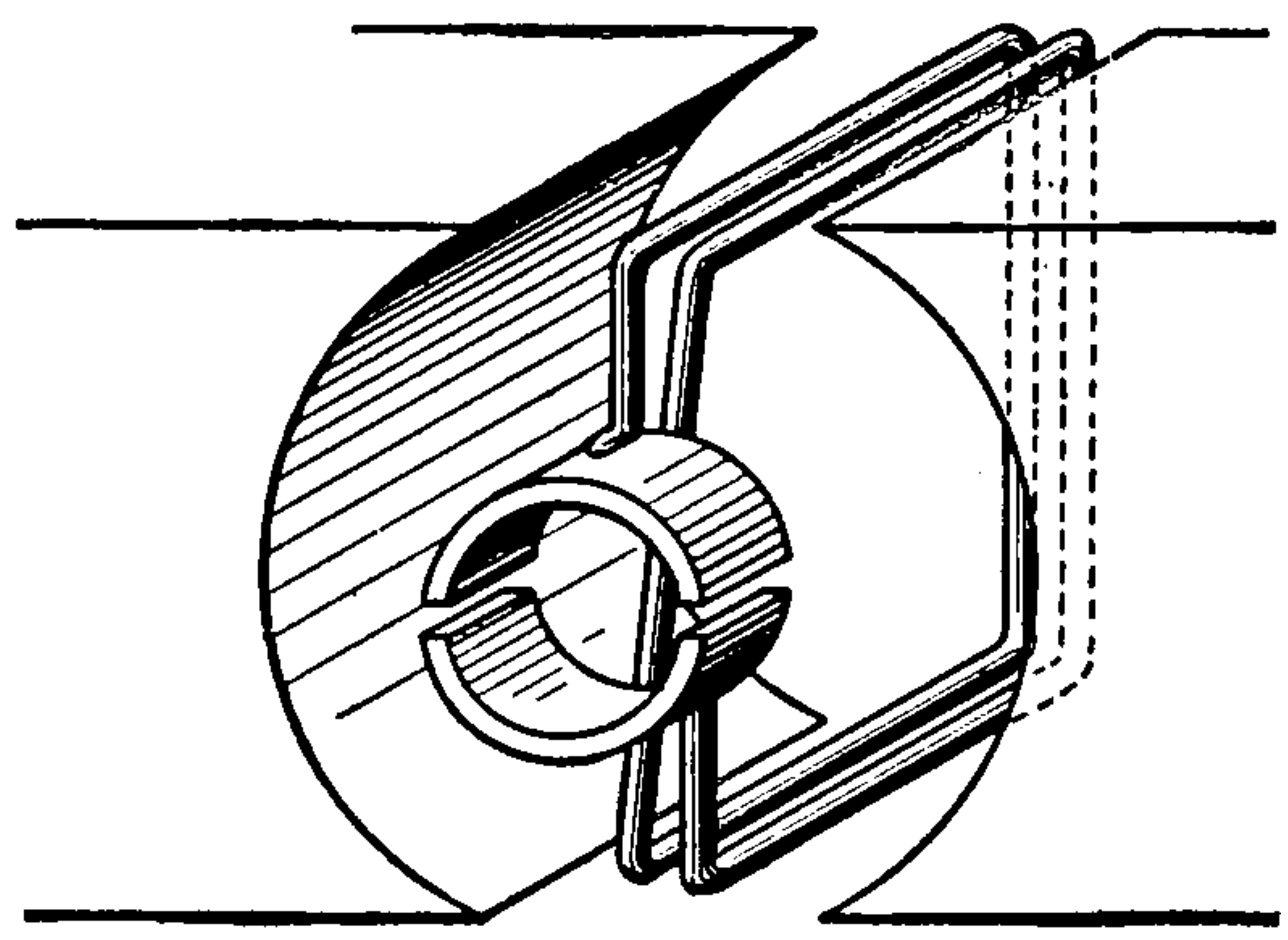


Fig. 22. Commutator with Double Turn

metallic springs or brushes which lead the current due to the generated e. m. f. to the external circuit. If, as in Fig. 23, these brushes are so set that each half of the split tube moves out of contact with one brush and into contact with the other brush at the instant

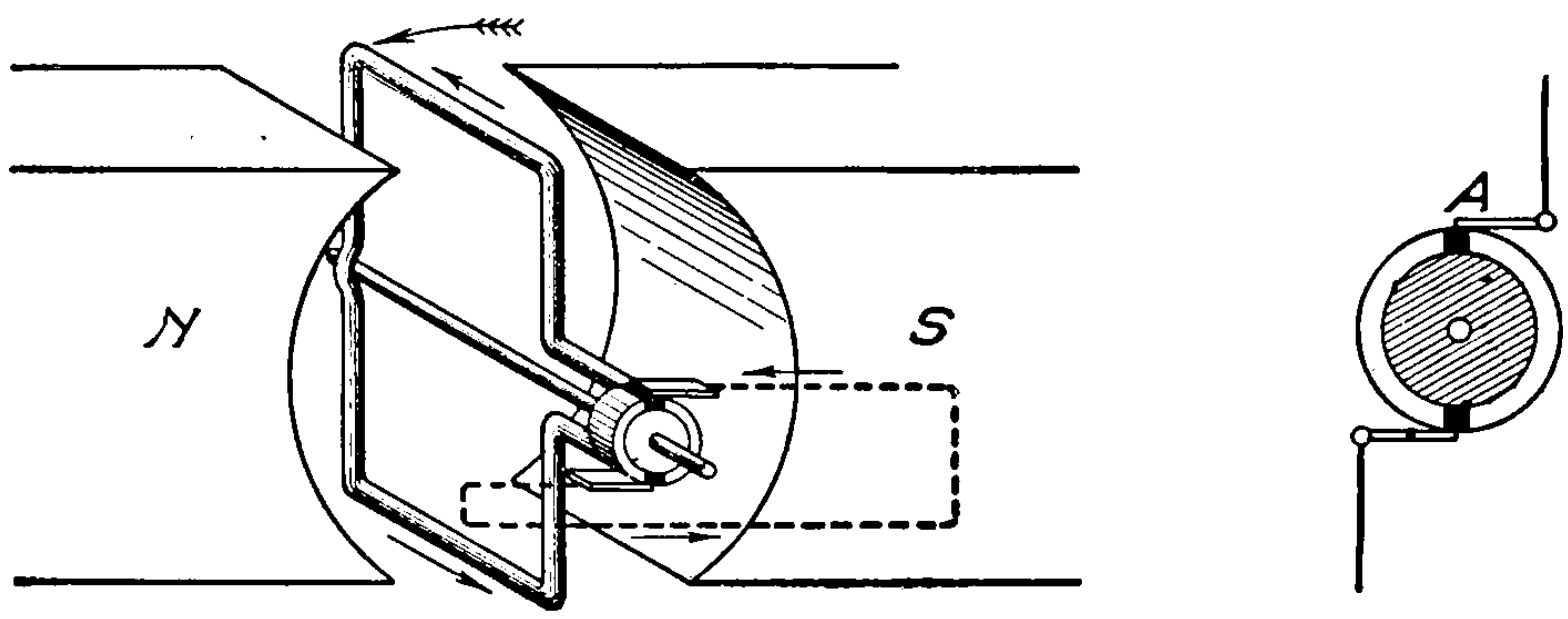



Fig. 23. Diagram of Reversing Action of Commutator

when the loop is passing through the positions where the time rate of cutting is minimum—as indicated in the enlarged end view of the commutator shown at *A*—the alternating e. m. f. generated will produce in the external circuit a rectified, commutated, or unidirectional current—*i. e.*, the current in the external circuit will flow in one direction. If this external current be plotted, it will be of the pulsating character, Fig. 24. This explanation need not be changed, if, for a single loop, a coil wound on an iron ring is substituted, Fig. 25. The effect of this is to increase the generated e. m. f. by in-

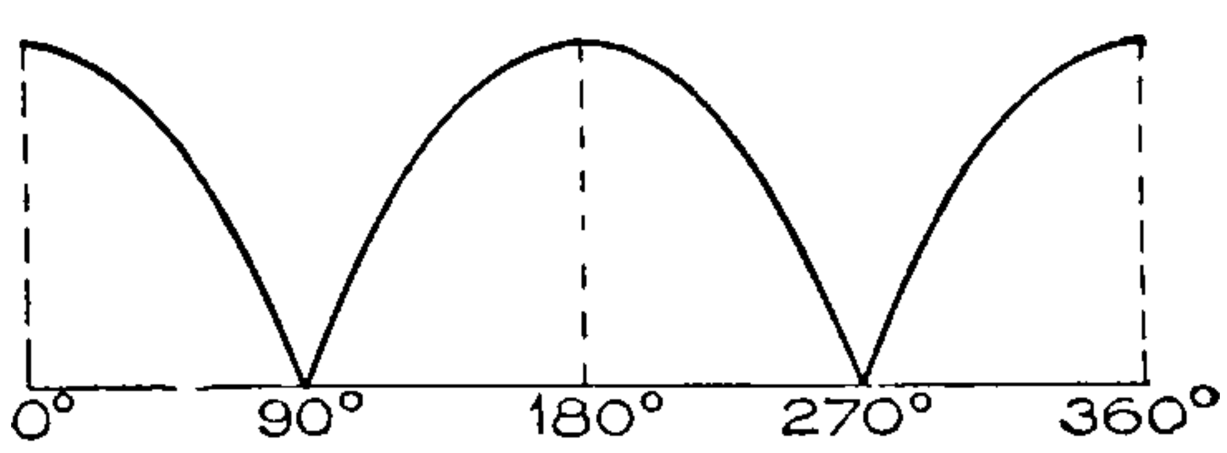



Fig. 24. E. M. F. Curve with Commutator

creasing the number of times the electrical circuit cuts the flux. Referring to Fig. 21, suppose, instead of one coil as shown, there are two coils mounted side by side and connected in parallel to the commutator segments, then the elementary conditions, Fig. 26, will obtain. If, then—similarly to the arrangement developed in Fig. 25—an exactly similar coil is placed at the opposite side of the ring, as in Fig. 27, it is seen that when its terminals are connected to the same two half-rings as the first, the electric circuits of the two coils are in parallel, and though the voltage generated by revolving this winding with two coils is no greater than with one coil, the current-carrying capacity of the resultant winding is evidently doubled.

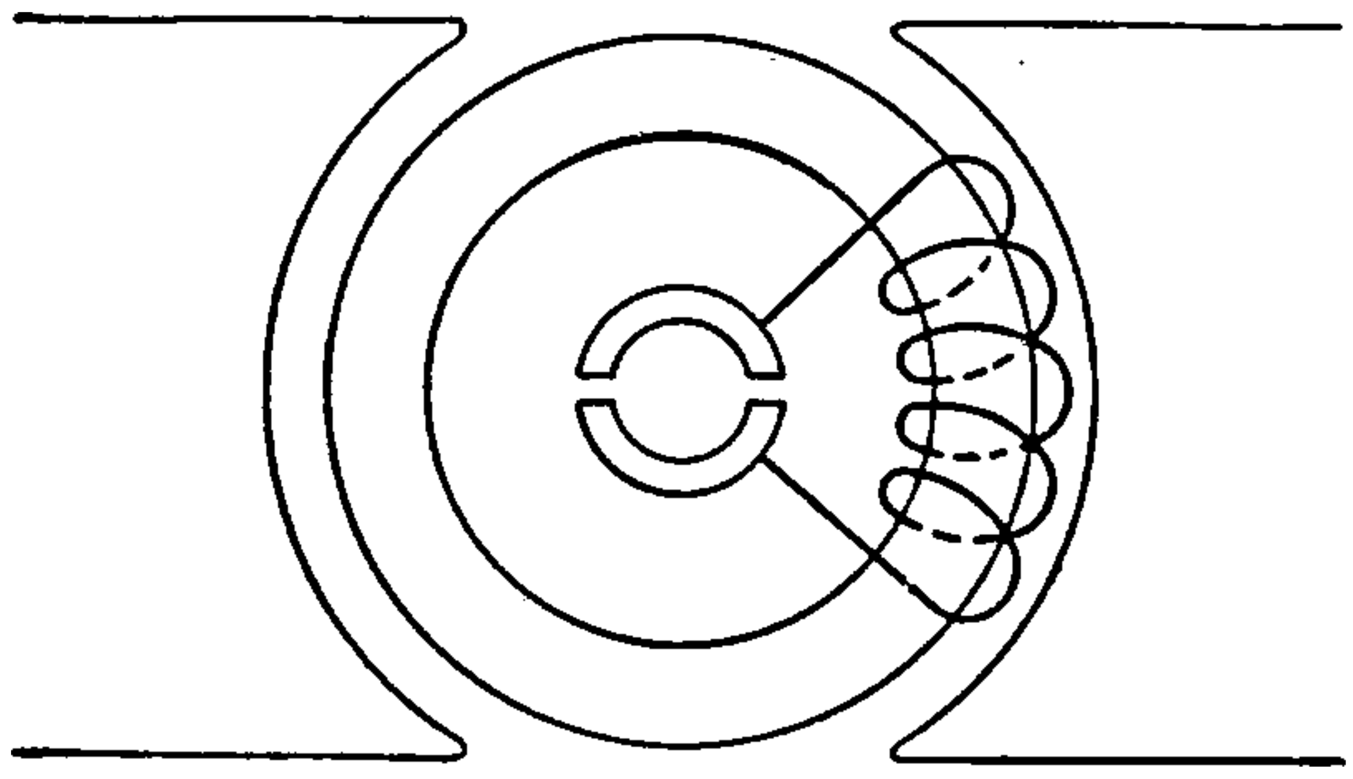


Fig. 25. Armature with Single Coil

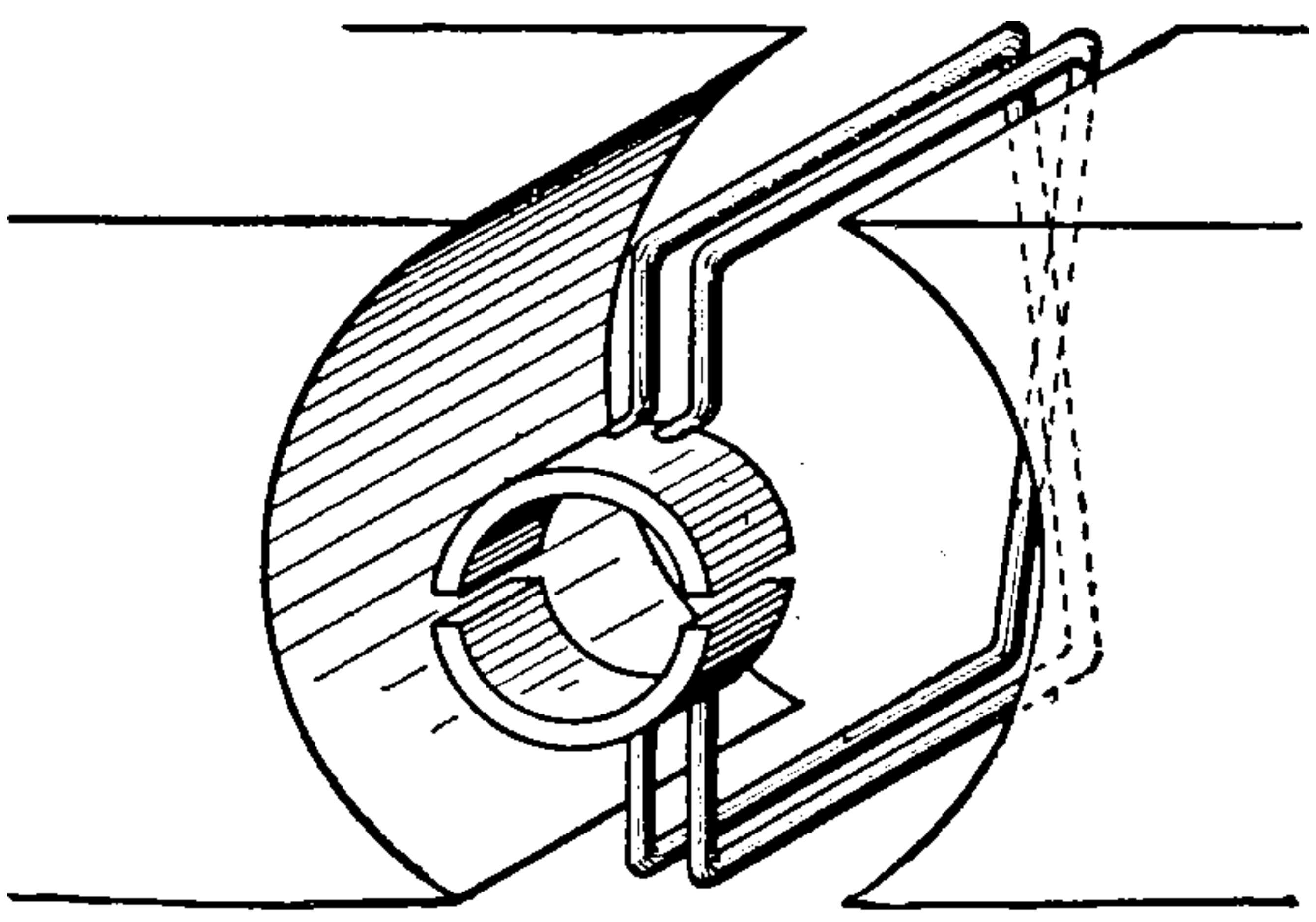


Fig. 26. Commutator with Two Single-Turn Coils

The current obtained, however, from this arrangement has the disadvantage of being pulsating, as already shown. To give continuity to the external current multiply the number of generating coils, and also the number of commutator segments, arranging the

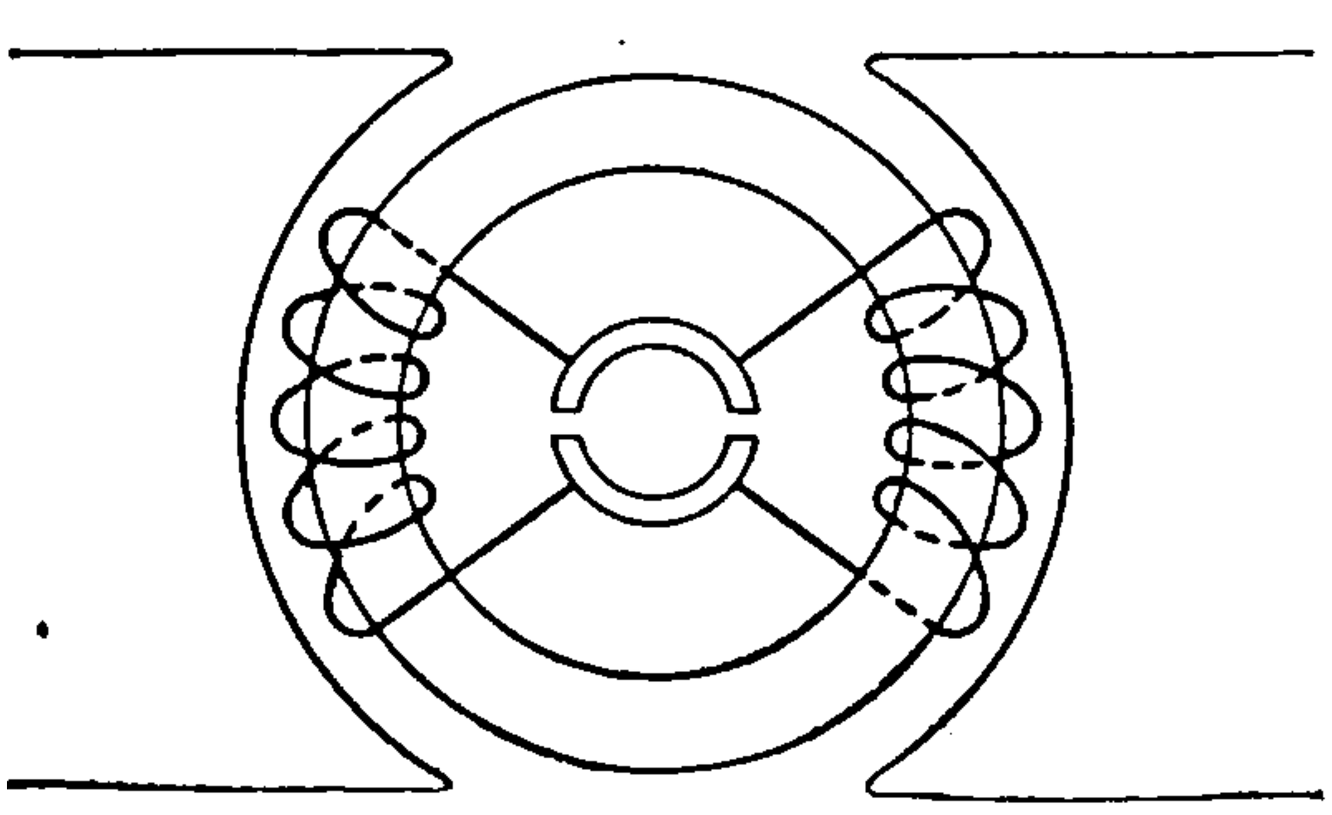


Fig. 27. Two-Coil Armature

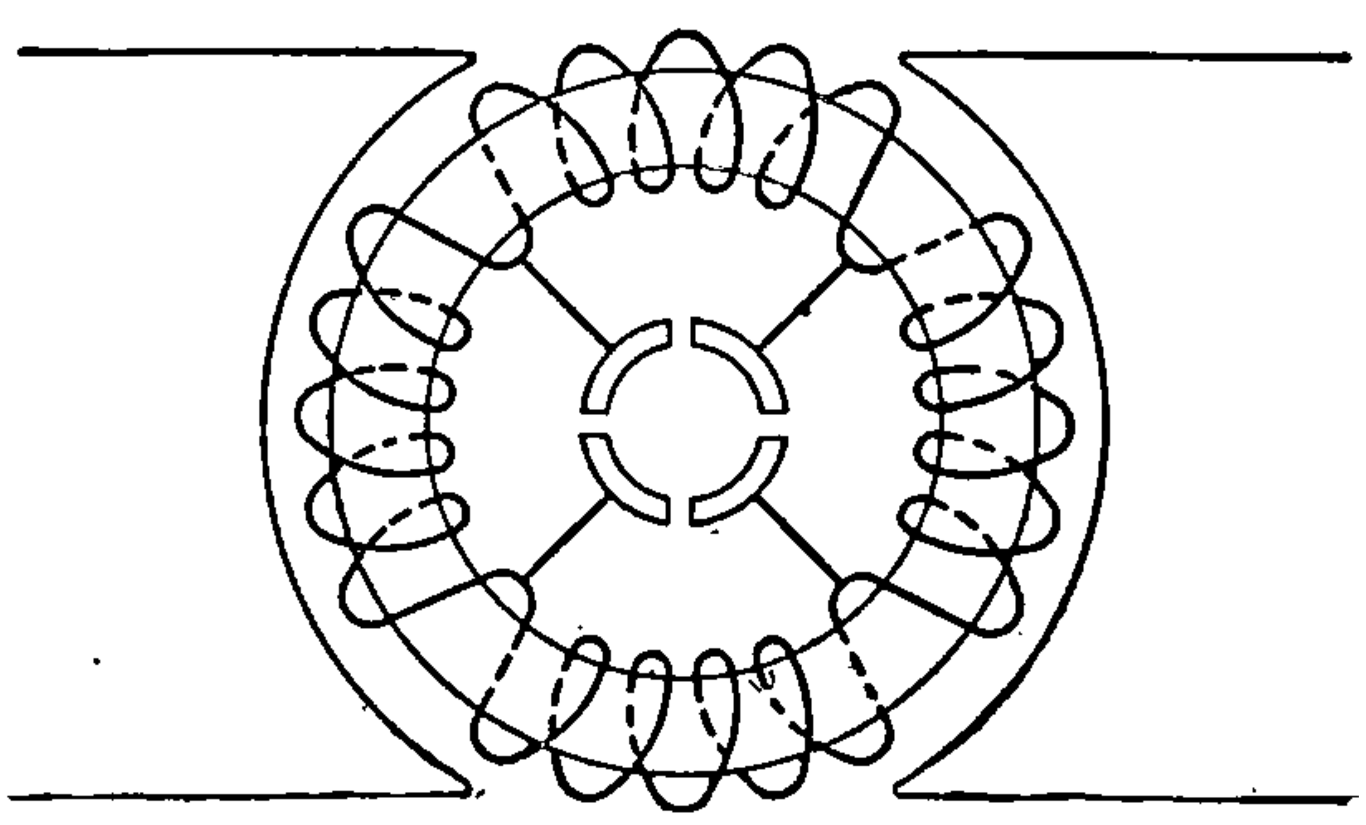


Fig. 28. Four-Coil Armature

coils around the armature so that one set will come into action before the other set goes out. If, then, two additional sets of coils are placed upon the iron ring at right angles with the first set, as in Fig. 28, one set will be in the position of maximum activity when the other is in the position of least action; the curves *A* and *B*, Fig. 29, represent the e. m. f. and current for the two pairs of coils, and curve *C* represents the resulting external e. m. f. and current, which, although continuous—*i. e.*, never becoming zero—is not quite steady, having

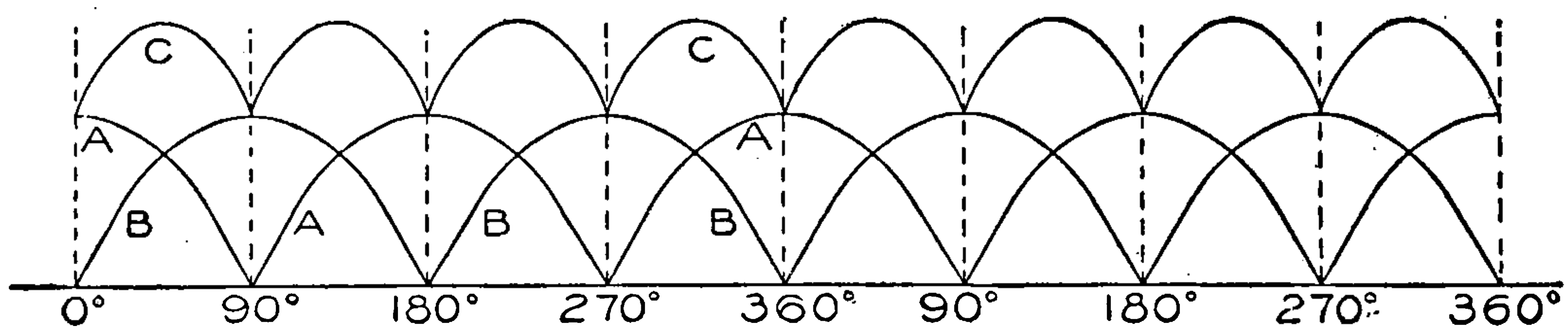



Fig. 29. E. M. F. and Current Curves for Four-Coil Armature

four slight undulations per revolution. By increasing the number of coils and commutator segments to a hundred or more, an external current may be obtained in which no undulations can be detected except by the telephone.

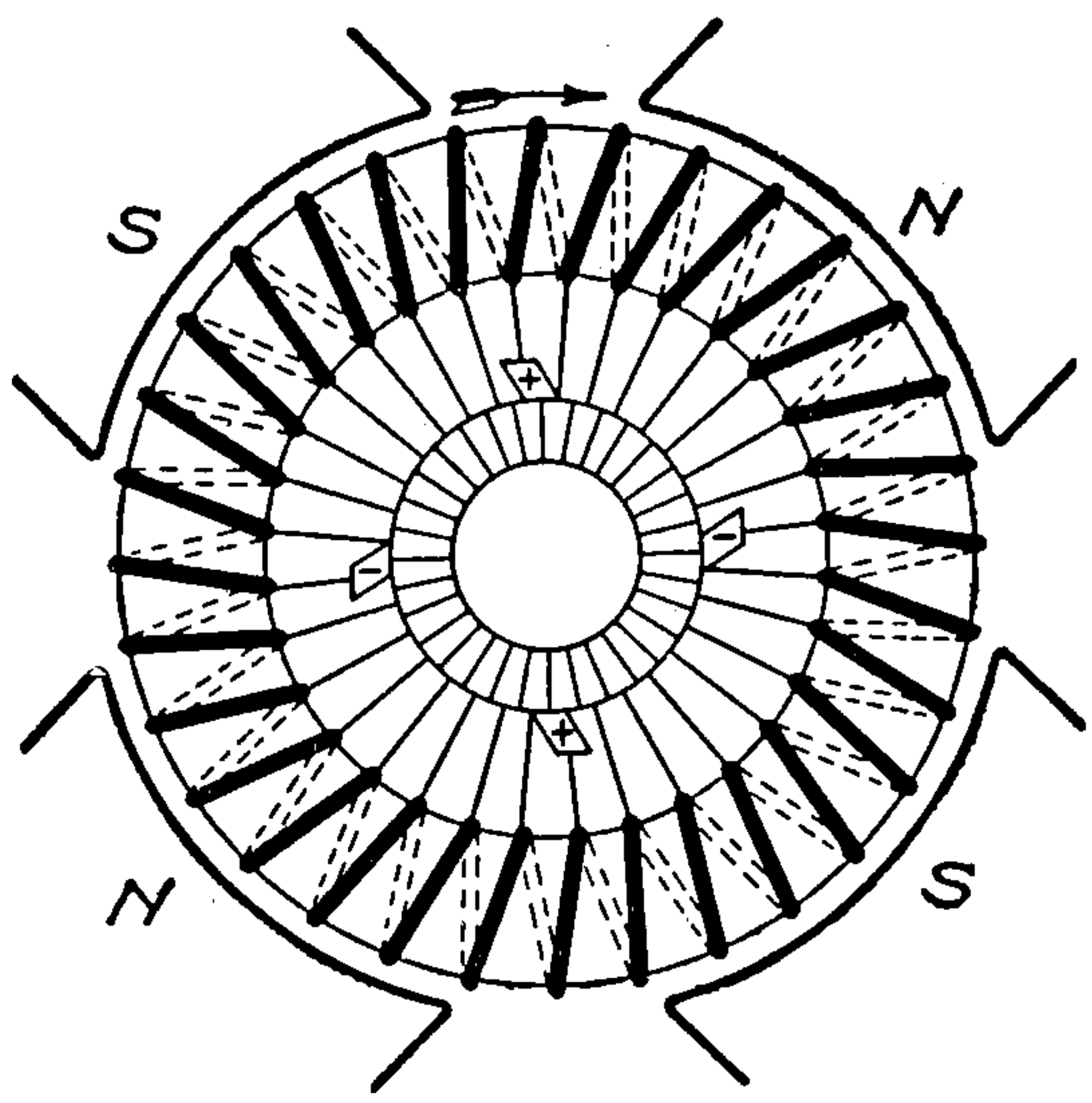



Fig. 30. Diagram of Coils and Commutator Sections

On examination of the winding, Fig. 28, it is apparent that the four coils are wound in series, the end of the first being connected to the beginning of the second, and so on, the end of the fourth being finally connected to the beginning of the first—the whole of the winding constituting, therefore, a single, closed coil. Also, it may be noted that the beginning of one coil and the end of the preceding one are connected to the same commutator bar. In practice the commutator is usually made up of a number of parallel bars of copper set around on, and separated from each other by, insulating material; and the armature is made up of a number of sections, as in Fig. 30, which represent a Gramme ring winding. This, and other windings, will be treated later.

## ORGANS OF CONTINUOUS-CURRENT DYNAMOS

It has been seen that a dynamo in its simplest form consists of two main portions—an *armature*, which, in revolving in a magnetic field, generates an e. m. f. in the conductors wound upon it; and a *field-magnet,* whose function it is to provide a flux for the conductors to cut as they revolve. These two parts are always present in all generators, whether for continuous current or for alternating current,

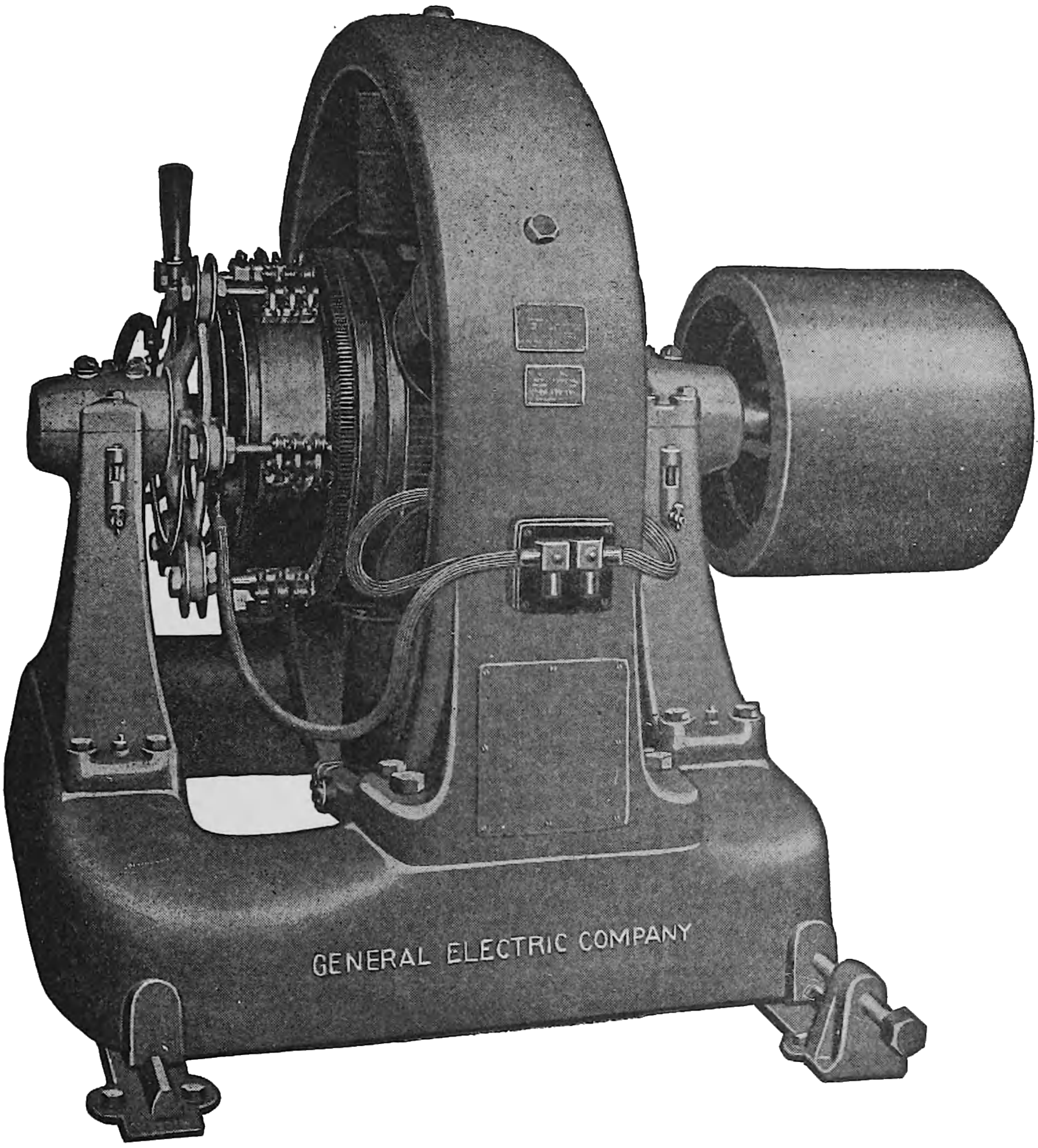



Fig. 31. Typical 6-Pole Belt-Driven Generator, Showing Armature, Field-Magnets, Commutator, and Brushes

and they are easily distinguished, Fig. 31. In almost all continuous-current machines, the field-magnet is a comparatively simple electromagnet which remains stationary; the armature, however, is more complex and usually rotates. In addition, it has been shown that continuous-current machines require a *commutator,* while alternating-current machines are provided with *collector,* or *slip, rings.* In either case, brushes are required to connect the revolving commutator or collector rings to the external circuit.

In continuous-current machines the field-magnet, being usually stationary, is combined with the bearings and bed-plate to form the frame of the machine. Similarly, the armature and the commutator are supported by a spider and a shaft, which rotate in the bearings attached to the frame.

**Armatures.** Any electrical conductor—as, for example, a simple coil of wire—revolving in a magnetic field so as to cut the flux, may act as an armature and tend to have an e. m. f. generated in it. In order to obtain a practically steady direct current, together with maximum effect for a given amount of material, and to secure compactness, convenience of working, and other practical conditions, armatures have resolved themselves into the following types, although theoretically, any figure of revolution around which coils are placed symmetrically, would answer:

(1) *Ring armatures,* in which the coils are grouped upon a ring core of iron whose axis of symmetry is also its axis of rotation.

(2) *Drum armatures,* in which the coils are wound longitudinally over the surface of a drum or cylinder iron core.

(3) *Pole armatures,* in which the conductors are wound around radial iron cores projecting outward from a central hub.

(4) *Disk armatures,* in which the conductors are arranged in the form of a flat disk the plane of which is perpendicular to the axis of rotation, and usually not comprising an iron core.

*Ring armatures* were first employed by Pacinotti in 1860, and described by him in 1865; but they are commonly known by the name of *Gramme,* the French electrician, who re-introduced them in 1870. Gramme wound the coils around the entire surface of the annular core, which he made of varnished iron wire in order to reduce the wasteful effects of eddy-currents; while Pacinotti had the coils wound between projecting teeth upon an iron ring. In ring armatures, the parts of the copper winding which pass through the interior of the ring do not cut any flux, and so are inoperative unless there are pole-pieces of the field-magnet projecting internally, which

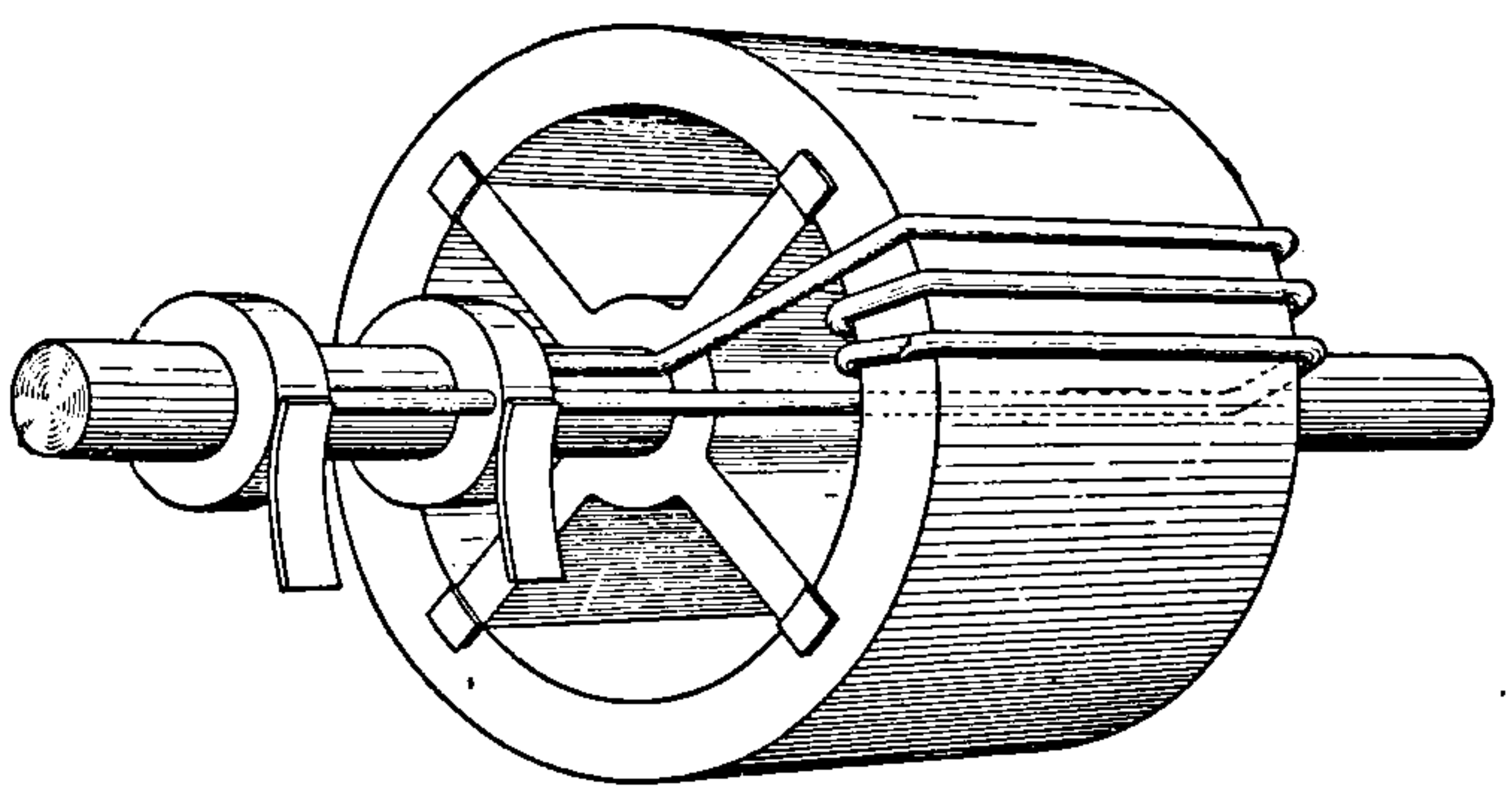


Fig. 32. Single Gramme Ring Winding

is not usually the case in practice.* Hence, the ring type of winding necessitates extra copper and offers a certain amount of wasteful resistance, which, however, can be made small compared with the resistance of the external circuit. Fig. 32 represents a Gramme ring of the armature type generally used, although some machines are so designed as to have the outside of the ring act as a commutator,

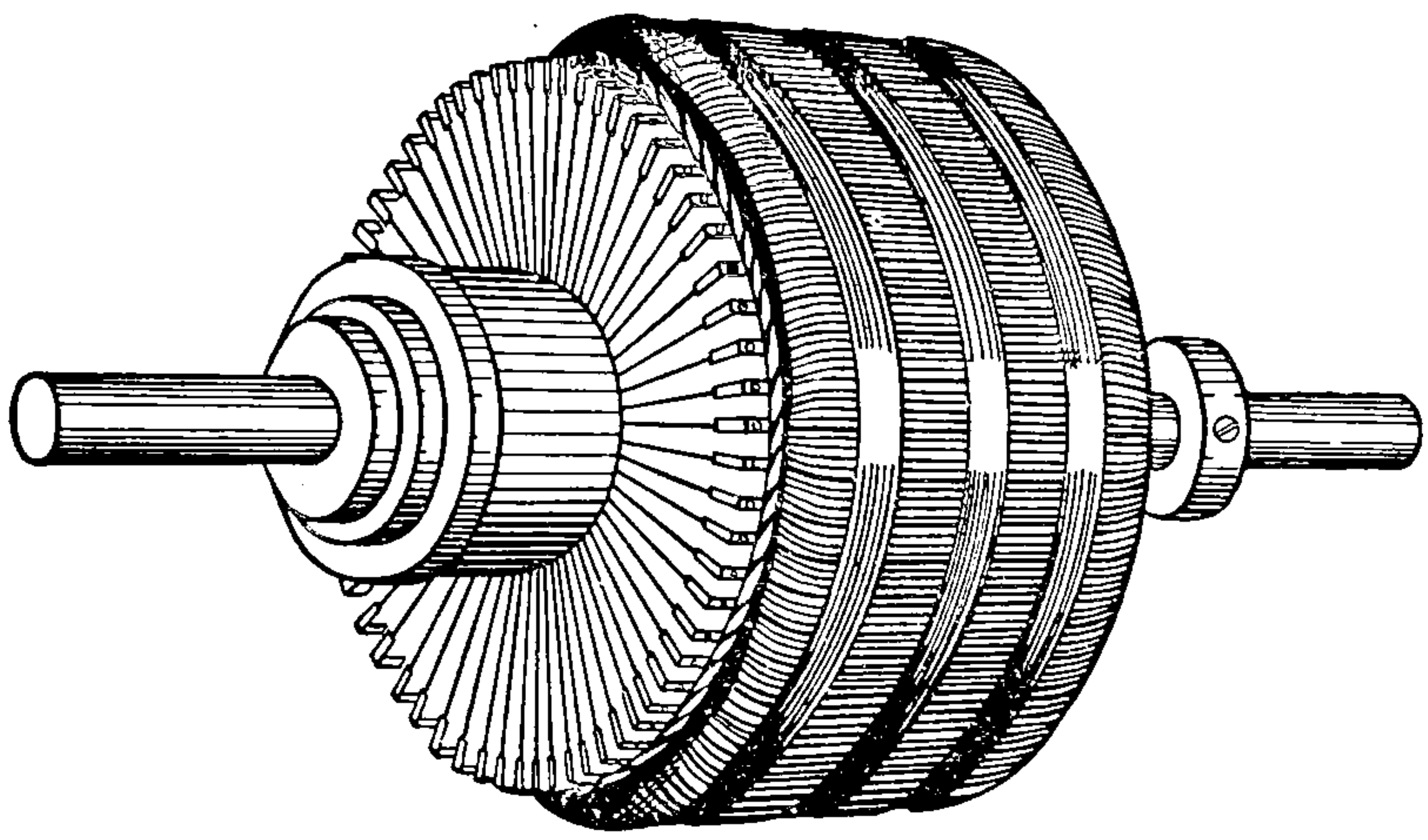


Fig. 33. Gramme Ring Armature

the current being collected directly from the windings by brushes which trail on the periphery of the ring, while the inner parts of the conductors cut the flux. Fig. 33 shows a completely wound Gramme ring armature.

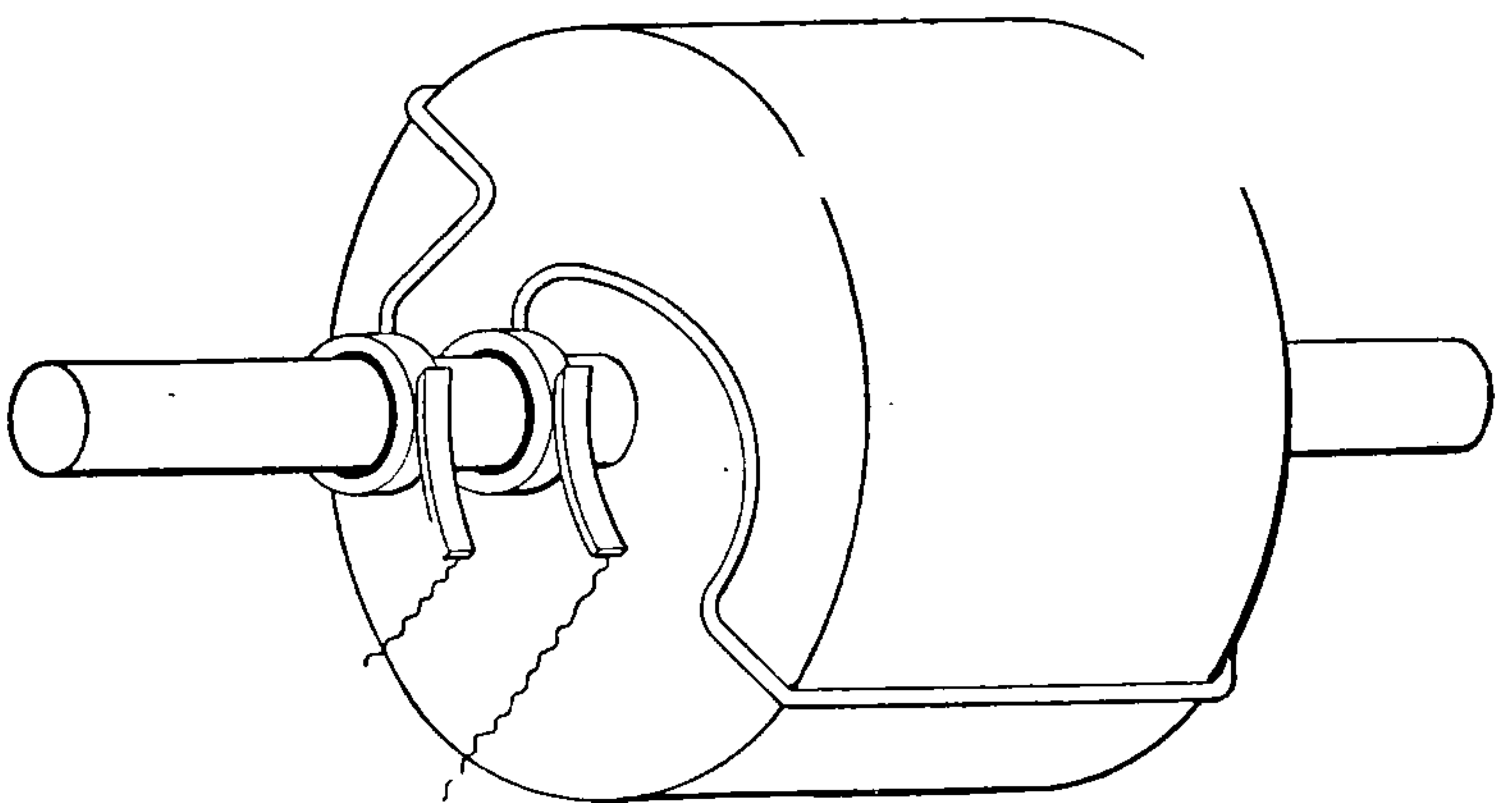


Fig. 34. Simple Drum Winding

*Drum armatures* were introduced by Siemens, who wound coils of iron wire upon a frame of non-magnetic material. In their com-

* In case of magnetic leakage through the opening in the ring core, the internal parts of the winding would produce an e. m. f. in the opposite direction to that generated by the outer sections, thus decreasing the effective voltage.

plete form, they were first brought out in 1871 by Von Hefner Alteneck, and improved later by Weston and others. As seen from Fig. 34, this type in its elemental form is of simpler construction than the ring type of Fig. 32 and consists of the loop, previously de-

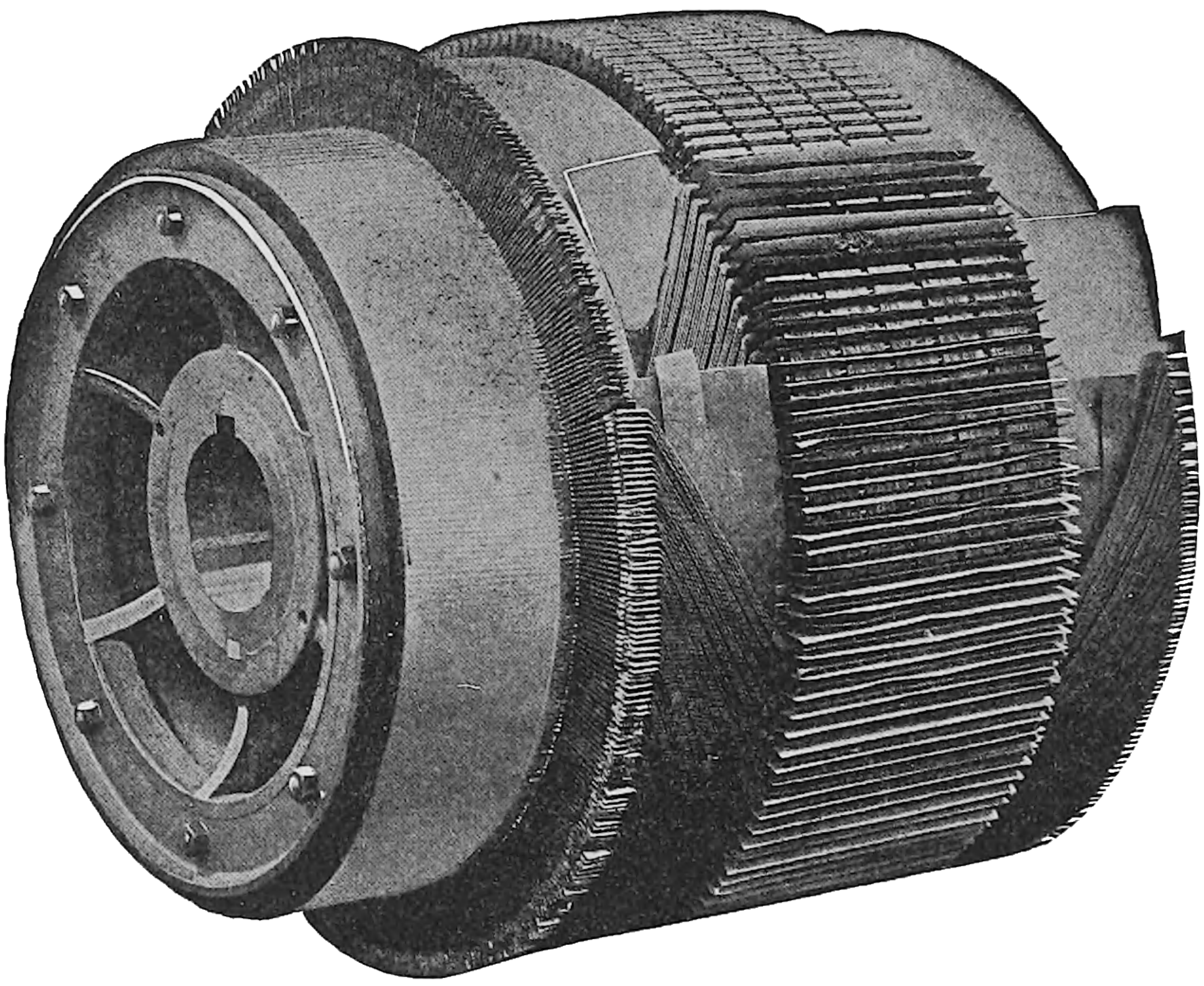


Fig. 35. Partly-Wound Drum Armature

scribed, mounted upon a supporting cylinder of magnetic material. The latter is used in place of the wooden cores of the earlier Siemens form in order to reduce the magnetic reluctance of the gap between the two faces of the field-magnet poles. This type of armature is almost exclusively used for continuous-current machines of to-day, because the drum form of winding effects a saving in wire for a given number of ampere-turns by the elimination of the inactive inductors which are necessarily present in the ring type. Machine-formed coils are also more easily applied, Fig. 35. Further, its self-induction is considerably less, so that sparking tendencies are diminished.

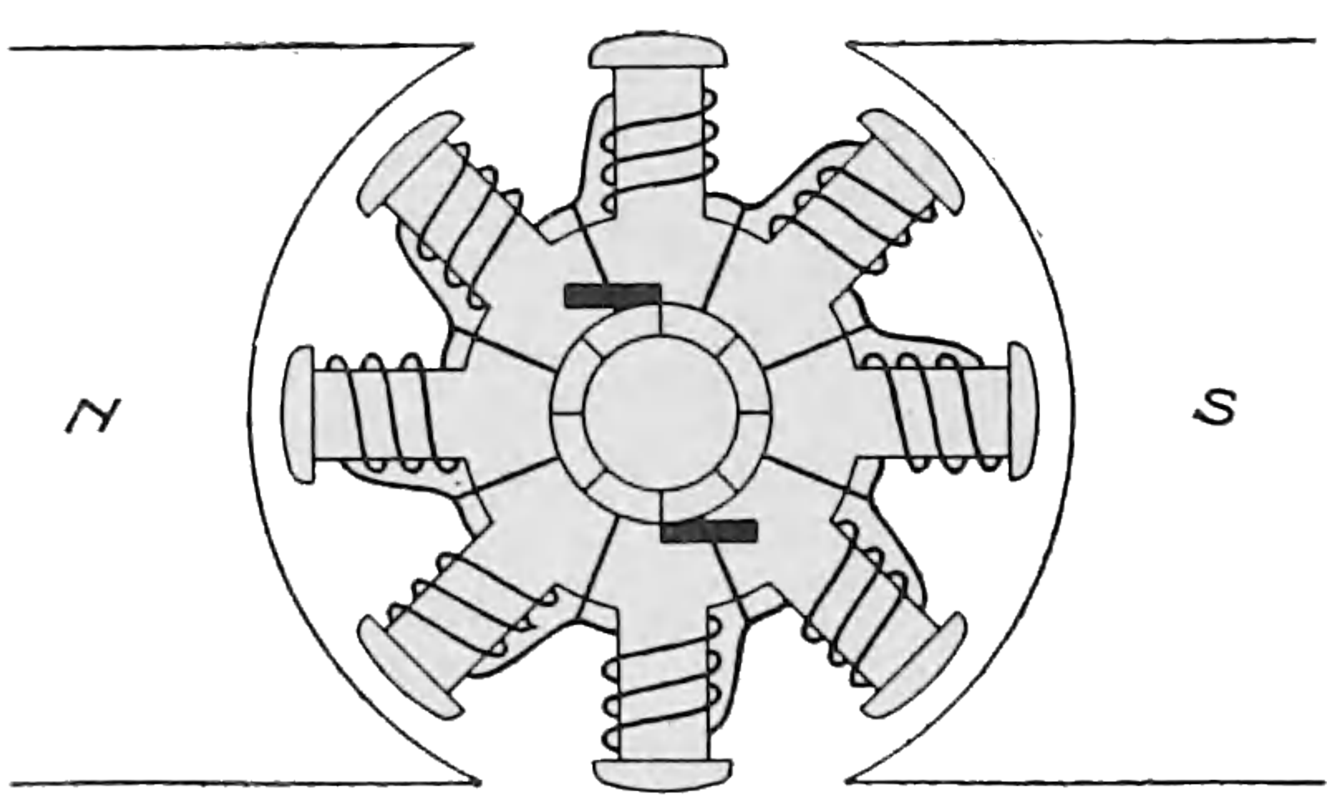
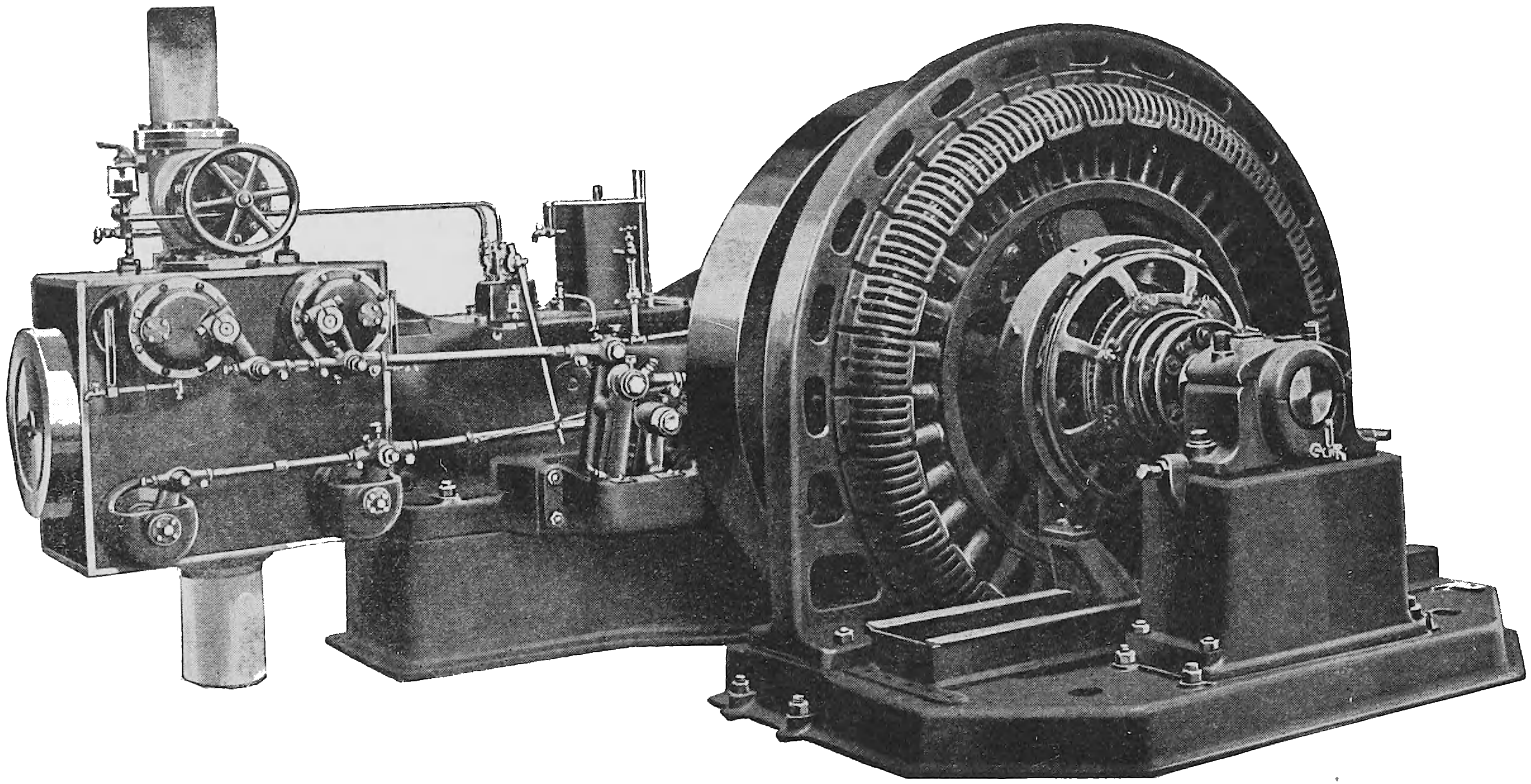


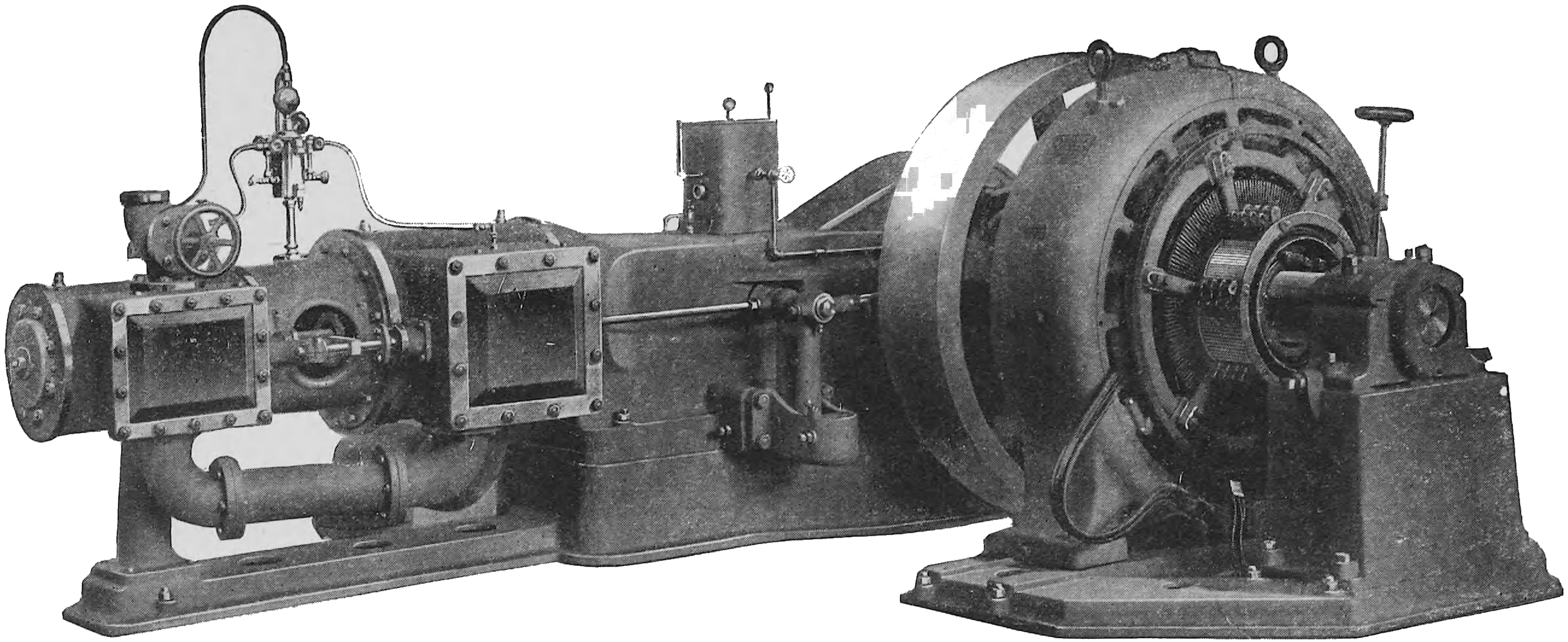

Fig. 36. Pole Armature

*Pole armatures*—those having the coils wound upon projecting poles—were devised by Allan, Lontin, Weston, and others. They



GENERATOR DIRECT-CONNECTED TO BALL HORIZONTAL, SINGLE CYLINDER CORLISS ENGINE

*Courtesy of Ball Engine Company*



HORIZONTAL TANDEM-COMPOUND, SIDE-CRANK BALL ENGINE DIRECT CONNECTED TO GENERATOR

*Courtesy of Ball Engine Company*

were used in Lontin's machines, as shown diagrammatically in Fig. 3. Owing, however, to the great self-induction thus introduced into each section of the winding, and the consequent sparking at the commutator, these machines were not successful. Pole armatures are to some extent used in alternating-current generators.

*Disk armatures,* Fig. 37, have never been very widely used. The interesting feature of this type is the fact that there is no neces-

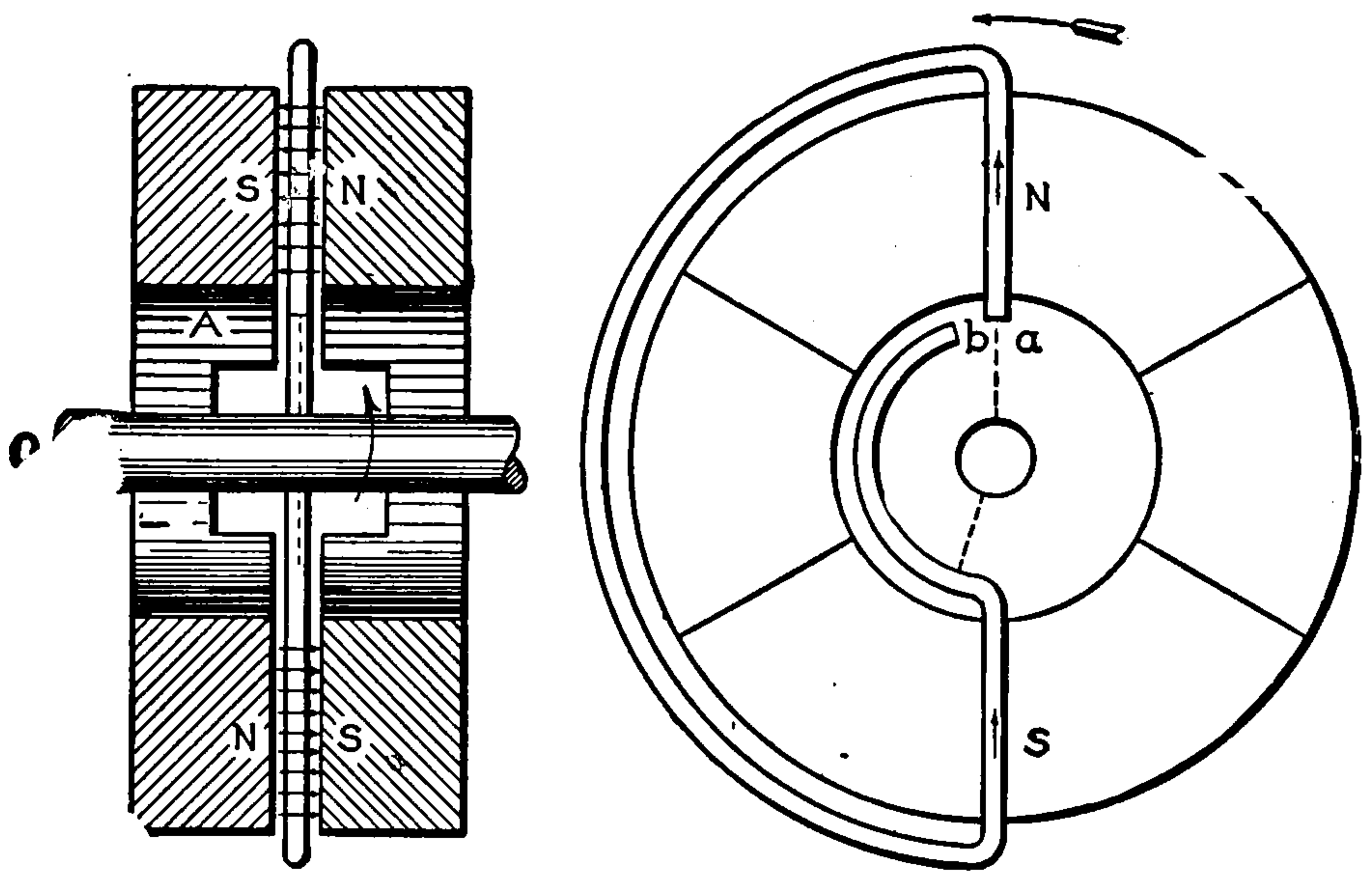



Fig. 37. Disk Armature

sity for magnetic conducting material between the two faces of the field-magnet.

**Armature Cores.** The function of the armature core is two-fold —it supports the generating conductors, and carries the flux from one face of the field-magnet to the other face. On account of its high permeability and its great strength, iron is by far the best material for armature cores. It has been seen, however, that when a mass of iron (or other conductor) is rotated in a magnetic field, wasteful eddy-currents are set up in the mass, hence solid cores of metal should on no account be used in any armature. In order to reduce these currents as much as possible, it has become the practice to build up armature cores of thin soft iron or mild steel disks, insulated from each other by varnish, rust, or paper. These disks are arranged to have their planes parallel to the direction of the flux and perpendicular to the flow of eddy-currents. An armature core composed of such sheets, and forced together by hydraulic or screw pressure, is found to contain from 85 to 95 per cent of its volume as iron, the balance being made up of insulation, air space, etc.

**Field-Magnets.** To generate an e. m. f. the armature inductors must be moved through a magnetic field. This flux is supplied by permanent magnets or by electromagnets in which the exciting current is supplied by the armature of the machine itself or by a separate source. These will be taken up in the order of their historical development.

*Magneto-Machine.* In this type of generator, historically the first, the magnetic flux was provided by a permanent magnet as shown diagrammatically in Fig. 38. This method has the disadvantage of requiring a much bulkier machine than those to be described later, since permanent magnetism cannot be maintained at such high flux-density as may be produced by an exciting coil. It has, however, the advantages of simplicity and constancy, but is used only in the smallest of generators employed, for example, to furnish current for ringing bells, for ignition in internal-combustion engines, etc.

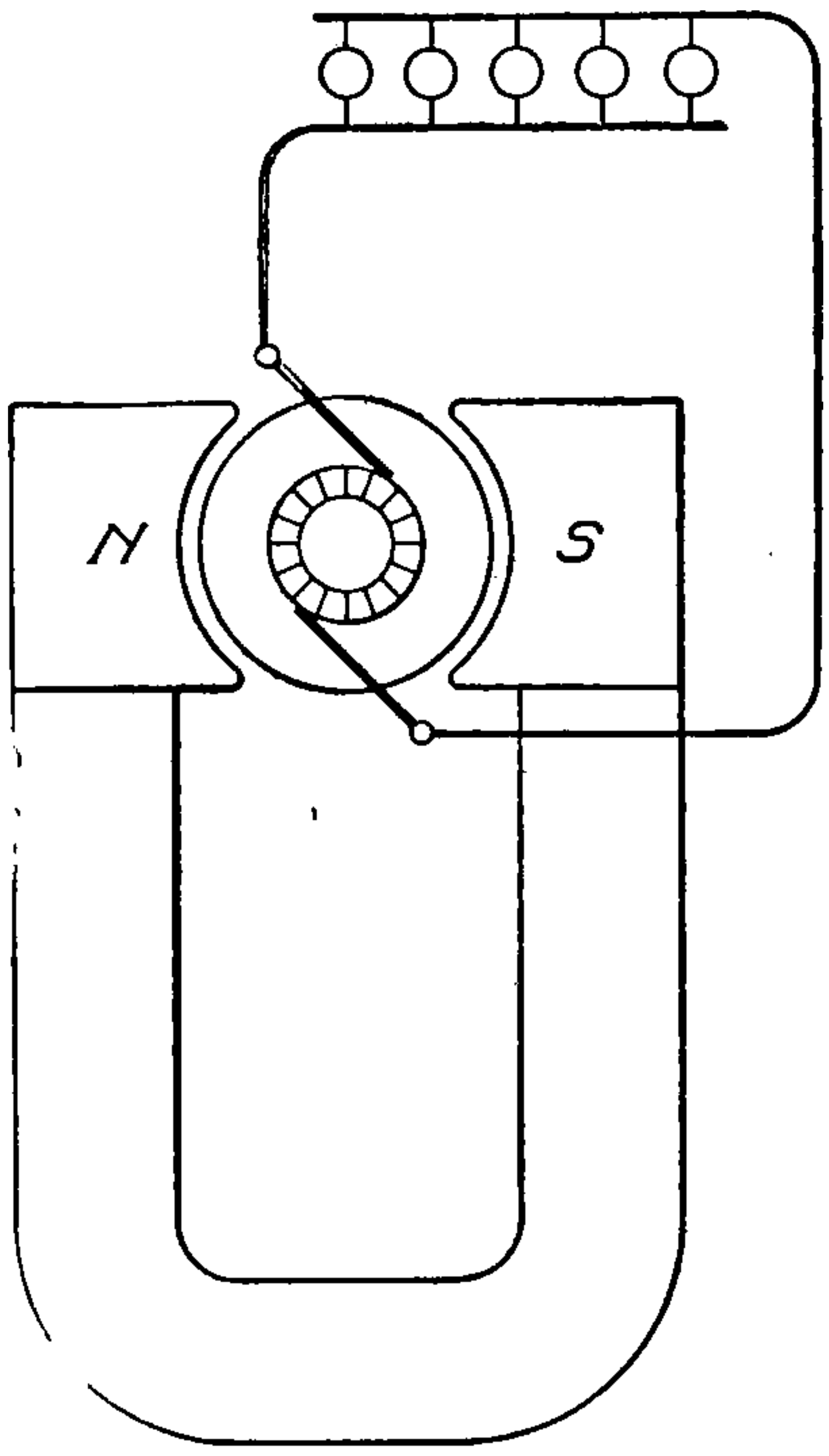



Fig. 38. Diagram of Magneto

*Separately-Excited Generator.* The next step was to excite the field-magnets by means of a coil fed from some source of electrical energy other than the generator itself. This method, outlined in Fig. 39, produces the same results as the magneto method, without the disadvantage of great bulk. It requires, however, a separate machine or battery for excitation purposes solely, and the method is not employed in continuous-current practice, except where many machines are in operation, or where their terminal voltage exceeds 800 volts. It is largely employed with alternating-current generators, since an alternating current will not produce a unidirectional magnetic field.

In either of the methods just mentioned, the e. m. f. of the machine may be governed in three ways—namely, (*a*) by altering the speed of rotation of the armature; (*b*) by varying the number of effective conductors by moving the brushes; and (*c*) by changing the magnetic flux through the armature. The latter is altered in the case of magneto-machines by shunting the flux away from the armature through an auxiliary piece of iron. In the case of separately excited machines, the flux is varied by regulating the exciting current or the number of turns of the solenoid.

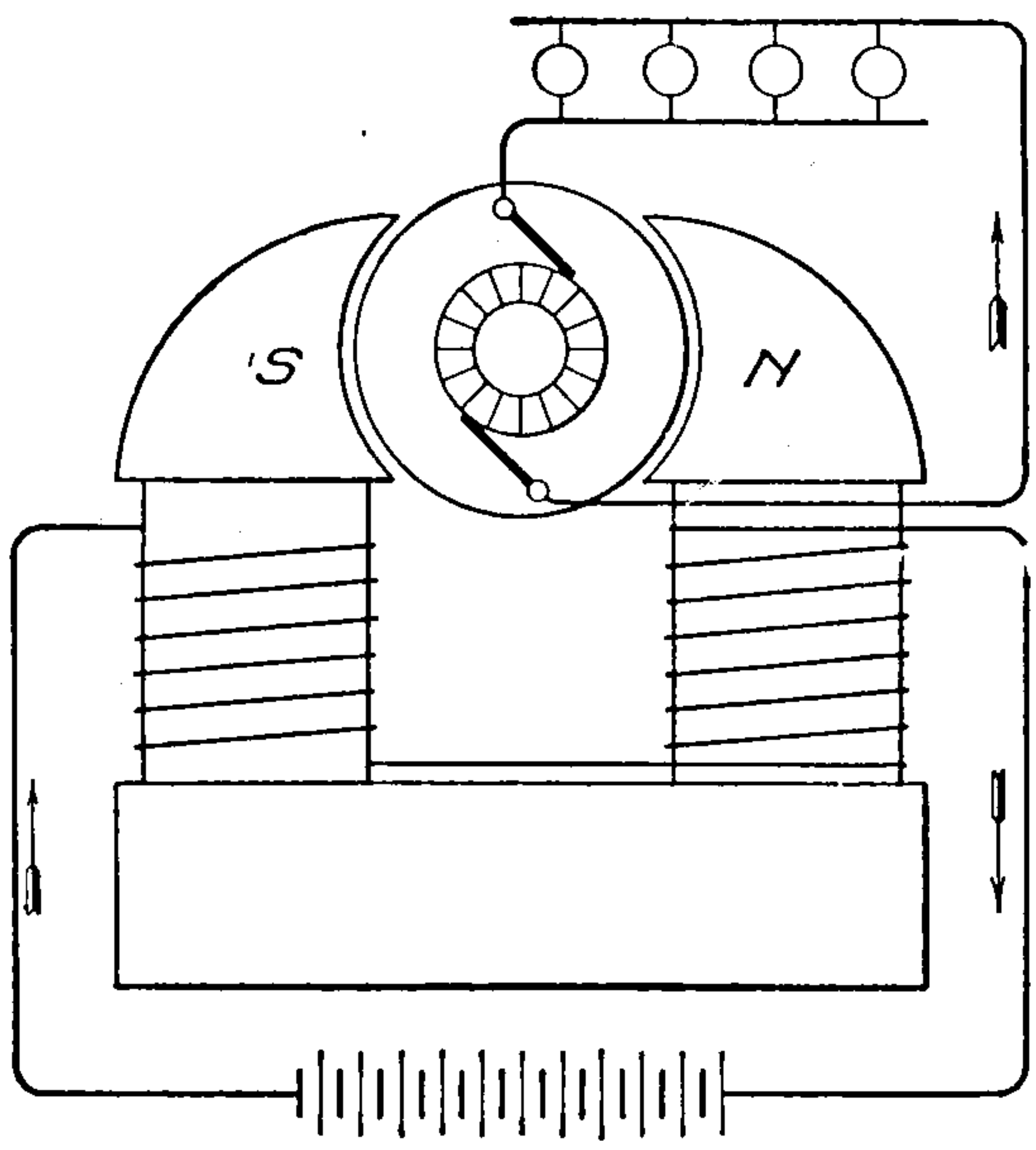


Fig. 39. Separately-Excited Generator Windings

Generators of the continuous-current type may be made *self-exciting* by either of four methods. The *whole current* supplied by the machine to the external circuit or *a part of it* may be passed through the field-winding; or *two field windings* may be employed, one traversed by the load current and the other by the shunt current; or, finally, the *field-exciting current* may be produced by an e. m. f. generated by a separate winding on the armature of the generator, though this latter form is seldom used.

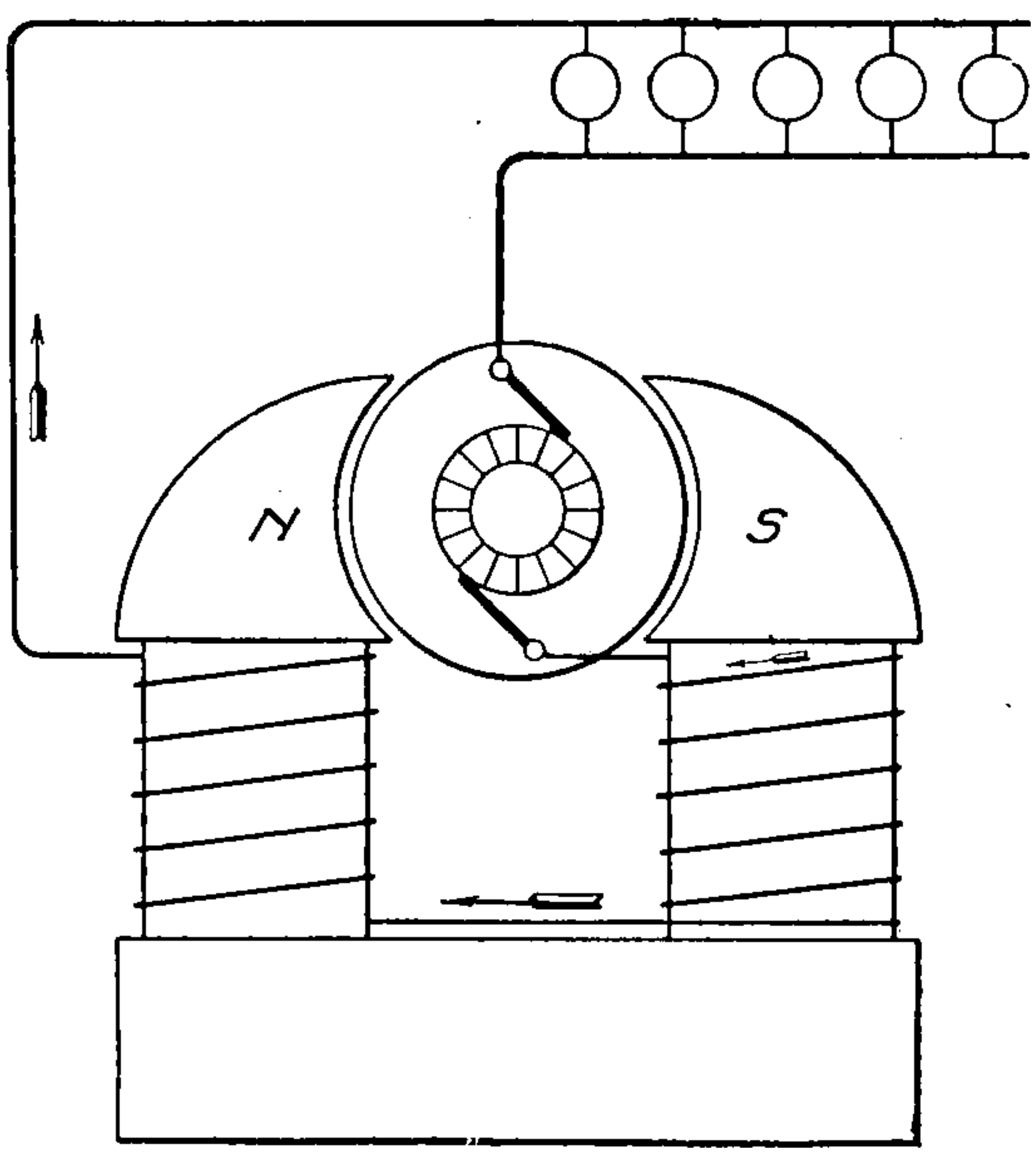


Fig. 40. Series Generator Windings

*Series Generator.* The series continuous-current generator outlined in Fig. 40 has but one circuit. It has, however, the disadvantage of not starting to generate until a certain speed has been reached or unless the resistance in the external circuit is below a certain limit. It also is liable to become reversed in polarity, thus unfitting it for electrolytic work. Any increase in its external resistance, at a given speed, diminishes the current strength that excites the magnetic circuit, thereby lowering the e. m. f. Conversely, reduction of external-resistance tends to increase the e. m. f. of the machine until the *IR* drop and the armature reaction become so large that the available voltage falls more rapidly than the field flux increases. The only series generators actually employed supply *arc lamps in series*, and are provided with automatic regulators to maintain constant current; hence the external voltage and power are directly proportional to the external resistance.

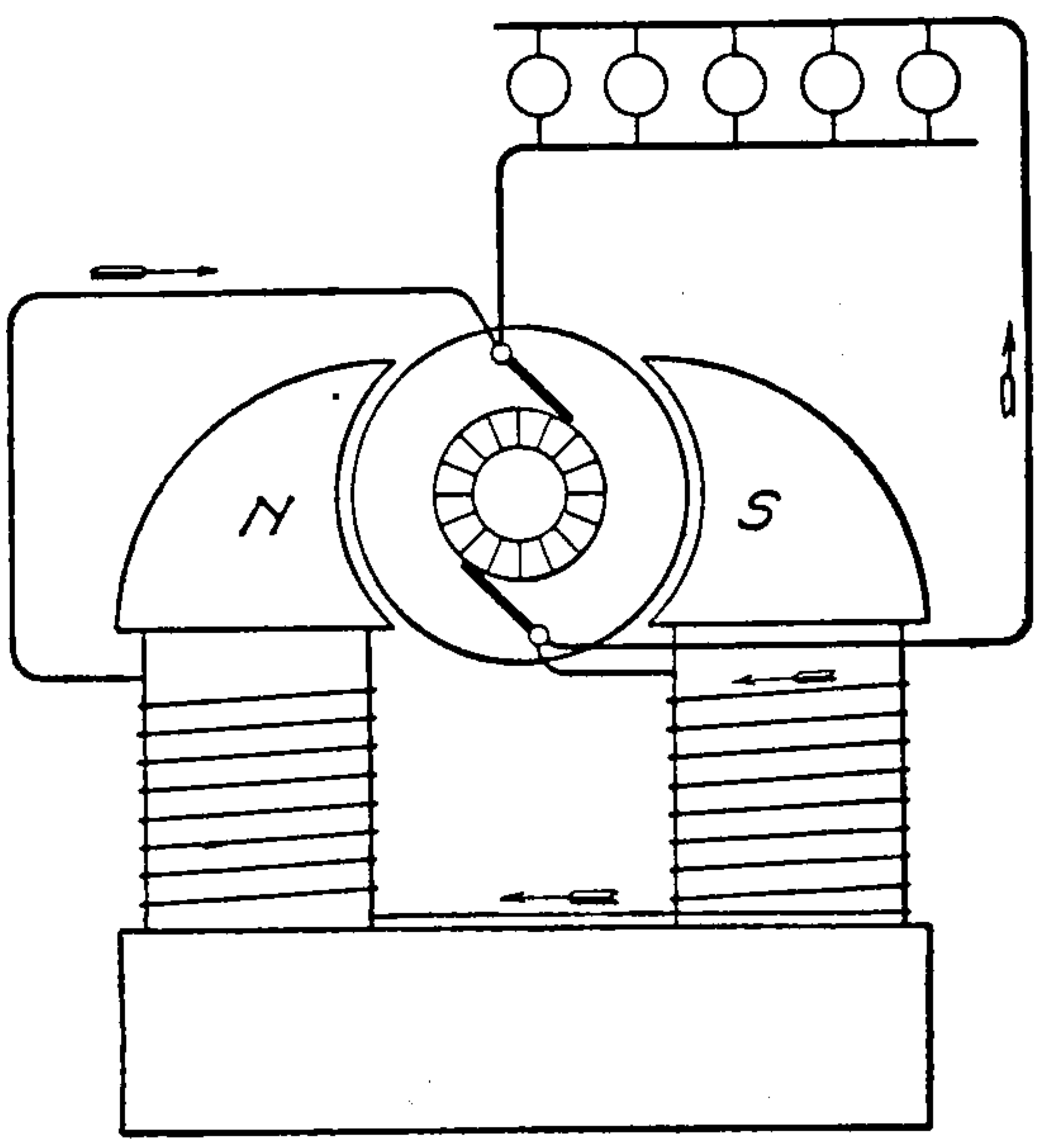



Fig. 41. Shunt-Wound Generator

*Shunt Generator.* In the shunt-wound generator, Fig. 41, only a small part of the current in the armature passes through the field winding. The field-exciting circuit has, therefore, a relatively high resistance compared with that of the external circuit. This machine is tolerably self-regulating within certain limits, when properly designed; but if overloaded, its internal actions are such as to reduce its generated e. m. f. to zero. The polarity of the shunt generator never reverses of itself; and although it is a trifle more expensive to buy than the corresponding series machine, its self-regulating properties more than overbalance this. The amount of energy required for excitation in either series or shunt field-windings for identical machines is precisely the same, since to produce a given flux (as shown in the discussion of the magnetic circuit) demands a definite number of *ampere-turns*. In the series machine, the *turns* of wire are few in number, while the current in *amperes* is relatively large. In the shunt type, the reverse is the case.

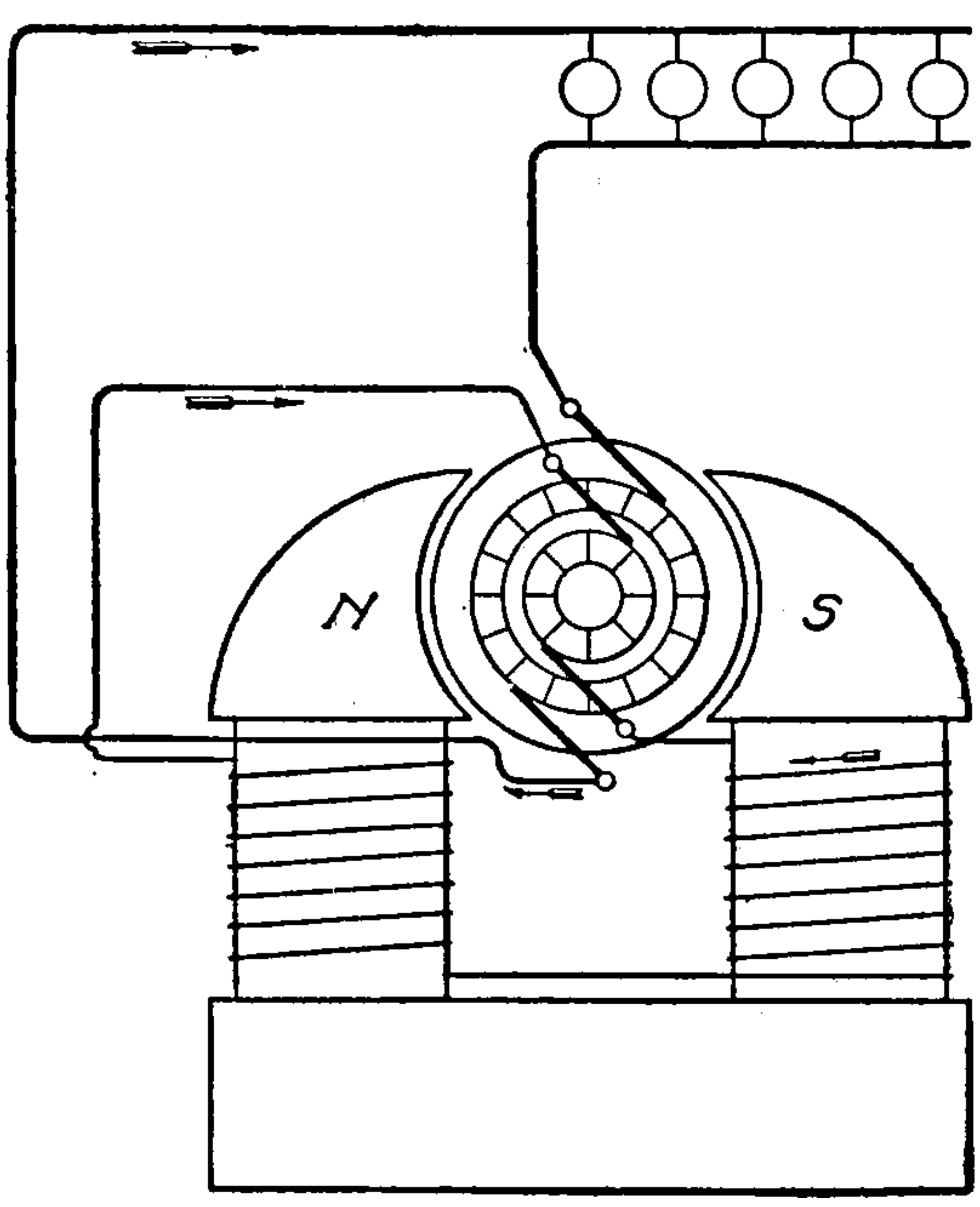



Fig. 42. Separate-Current, Self-Exciting Generator

resistance of the field-exciting circuit or by increasing the terminal voltage impressed there. Also, the flux may be made to increase with load, by passing the external current of the generator through a few turns of thick wire, called *series turns* or *compounding turns,* placed upon the field-cores. The first method is usually non-automatic, and is applicable to shunt and separately excited machines; the second is applicable to separately excited machines; and the third, to both types; and a generator thus equipped is called a *compound generator.*

**Methods of Compounding.** *Separate and Series* (Deprez). A separate source of current is used to produce the initial and constant excitation, while the external current of the machine is led through a series winding, thus compensating for the internal drop of the generator to any desired degree, even *increasing* the terminal voltage with load if desired. The connections are shown diagrammatically in Fig. 43.

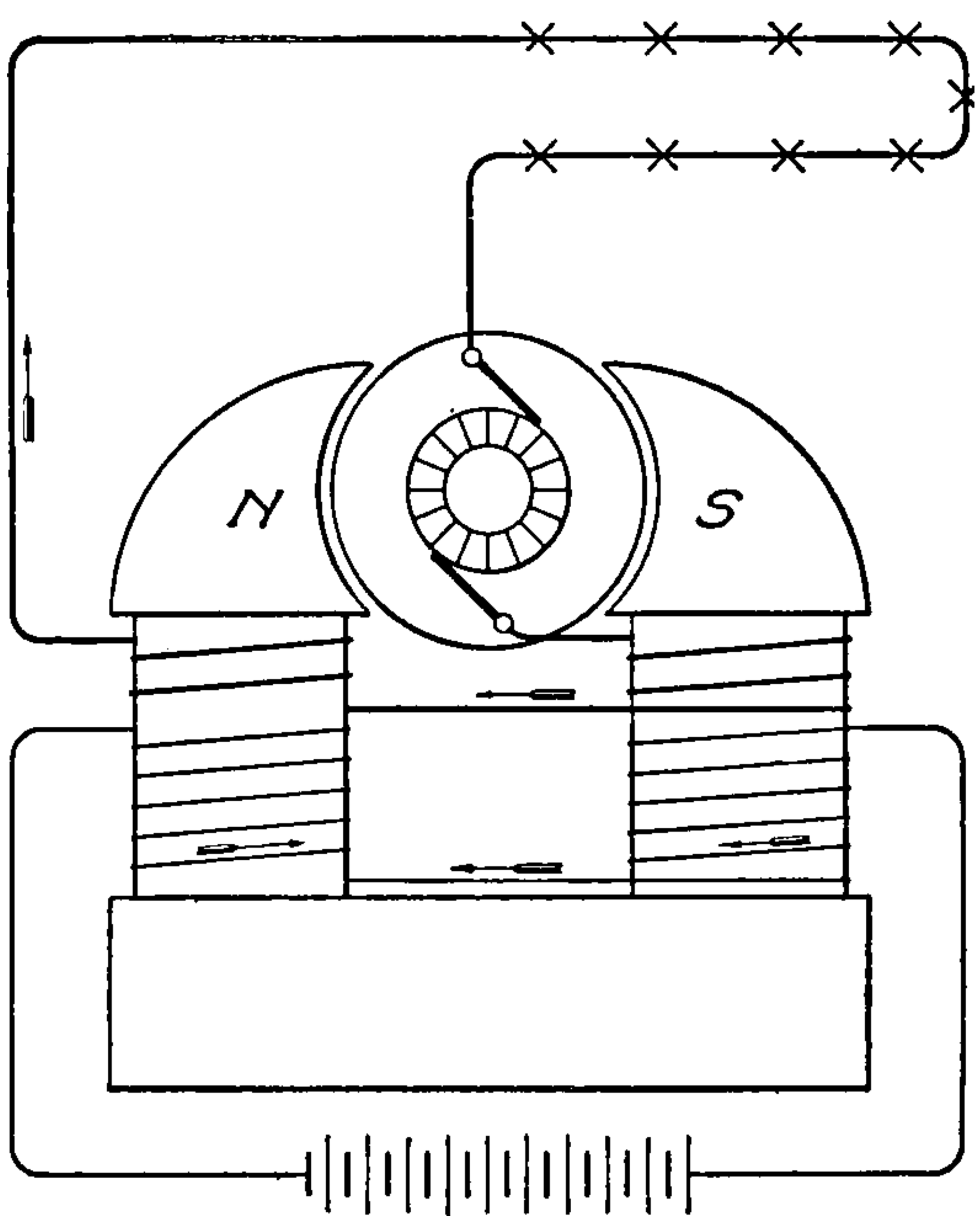


Fig. 43. Separate and Series Compounding

*Shunt and Series.* By far the most widely used of all compounding schemes, however, is the one in which series turns are added to the plain shunt winding, as shown diagrammatically in Fig. 44. By properly proportioning the ampere-turns in the shunt and series coils, the terminal voltage-load curve may be made to take any desired form, *i. e.*, it may be made constant, increasing or decreasing throughout the rated load range of the machine. This arrangement will be considered in detail later on.

*Booster.* This consists essentially of an auxiliary generator in series with the main machine, the e. m. f. of the former being low; and since its field winding is in series with the external circuit, it will automatically regulate the voltage of the combination in accordance with the load.

*Miscellaneous.* If the generator armature be wound according to a special scheme devised by Sayers,* the field excitation may be produced by a simple shunt winding, and a compounding effect produced by giving the brushes a backward lead. Other methods of compounding may be found in S. P. Thompson's "Dynamo-Electric Machinery."

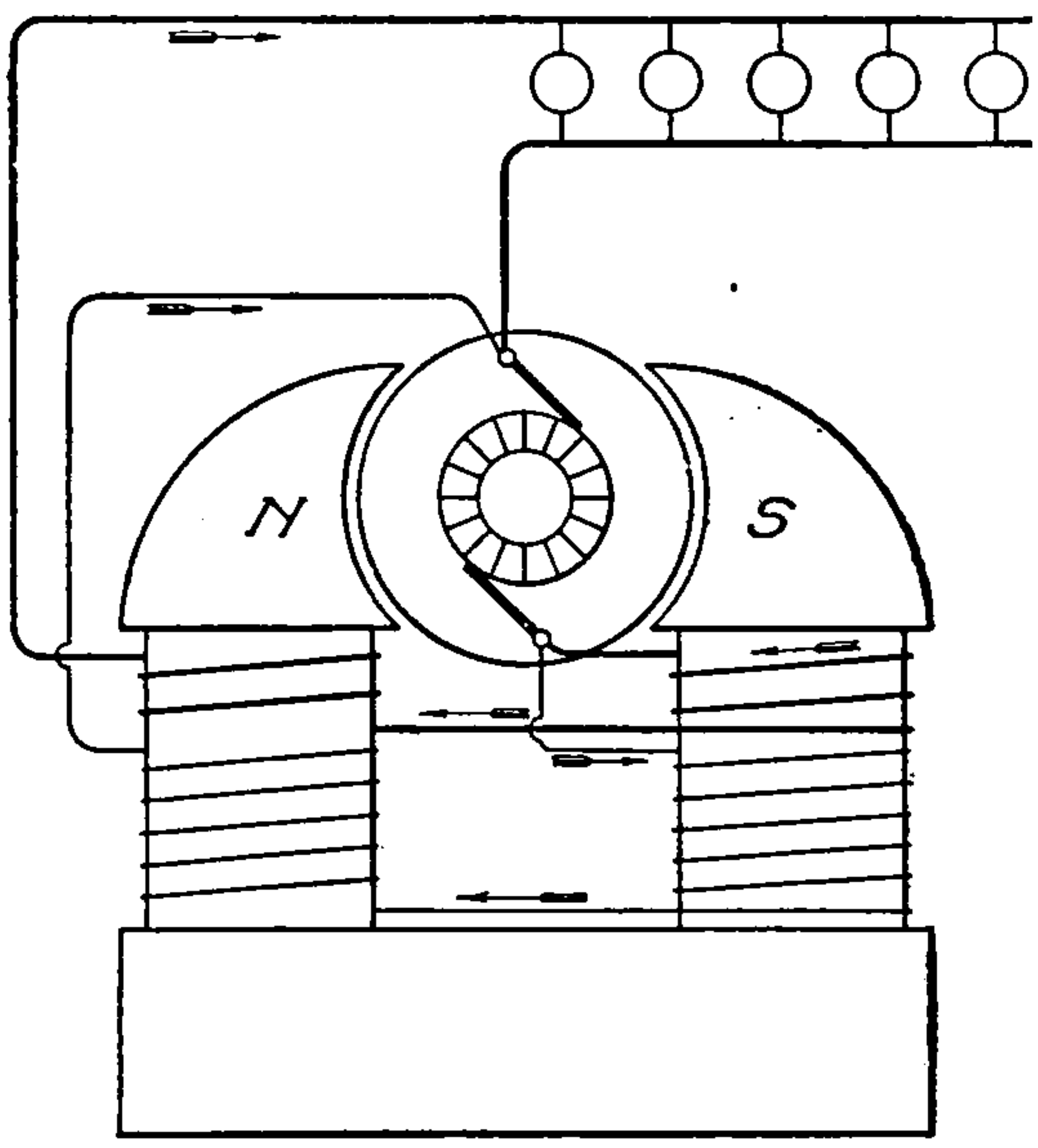


Fig. 44. Shunt and Series Compounding

**Actions in the Armature.** Thus far the armature and the field of the generator have been considered separately, assuming that the former did not affect the latter. It is found, however, that when the armature of a generator or motor is carrying current, its action is not the same as when it is operating without load, owing to the distortion of the field flux by the magnetizing action of the armature current. In order to study the effects produced by the armature current, consider a dynamo of the simple bipolar type, Fig. 45, with a ring armature, when the machine is operating without and under load.

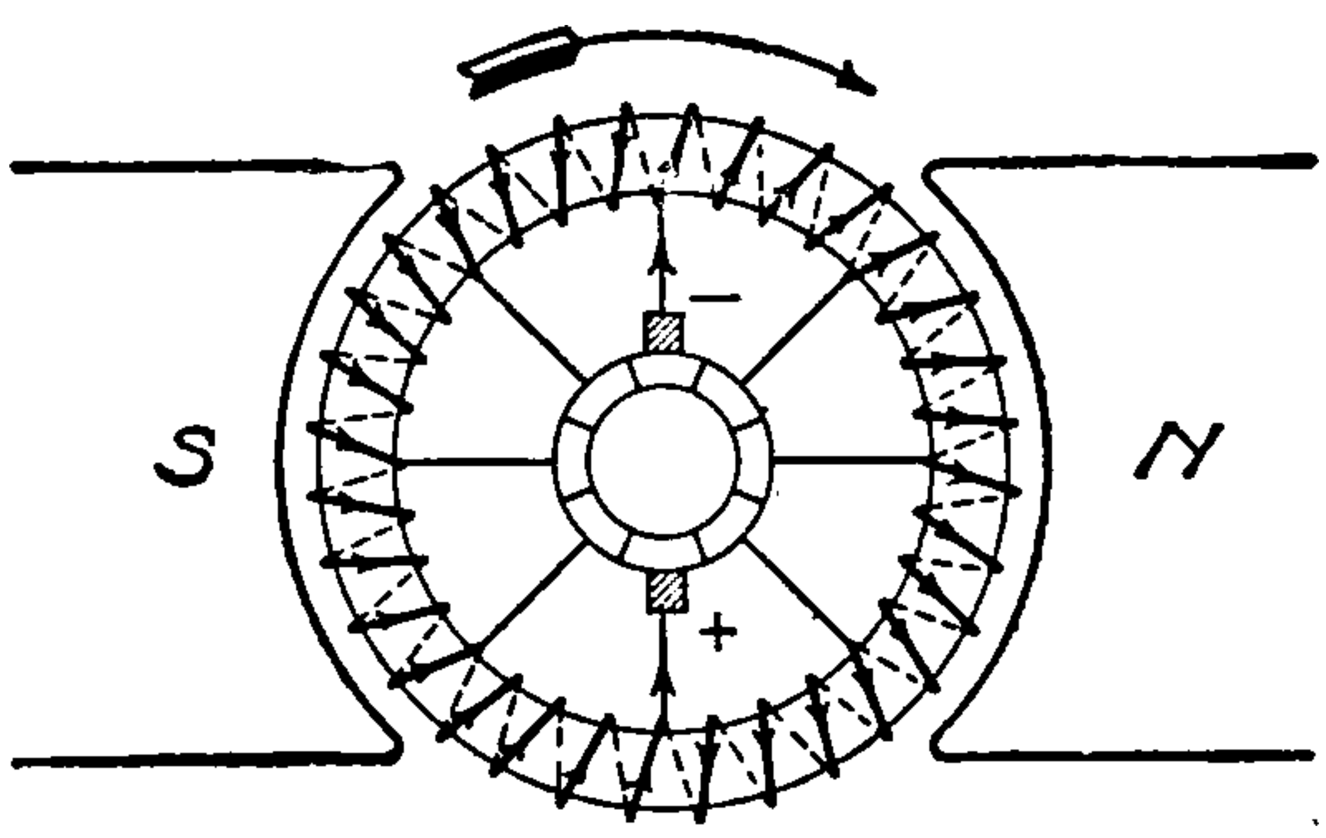


Fig. 45. Diagram of Simple Bipolar Generator

Suppose the armature to be rotating clockwise, when viewed from the commutator end, and that the north pole of the field-magnet is at the right of the armature, the south pole being on the left. The flux will then pass from right to left through the armature; and, in accordance with Maxwell's law, the generated e. m. f. in all the outer conductors which are ascending is directed toward the observer, as is designated by a + sign, Fig. 46; while in all the descending conductors it is directed away from the observer, as indicated by a − sign. If the circuit through the armature is closed, the generated e. m. f. will produce a current flowing in the same direction; and in Fig. 45 the

* See A. Arnold's *Gleichstrommaschine*, Berlin, 1902, Vol. I, Pages 417, 449, *et seq.*

current-flow in the armature is toward the bottom and away from the top on both sides. This result is obtained when the winding of the armature is right-handed, and the opposite effect is obtained if the winding is left-handed.

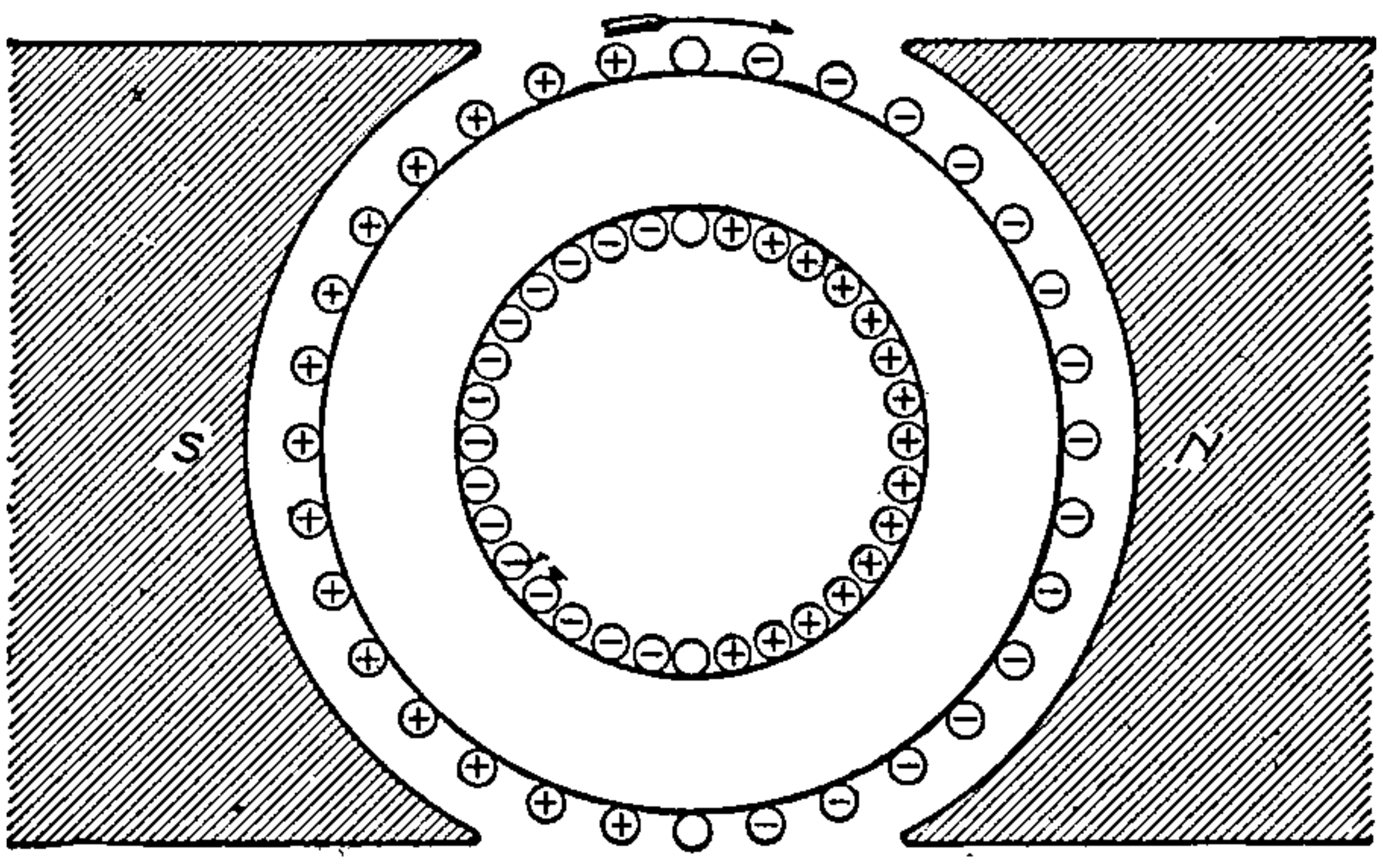


Fig. 46. Direction of Armature Current

It will be noted that the path of the current is from brush to brush, through each of the armature coils, without going to the commutator except where it passes *out to* or returns *from* the external circuit. It has been seen, however, in the ideal dynamo, that the voltage generated in an armature coil is proportional to the rate at which the flux is cut. In the case illustrated in Fig. 45, no two armature coils are cutting the same amount of flux at any given instant, so that the voltage generated in each coil depends upon its position in the field. Since one-half of the coils are connected in series between the brushes, the total difference of potential (p. d.) measured at the latter will at any instant be the sum of the instantaneous e. m. f.'s generated in the individual coils.

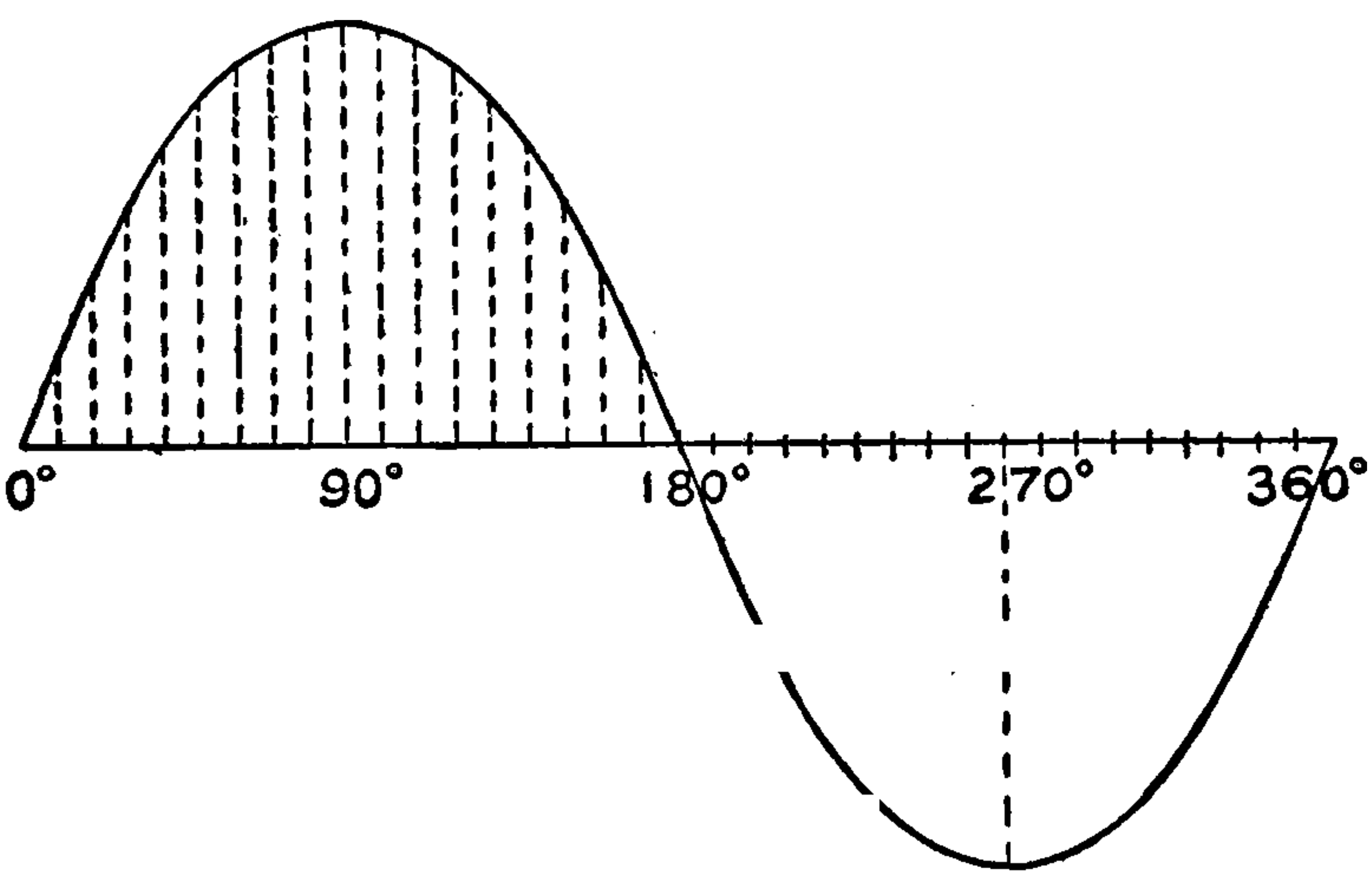


Fig 47 Sine Curve

If the field were uniform, it is plain that the flux cut at a given instant by any one coil would be dependent on the angle which it makes with the direction of the field at that instant as explained, page 25; so that if the values of these instantaneous potentials be plotted as ordinates, and the corresponding angles as abscissæ, the curve, commonly known as a *sine curve,* Fig. 47, is obtained.

Thus it is seen that the p. d. obtained at the brushes may be compared to that obtained at the terminals of a battery connected as shown in Fig. 48, each cell representing an armature coil and being supposed to supply an e. m. f. equal to that generated by the coil it

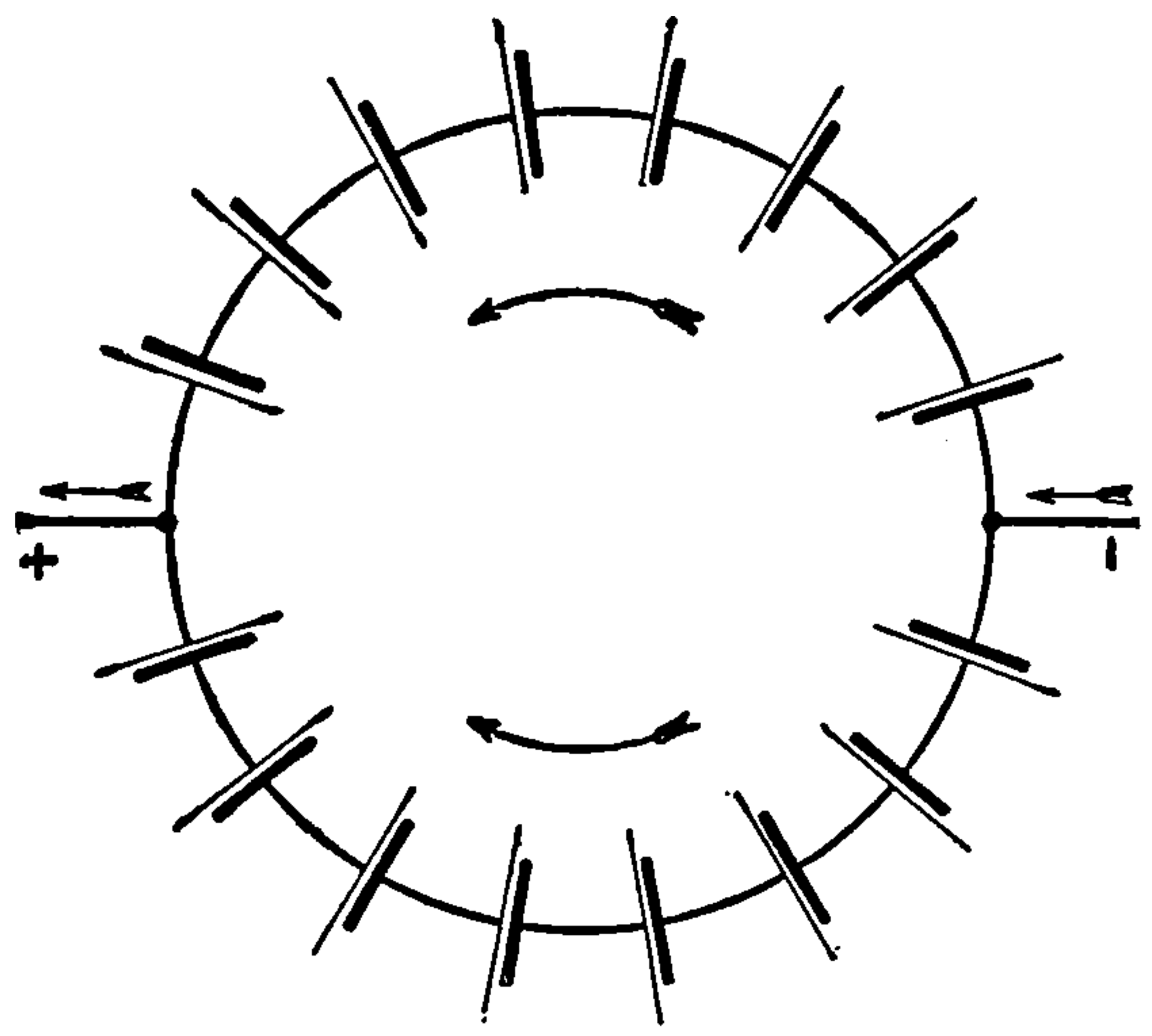



Fig. 48. Battery Circuit to Illustrate Brush P D.

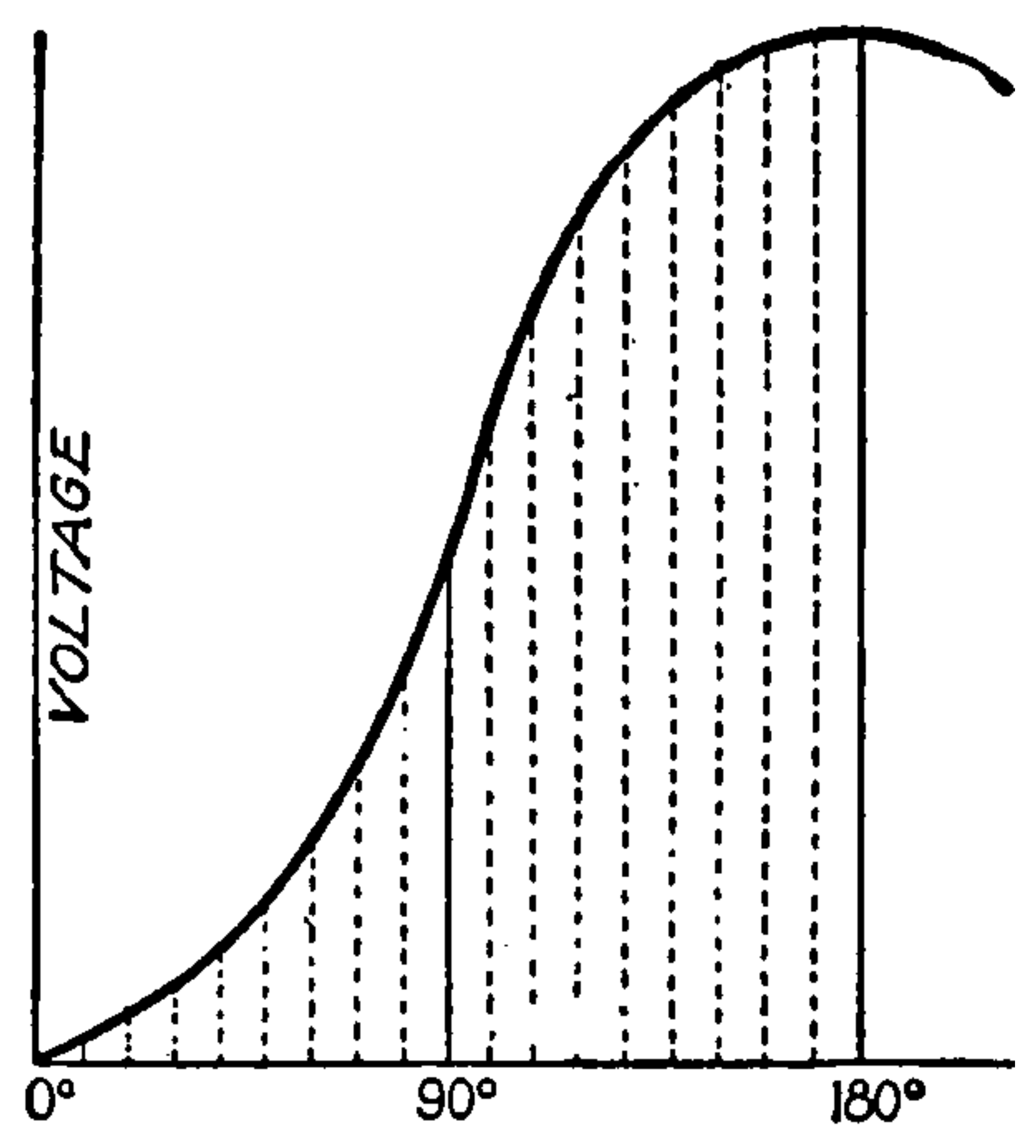



Fig. 49. Terminal Voltage Curve

replaces. The terminal voltage will then be obtained by adding all these potentials between the 0° and the 180° positions in Fig. 47, the negative part being exactly equal to the positive half if the dynamo is symmetrical, and in practice this is so. The sum thus obtained grows slowly at first, then rapidly, and slowly again as it reaches its highest value, repeating this program in the other half-circumference. These facts are shown at reduced scale in Fig. 49. In the actual dynamo, this addition is effected because the coils are connected in series, and it is possible to demonstrate this experimentally.

**Exploration of Potentials around a Commutator.** Several more or less simple ways of showing the distribution of the generated e. m. f. around the commutator of a dynamo have been suggested,* but only Mordey's method will be taken up here. It consists in connecting one terminal of a voltmeter, preferably an electrostatic one, to one brush of the machine, and the other terminal to a small pilot brush *b*, Fig. 50, which can be moved from point to point around the commutator. The armature of the generator is then rotated

* See S. P. Thompson's "Dynamo-Electric Machinery," N. Y., 1904, Vol. I. P. 204.

at its rated r. p. m.; and, starting at the brush $N$, $b$ is placed in successive positions around the commutator, the voltmeter reading in each position being noted, together with the corresponding angular situation of $b$.

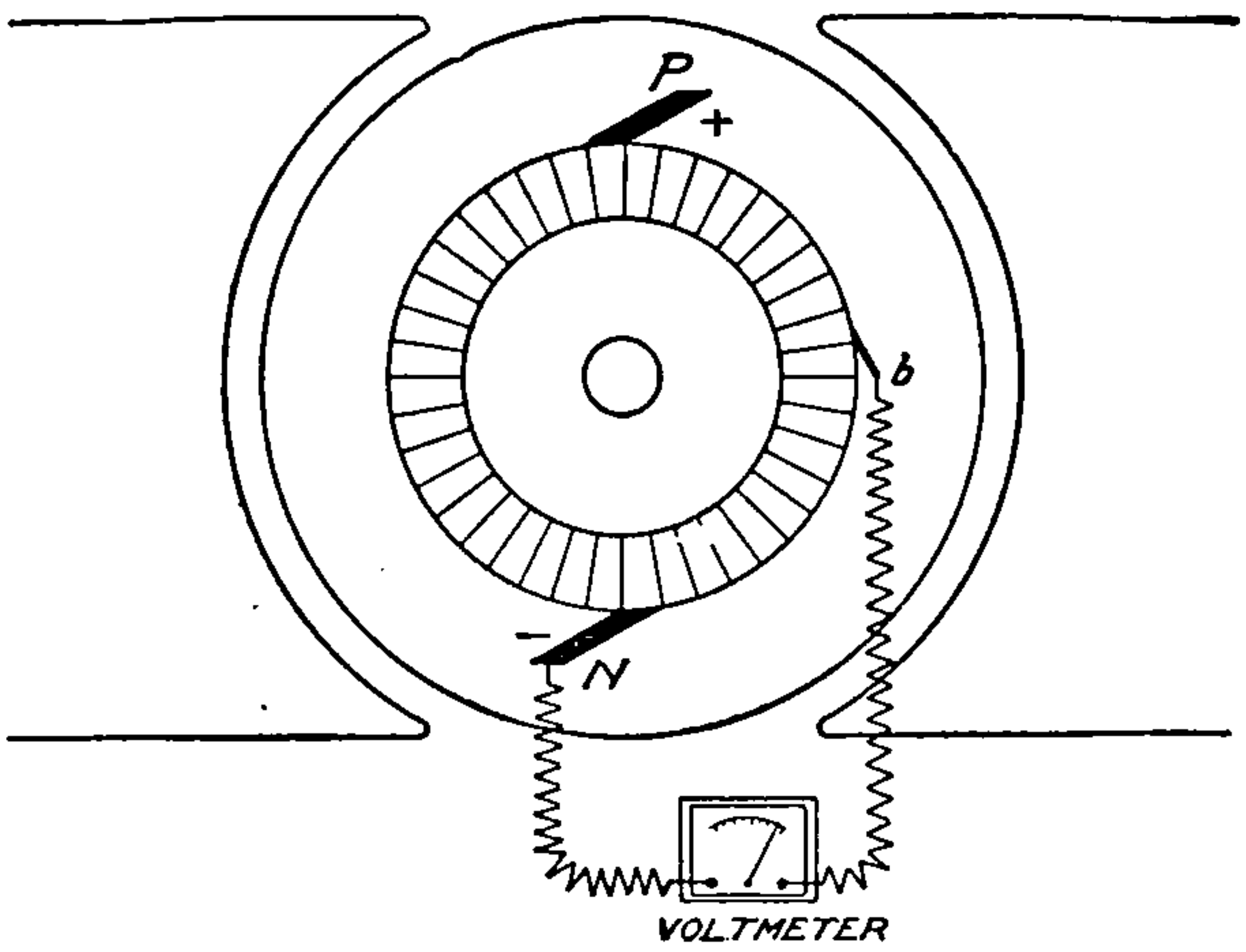



Fig. 50. Exploring Device for Commutator Potentials

The results, with the voltage readings plotted vertically and the corresponding values of angular positions of $b$ plotted horizontally, are as represented in Fig. 51, when the armature is carrying no current. The curve so obtained is not usually a true sine curve in commercial machines, because the magnetic field in which the armature rotates is not uniform but it is generally close to it. It will be seen later that when the armature carries a current, its presence causes a further distortion in the distribution of the flux. Furthermore, the setting of the brushes or an injudicious shaping of the pole-pieces will cause minor irregularities to be present in this curve,examples of which have been given by VonGaisberg,*Kohlrausch,** M.E. Thompson***, Ryan†, and Shephardson††.

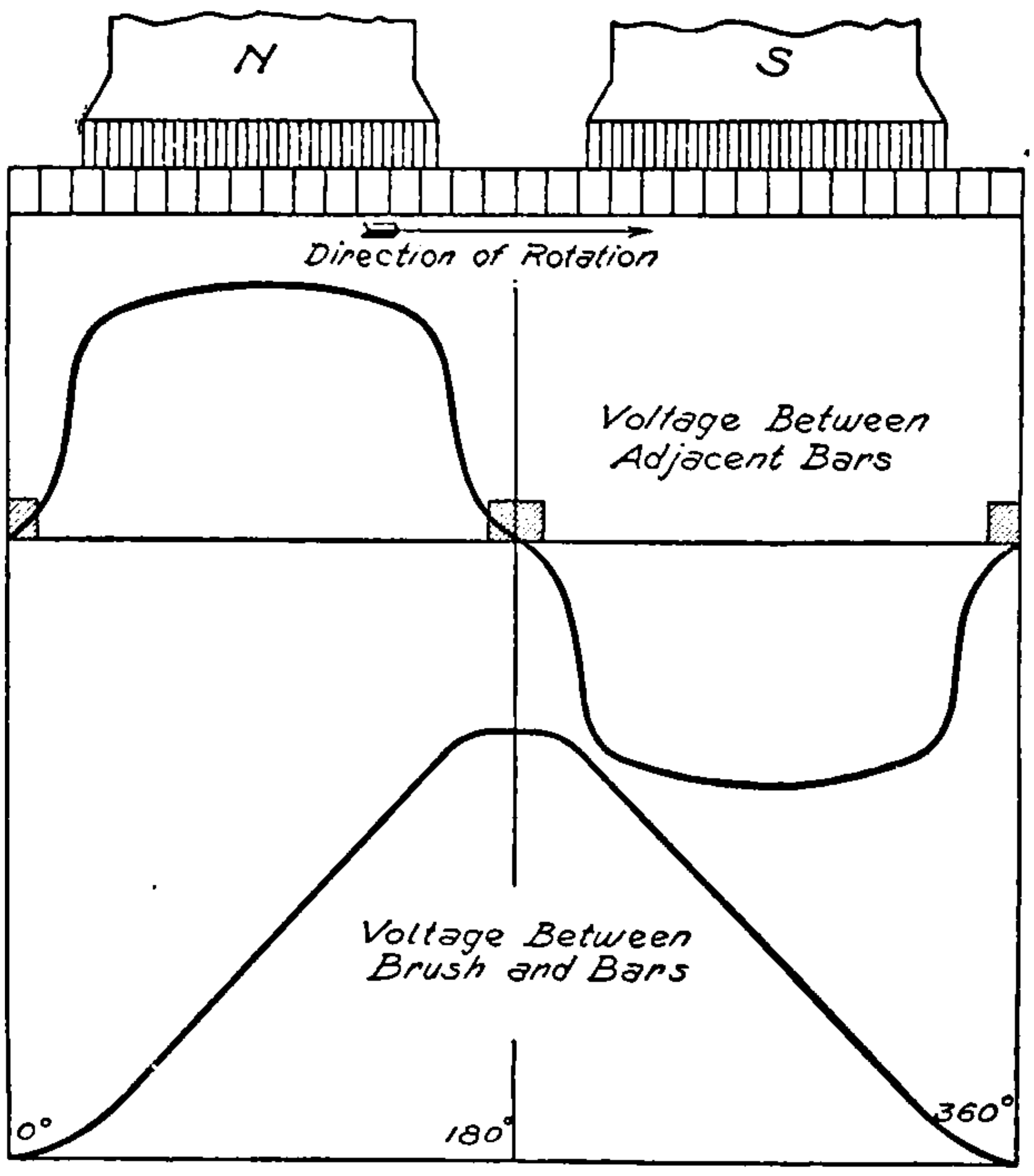



Fig. 51. Voltage Curves at No Load

**Armature Reactions.** This leads to a consideration of the reactions of the armature when the generator is operating, which are manifested in many ways, the most important being:

* *Elektrotechnische Zeitschrift*, vii 67, Feb. 1886.
** *Centralblat für Elektrotechnik*, ix 419, 1887.
*** "Electrical World," xvii 392, 1891.
† Trans. Amer. Inst. Elec. Engrs., vii 3, 1890.
†† "American Electrician," x 453, 1898.

(1) A tendency to *cross-magnetize* the armature.
(2) A proneness to spark at the brushes.
(3) Variation of the neutral point of the armature with the amount of current.
(4) The consequent necessity of shifting the brushes.
(5) A resultant tendency to further demagnetize the armature.
(6) Losses due to eddy-currents in the pole-pieces, armature core, and coils.
(7) A resulting difference between the input and output.

As these reactions have much effect upon the operation of the commercial machine, they will be considered in detail.

**Cross-Magnetizing Effect of Armature Current.** It has been seen from Fig. 48 and the accompanying text, that the armature of a generator may be likened to a combination of voltaic cells; but the armature carrying current manifests a magnetic effect absent in the latter case.

If the solenoid, Fig. 6, were bent around so as to form a semicircular ring, and had inserted into it an iron core of the same form, one end of this core would act as a north pole, and the other end as a south pole, when current circulates in the winding, Fig. 52. By taking an exactly similar semicircular ring and placing the two together so that their north and south poles are, respectively, coincident, the magnetic effect of current flowing in the armature may be reproduced. That is, when the generator supplies energy to the external circuit, the armature has poles produced in it corresponding to the brushes—namely, where the current enters and leaves the winding. This magnetization of a simple Gramme ring armature, Fig. 53, is indicated in Fig. 54, the general direction of the flux being through the armature core along both paths from $a$ and $b$ to $N$ and $S$, where it emerges into air, forming, respectively, the poles of the armature. The main portion of this flux returns outside the ring, while a small portion passes across the interior. This latter portion is extremely small in commercial machines on account of the presence of large masses of iron in the pole-pieces which are outside.

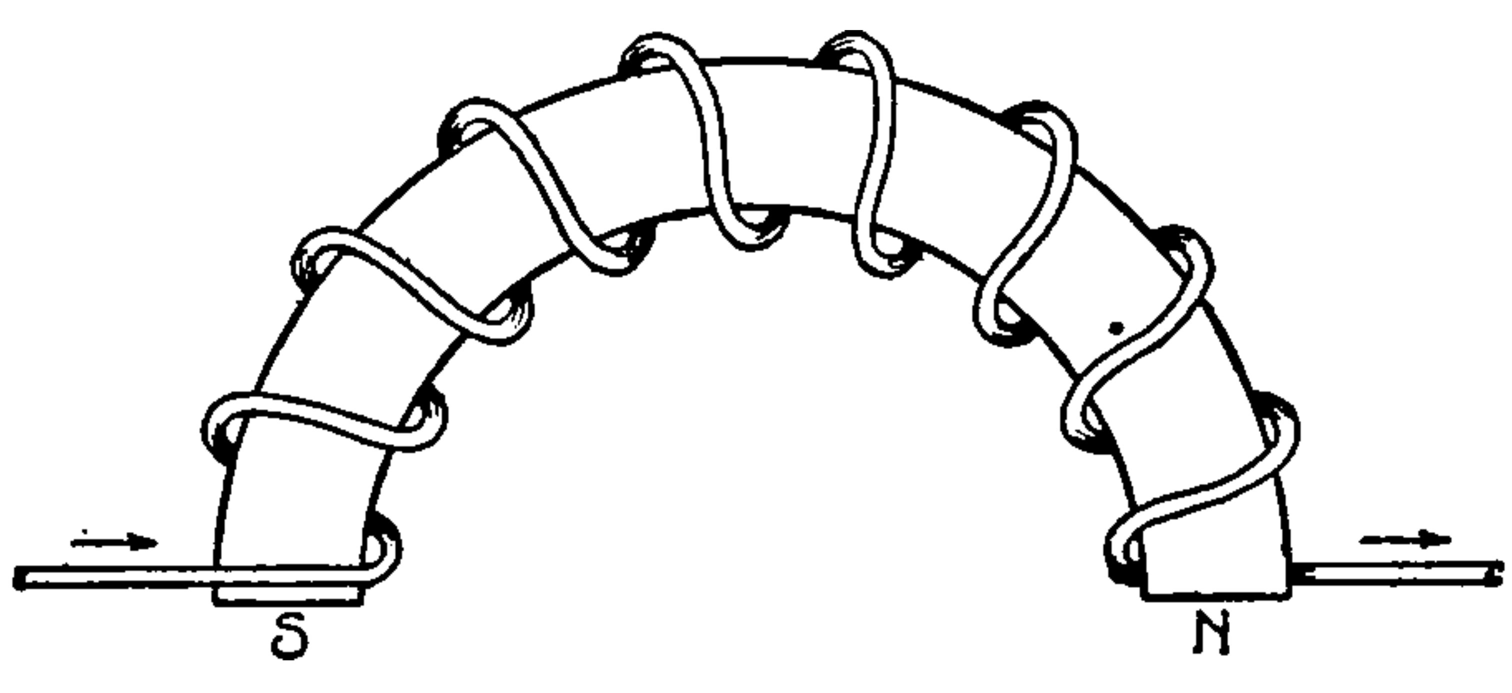


Fig. 52. Semi-Circular Coil with Iron Core

The cross-magnetization of the armature produces a distortion of the flux in it; but this would have small effect upon the e. m. f. if the line of commutation did not also change with the armature current. This change necessitates the moving of the brushes; and then

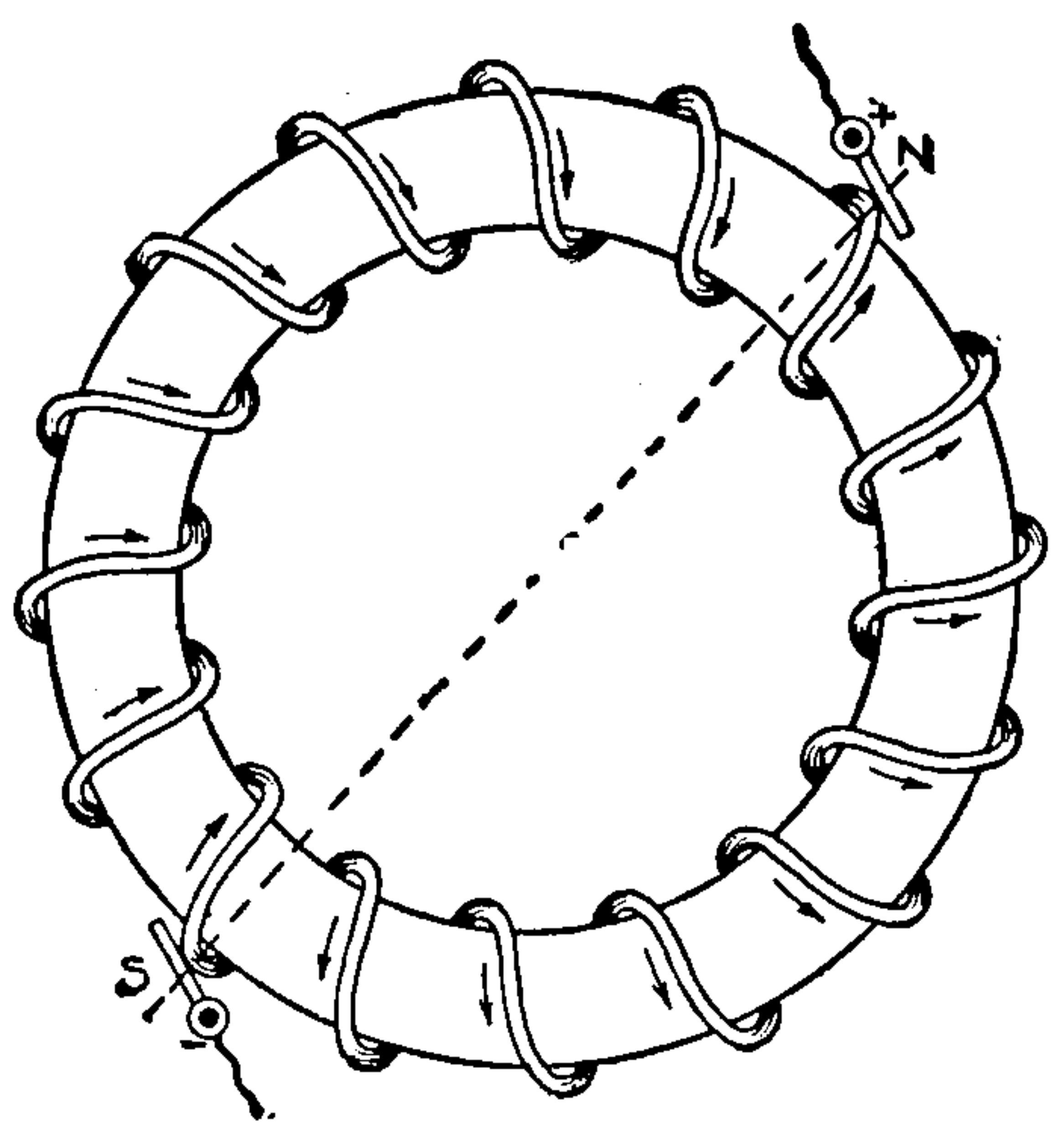



Fig. 53. Complete Ring Showing Brushes

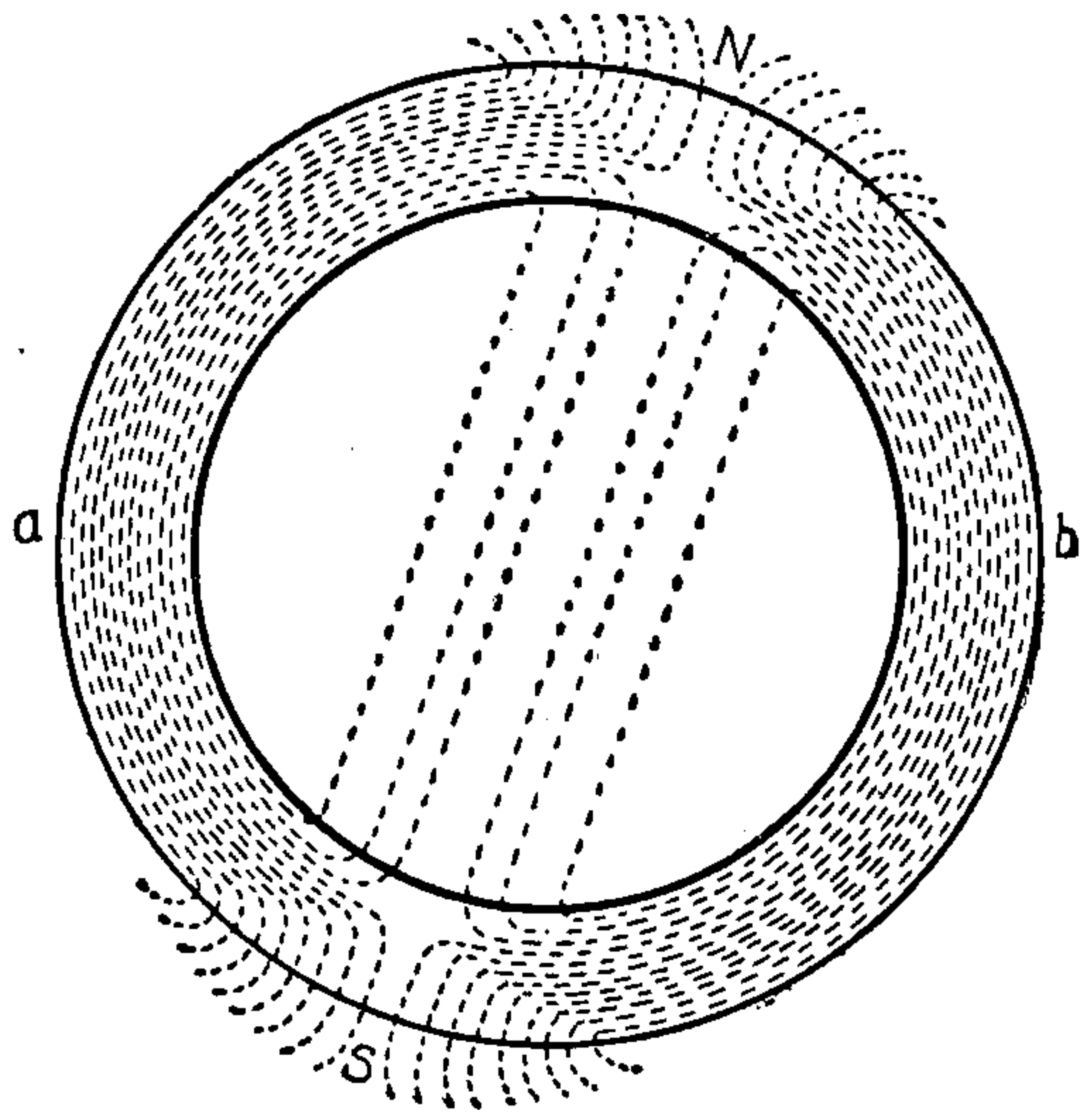



Fig. 54. Magnetic Field of a Gramme Ring Armature

the armature not only produces a cross-magnetizing effect, but also a greater demagnetizing tendency. It is this latter effect which diminishes the generated e. m. f.

In order to study the result, suppose a simple bipolar drum generator arranged so that current may be passed through its field windings, its armature when rotating, or through both. When the field alone is excited, the flux distribution will be substantially

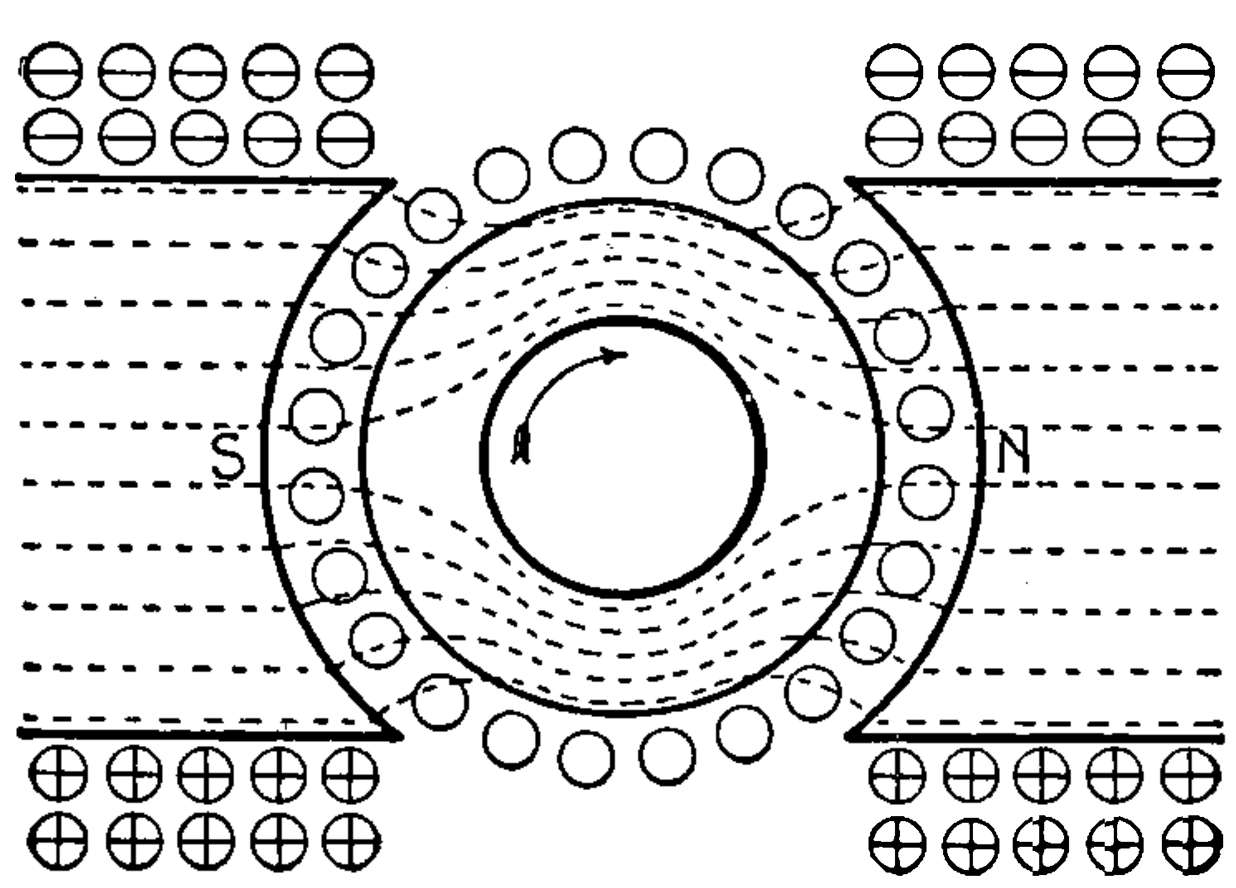



Fig. 55. Flux Distribution with Field Excited

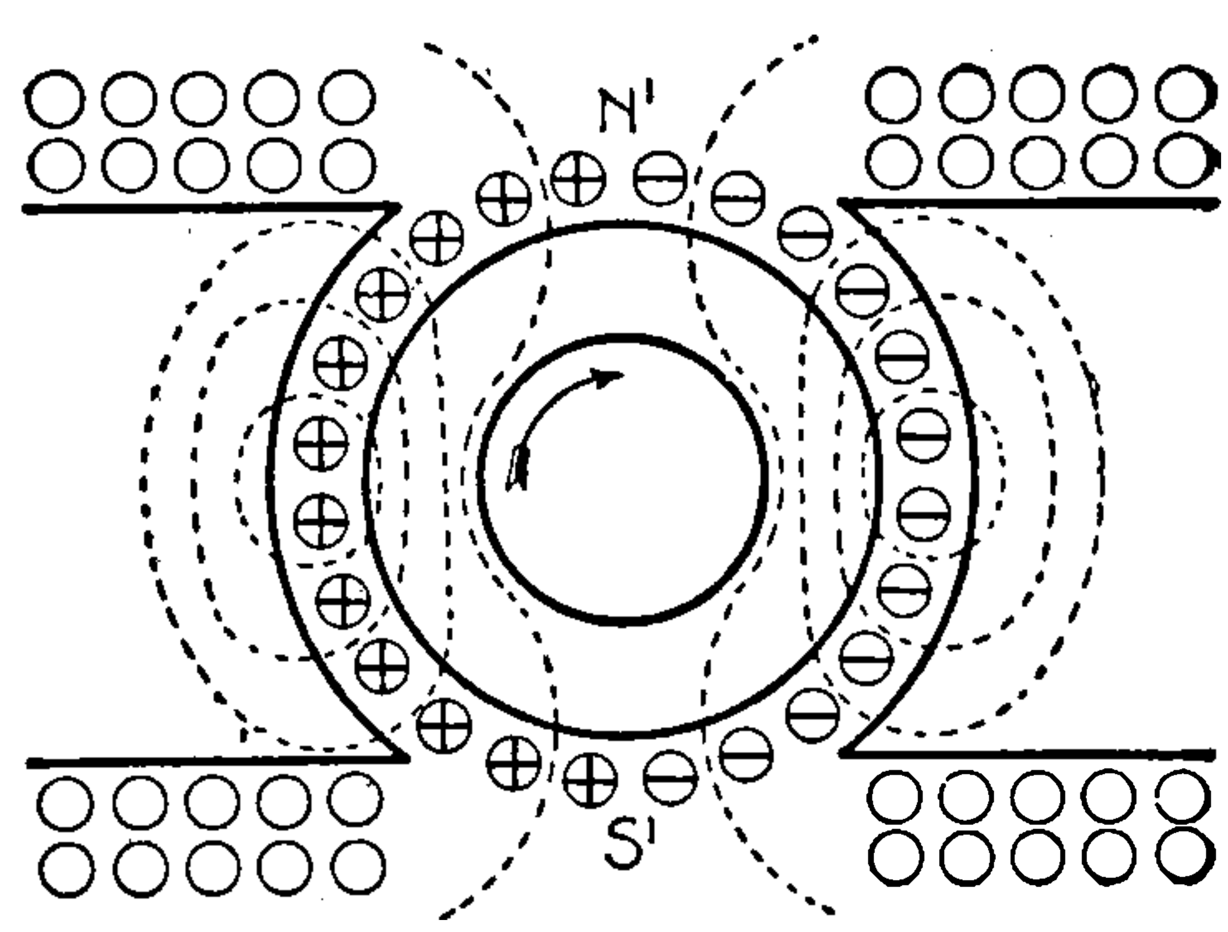



Fig. 56. Flux Distribution with Armature Excited

as indicated in Fig. 55, *i. e.*, quite uniform in the pole-pieces, air gaps, and armature. If, now, the field-exciting circuit be opened, and a current be supplied to the rotating armature equal to its

be oblique to that due to the field-magnet, and additional distortion will result, thus making it necessary for the brushes to be shifted still further. The shifting is continued until there is approximately no sparking.

In the case of drum-wound armatures in consequence of the overlapping of the end-connections, the magnetizing effects of some of the coils are neutralized, and as a result the production of poles is not so marked. Neither can there be any internal field. As a matter of fact, drum-wound armatures are not troubled to the same extent with induction effects as are ring-wound armatures. With these exceptions, however, the facts here considered apply equally well to drum-wound and ring-wound armatures.

The distortion of the flux through the armature also produces a distortion in the wave of induction, as may be shown by exploring the potential differences around a commutator by Mordey's method, when the machine is carrying its rated load. Such a curve is shown in Fig. 58, and it is to be noted that in the case of a generator the leading pole corners are weakened while the lagging ones are strengthened; in the case of the motor, these conditions are reversed. The effect of this distortion is considered under "Commutation."

**Commutation.** *Sparking at the Commutator.* On page 25 it has been seen that the rotation of the armature in the field of the machine generates alternating currents in the conductors. A consideration of Fig. 57 shows that the current flows toward the spectator in the conductors which are rising, and away from the observer in all the descending conductors, the brushes in this case being supposed present at $N'$ and $S'$. Thus, when a coil passes under one of the brushes, the direction of the current in that coil is *reversed.* Owing to the fact that even a single armature coil possesses some self-induction, the current cannot change instantaneously; *i. e.*, a certain definite interval of time is required, dependent upon the self-inductive property of the armature coil as well as upon its resistance. During this interval, and until the whole current can take the new path through the coil, a portion of the current continues to flow from the receding commutator bar, through the air, to the brush. It is the interruption of this latter current, as the commutator bar leaves the brush, that produces the spark.

*Methods of Commutation.* In order to understand exactly what happens when a current is commutated, it is necessary to consider what takes place in one section of an armature winding, and at the two commutator bars attached to the latter, when the bars pass under a brush.

Fig. 59 shows a portion of a ring-wound armature with its coils *A, B, C, D,* and *E* connected to segments 1, 2, 3, 4, and 5 of the commutator, and a positive brush just beyond the leading tip of one of the pole-pieces. The line *nn'* represents a line drawn in space so as to cut the commutator at a point where the voltage between two adjacent bars is zero. The brush is assumed placed in this line.

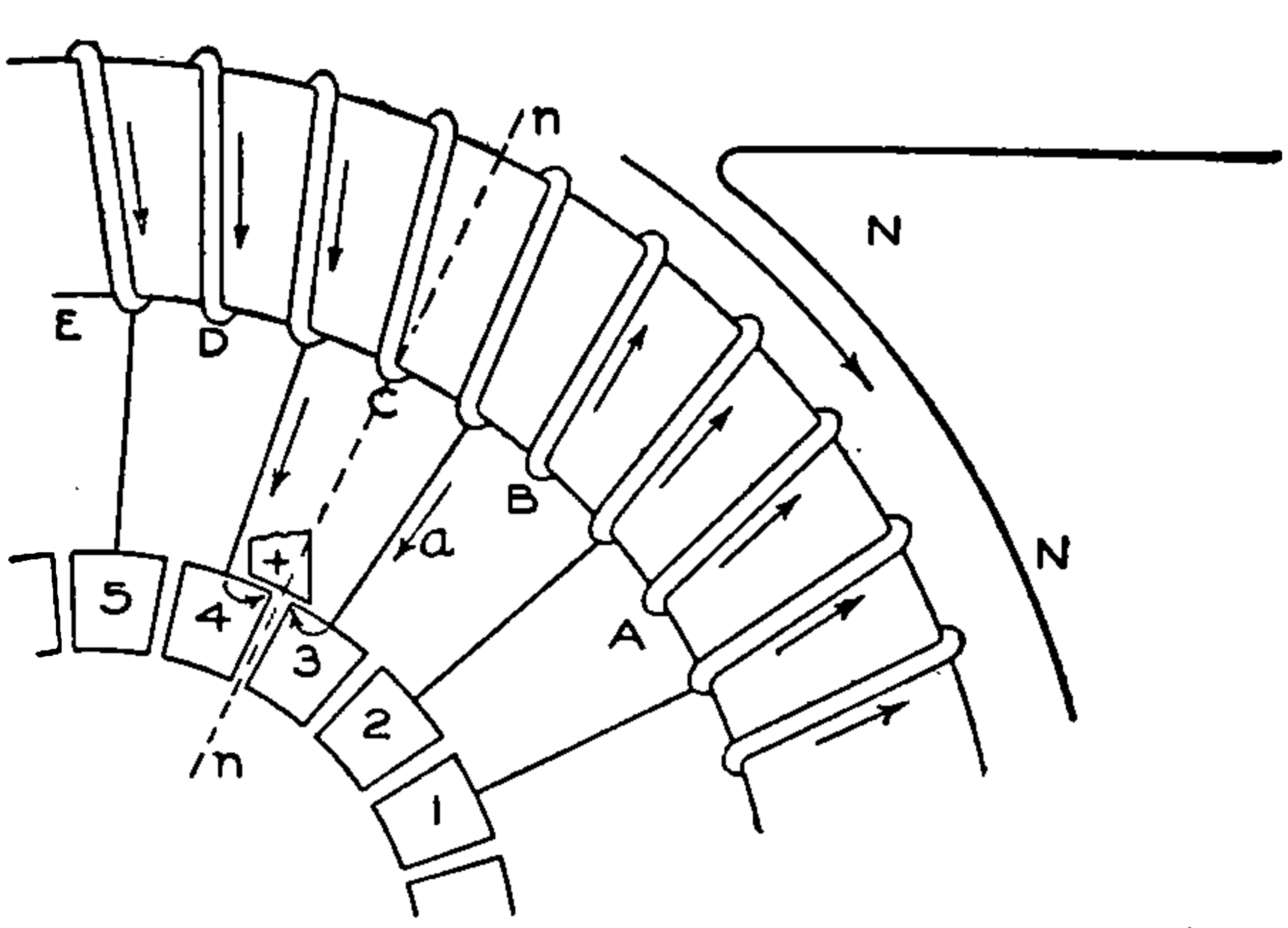


Fig. 59. Section of Ring Armature

Now, before any given section of the winding reaches the brush shown in the figure, a current will be flowing in it in the direction of the positive brush; and after the section has passed the brush, the current, although reversed in direction, is still flowing towards the brush.

The figure shows the instant at which coil *C* is short-circuited by the brush through the commutator bars 3 and 4; and it is during the brief interval of this short circuit that the current in coil *C* must be reduced to zero, reversed, and then built up again in the other direction in order that there shall be no tendency for a spark to form between the brush and the bar 3 at the instant they part.

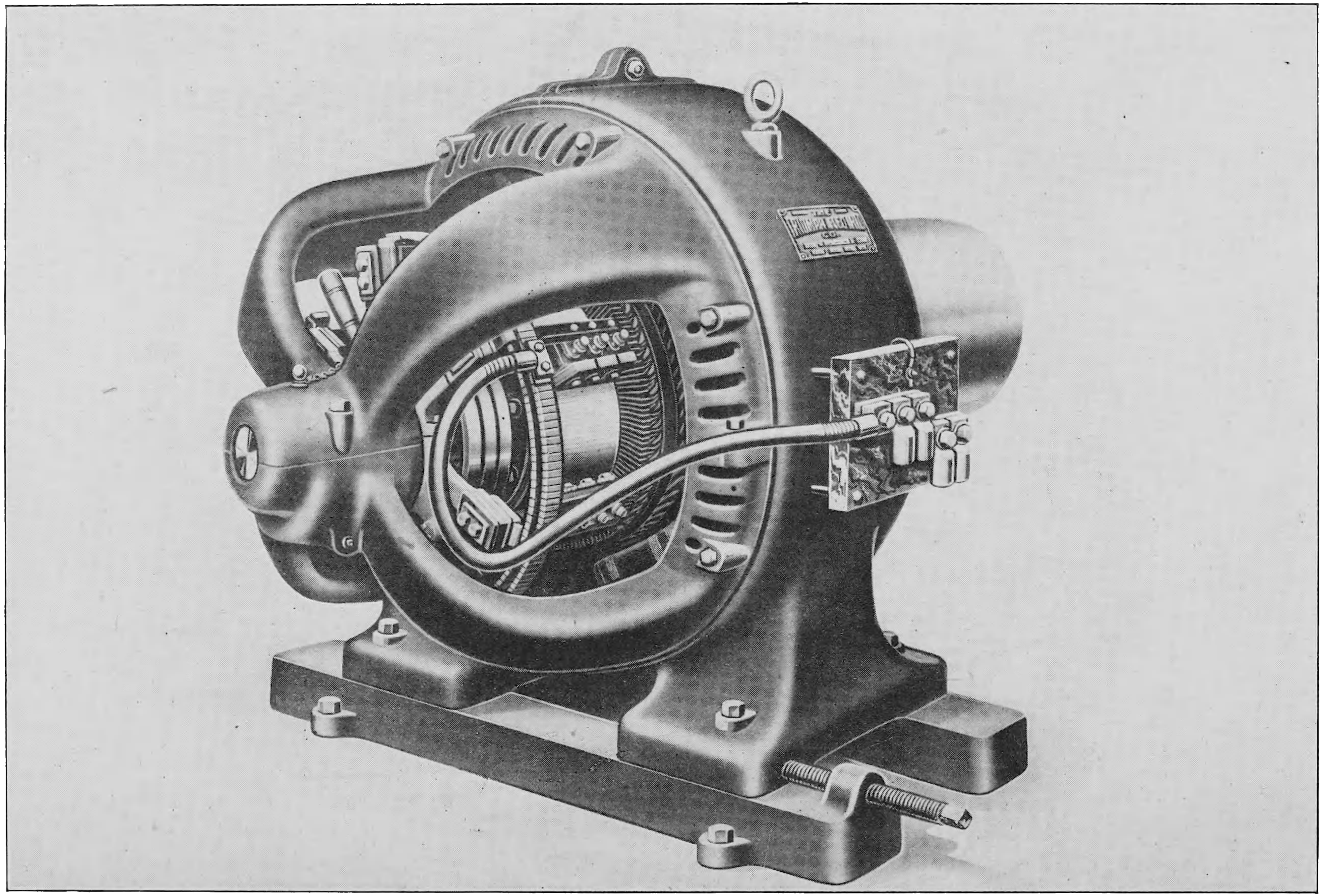
As to the establishment of a reversed current in section *C* while it is short-circuited by the brush, it must be remembered that this coil is at this instant supposed to be occupying a position such that there is no e. m. f. being generated in it; that is, it is in a neutral position. In coils to the immediate left and right of coil *C,* however, e. m. f.'s are being generated in such a direction as to cause the resulting current to flow *towards* the brush. If, therefore, the brush is moved forward—*i. e.,* in the direction of rotation—from its present position in the neutral line, the section short-circuited by that brush will be placed in a region where a p. d. will be generated between its terminals in such a direction as to assist the reversal of current above mentioned. Also, the greater the forward lead—*i. e.*, the further away from the neutral line in the direction of rotation the brush is moved—the greater will be the potential difference so generated; so that by trial, a position of the brush may be found where the condition of sparkless commutation is fulfilled.

The use of high-resistance carbon brushes tends to cause a decrease of the current existing in the sections before they reach the brush, since the latter forms part of the short circuit. Their use also aids the establishment of the reversed current in the short-circuited section before the brush and segment part company which is due mainly to the contact resistance between the brush and the commutator. This may be explained thus. The current flowing across the contact area of the brush and leading segment under it (Fig. 59, segment 3), produces a drop of potential there, which is small on account of the large area of contact, at the instant depicted. A moment later the brush is making better contact with segment 4, and poorer contact with segment 3, so that the voltage drop across the contact area of the brush and 3 has risen above that of the brush and 4. Hence a current will tend to flow from segment 3 to segment 4, as a reverse current through *C*, being produced by the difference of potential between them. This state is comparable to that of the ordinary potentiometer, where a "drop" acts as an e. m. f. in producing a current flow. The voltage resulting from this potential difference across the two contact areas mentioned, assists the voltage tending to produce reversal.

Thus, as the commutator moves under the brush—assuming the latter to have a forward lead—the e. m. f. for reversal, the p. d. due to the varying contact area of the brush, and the resistance of the short-circuited coil, combine to reduce the current in the latter to zero, while the self-induction of the coil tends to prevent any change of the current in it.*† This zero condition should occur when the areas of contact between the brush and the two (in this case) bars passing under it are equal. Then, when the segments leave this position, the p. d. between them will increase, thus assisting the

* See S. P. Thompson's "Elementary Lessons in Electricity and Magnetism," N. Y., 1903, P. 466 *et seq.*

† "Cyclopedia of Applied Electricity," Chicago, 1909. Vol. I, P. 63.



THREE-WIRE GENERATOR
*Courtesy of Triumph Electric Company*

direct e. m. f.—produced in the coil by the flux from the hindward pole-horn—in establishing a current in the coil in the reverse direction. Opposing this are the resistance and self-induction of the coil. With proper conditions, the various reactions mentioned may be so proportioned as to produce in the coil from which the short circuit is about to be removed, a current equal in strength and direction to that flowing towards it from the preceding coil. In Fig. 59, coil $C$ would be the one to have the short circuit removed; and $B$ would be the preceding coil. Then segment 3 will pass out of contact with the brush without a spark attempting to follow.

*Resistance during Reversal.* Let us assume that during commutation the brush contact resistance is inversely proportional to the area of contact. Then, in the ideal case, where the coils of the armature are devoid of resistance and inductance, the curve of com-

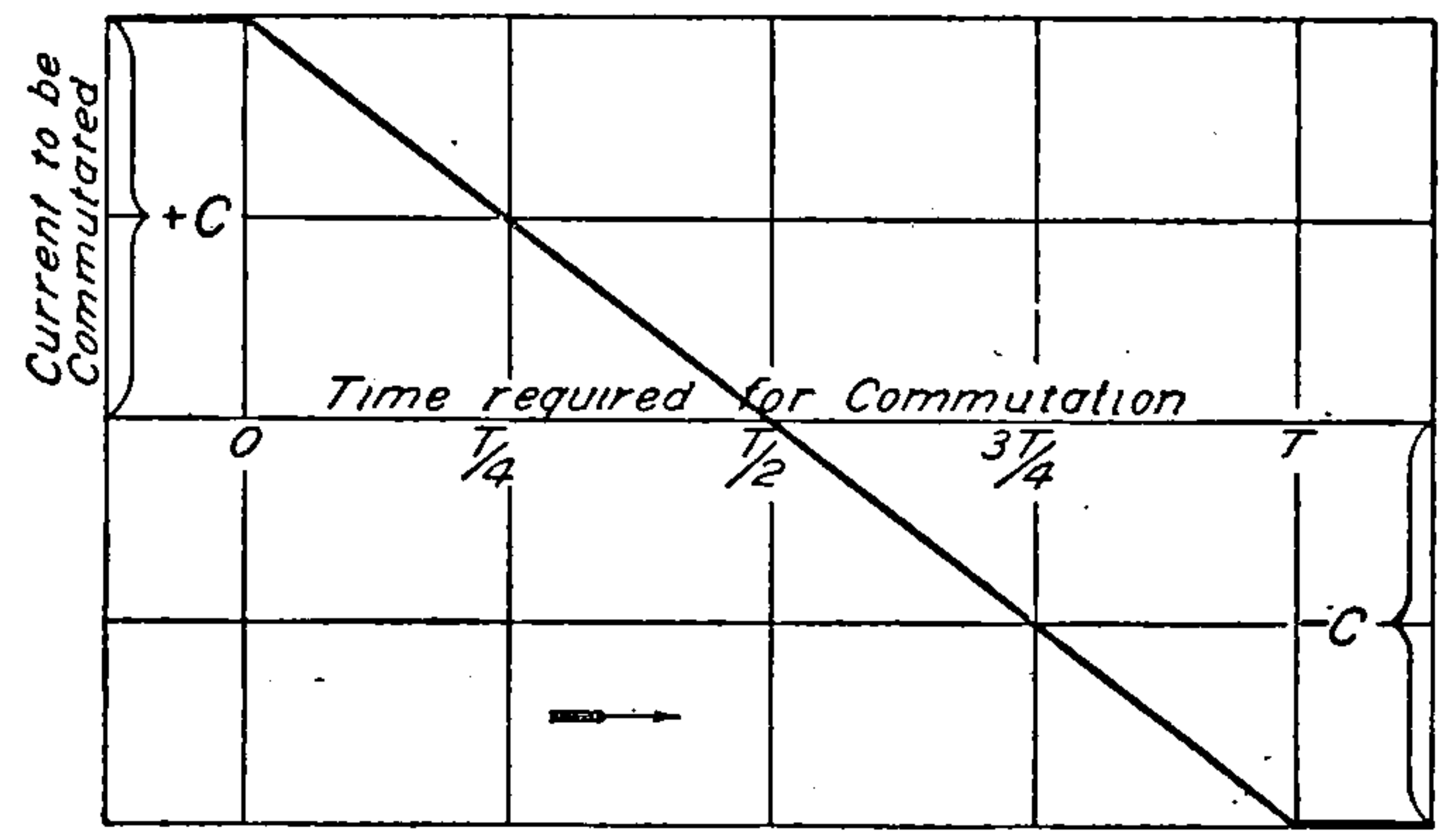



Fig. 60. Ideal Commutation Curve

mutation will be as shown in Fig. 60, $C$ representing the value of the current to be commutated, $O$, the instant when commutation commences, and $T$, the period requisite for this action. Here the current gradually diminishes to zero at the middle of the commutation period, and reaches its negative maximum value at the end of the time $T$. This process is shown in detail in Fig. 61, the brush being wide enough to span one commutator bar.

In this case 10 amperes flow from either side of the armature to the brush, the latter leading away 20 amperes. Suppose the brush area to be one sq. in.; then, when the commutator is in the position indicated by Fig. 61 (*b*), the area of contact of the segment $C$ is reduced to $\frac{3}{4}$ sq. in., while that of the segment $D$ has become $\frac{1}{4}$ sq. in., so that 5 amperes will flow into the brush from $D$ and 15

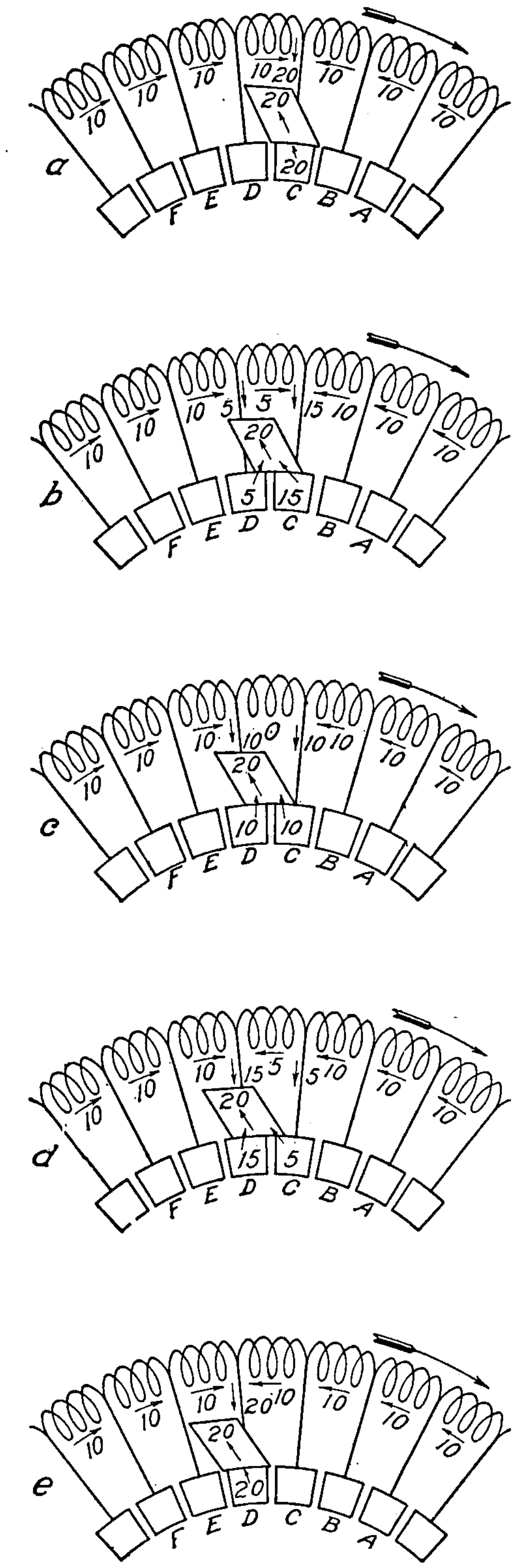



Fig. 61. Diagrams Showing Process of Commutation

amperes from *C;* the additional 5 amperes through the latter coming from the short-circuited coil. When the commutator has moved forward so that the area of contact of each brush is the same, *i. e.,* $\frac{1}{2}$ of a sq. in., *C* and *D* will pass 10 amperes to the brush from either side of the armature, the coil undergoing commutation carrying no current at this instant, Fig. 61 (*c*). At the end of the third quarter of the commutation period, the commutator has reached the position shown in Fig. 61 (*d*), the area of the segment *C* with the brush being $\frac{1}{4}$ of a sq. in., while that of *D* is $\frac{3}{4}$ of a sq. in. Hence *C* will contribute 5 amperes and *D,* 15 amperes to the brush, the coil undergoing commutation now carrying a current in the direction reverse to that indicated in Fig. 61 (*b*) and in the same direction as the current in the coils on the right. At the end of the commutation period, the current in coil $C-D$ has increased to the full value of that flowing in its right-hand neighbor; and when the brush and segment *C* part company no spark will result.

Fig. 60 shows the variation of the current during this period, if the resistance and inductance of the armature coils are neglected. It, therefore, remains to consider the effect of these reactions.

*Commutation Curves.* If the re-

mutation period. At the last instant, then, as the surface of contact between the segment $C$ and the brush diminishes to zero, the contact resistance rises with extreme rapidity. The product of this resistance and the still uncommutated part of the current, will constitute a p. d. between the retreating segment $C$ and the tip of the brush. This p. d. represented graphically by $QU$ in Fig. 63, tends to set up a spark, and may be briefly called the *sparking* e. m. f.

The resulting commutation curve for any machine is made up of these two effects, the quantity of each depending upon the design, and some details at present obscure. Messrs. Everett and Peake* found experimentally that the curve had the form shown in Fig. 64. Curve $A$ indicates the initial rise which may obtain at light loads, with an oval resultant at the negative end. $B$ illustrates under-commutation with insufficient lead. $C$ shows, with increased load, a rapid reversal at the beginning of the commutation period, but under commutation toward the end. $D$ represents a gradual fall of the current, which slackens toward the end.

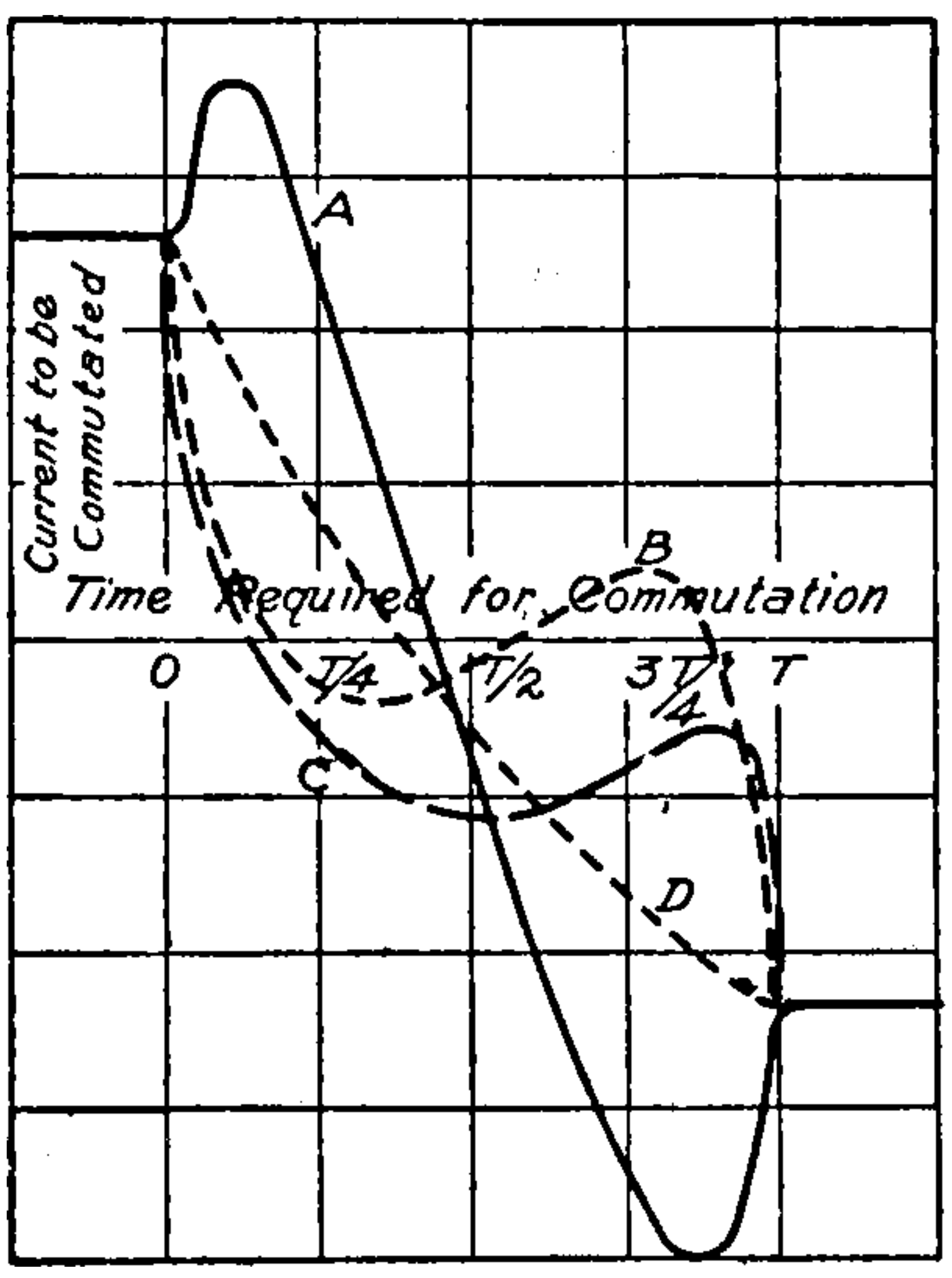


Fig. 64. Complete Commutation Curves for Practical Machine

*Effect of Increasing Breadth of Brush.* Increasing the breadth of the brush not only lengthens the period of commutation, but also permits commutation to start in one coil before the preceding coil has entirely passed through this stage.

In Fig. 65, assume the brush to have an area of 3 square inches, and to completely cover two segments at one time, the current collected by the brush being 60 amperes. Then Fig. 65 ($a$) shows the state of affairs when the segments $C$ and $B$ are under the brush. An instant later, the commutator, in moving clockwise, starts to uncover segment $B$ and to cover segment $D$, so that at the end of the first quarter of the period of commutation, the result will be as indicated in Fig. 65 ($b$), for the ideal case. Similarly, Fig. 65 ($c$), ($d$), and ($e$), represent, respectively, the conditions at the end of the second, third, and fourth quarters of the commutation period, the direction of current and its magnitude in each coil being indicated by arrows

* See *Electrician*, London, Vol. 40, P. 861: Vol. 42, P. 328.

and figures. It is seen from these that the conditions of Fig. 61 obtain throughout, the current in the short-circuited coils being zero at the middle of the period of commutation; so that it may be concluded that the act of commutation is not altered by increasing the width of the brush.

*Summary of Results.* From the preceding considerations the methods for controlling the sparking at the commutators of continuous-current machines, may be summed up as follows:

(1) Keep the inductance of the armature coils low, by decreasing the number of turns per commutator segment, by saturating the teeth, and by properly shaping the pole-pieces to produce a reversal fringe.

(2) Keep the volts per segment of the commutator low by having a large number of commutator segments.

(3) Control distortion of the main flux in order to have the field under the hindward pole-horn sufficiently strong.

(4) Properly dimension and design the commutator-brushes, brush-holders, and other brush-gear, so as to permit the shifting of the brushes to the proper position, and to enable the brushes to make contact with the commutator at all times.

(5) Keep the surface of the commutator smooth.

(6) Add special features to the machine. (See following pages.)

To see clearly the application of most of these special features, it is desirable to consider another property of an armature carrying a current—namely, its demagnetizing effect.

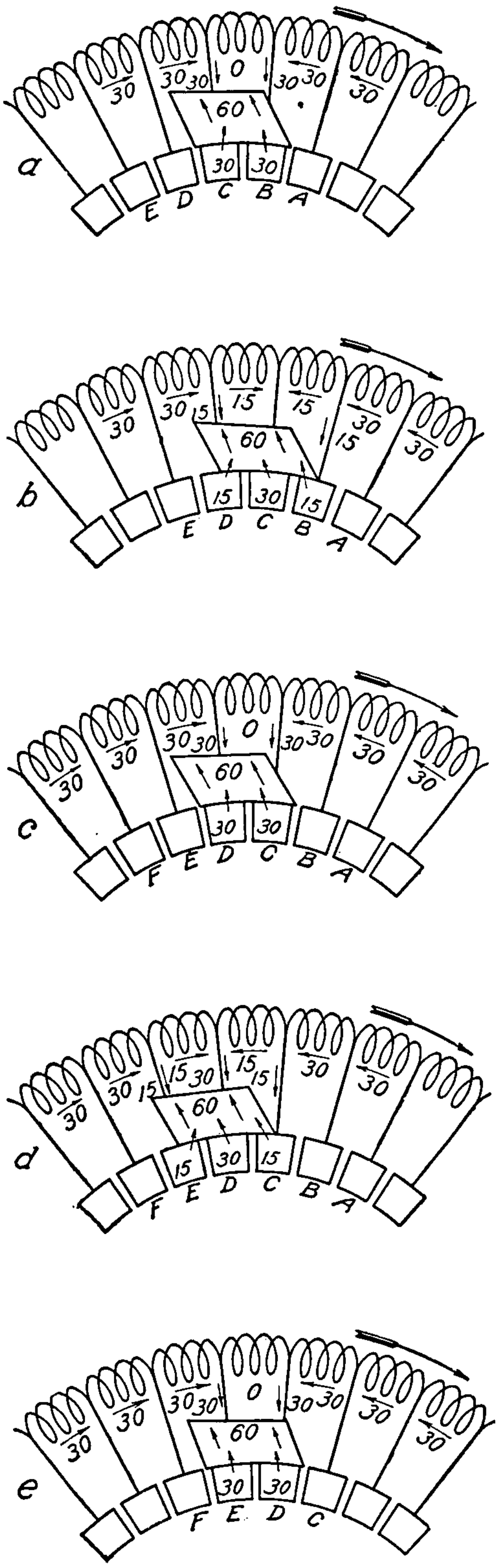



Fig. 65. Commutation Process with Wide Brush

**Demagnetizing Effect of Armature.** It has been found necessary to shift the brushes ahead of the neutral line in generators, and back in case of motors, to eliminate sparking at the commutator. The resultant effect is to produce in the armature a magnetomotive force opposed to that of the field-winding. Considering Fig. 66, wherein the brushes are supposed to be shifted to the line *nn'*, the remainder of the figure being as before, it is seen that the currents are flowing toward the observer in the armature conductors to the left of the neutral line *nn'*, and from the observer in those to the right of that line.

Now, suppose the two vertical lines *ad* and *bc* to be drawn

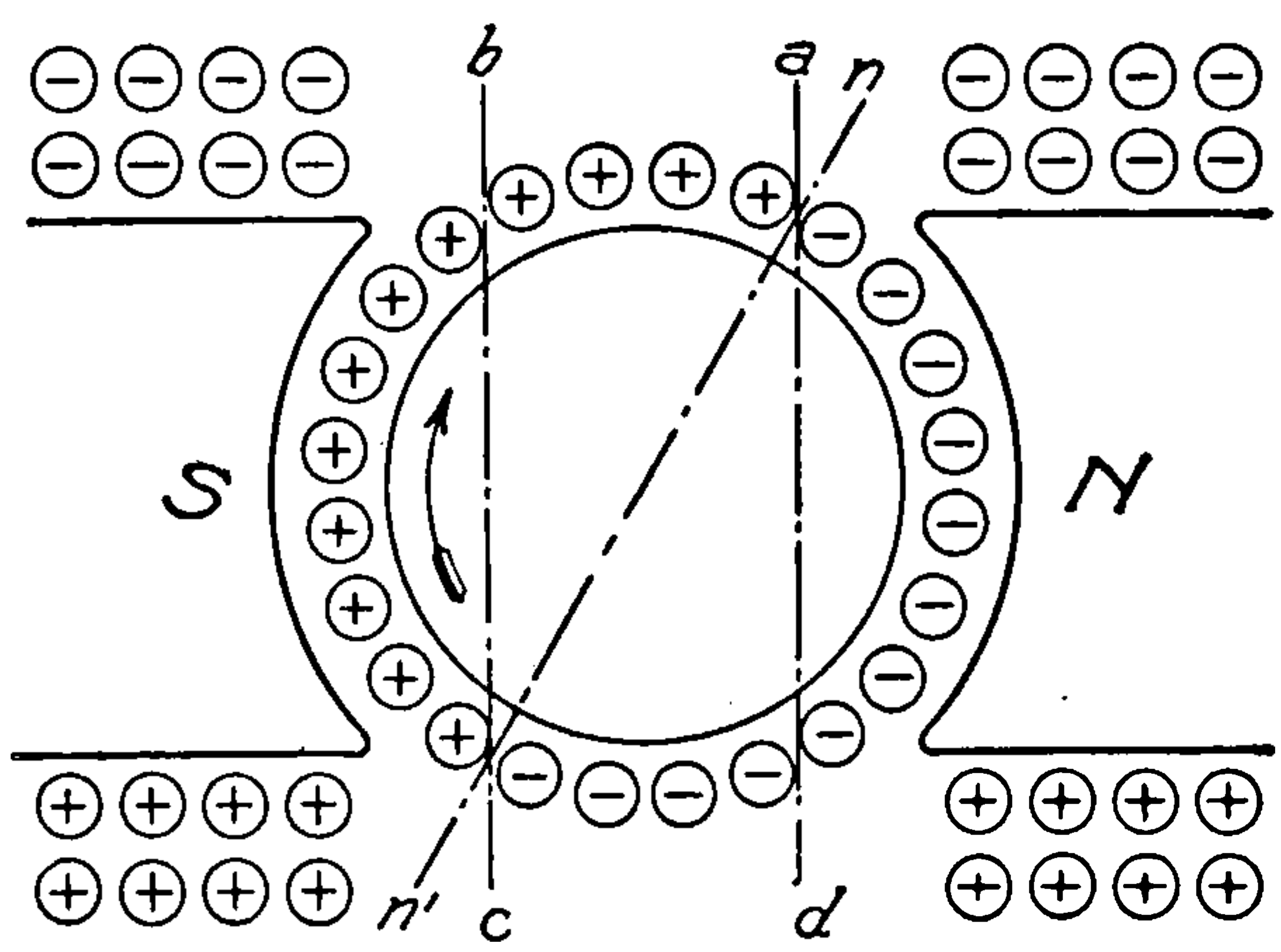



Fig. 66. Diagram Showing Demagnetizing Effect of Armature

across the section of the armature and through the points of commutation. The armature conductors are thus divided into two bands, those to the right of the line *ad* and to the left of the line *bc* tending to cross-magnetize the armature, *i. e.*, produce a flux at right angles to the field flux as explained in connection with Fig. 55. The turns producing this cross-flux are known as the *cross-magnetizing turns.* Those inductors included between lines *ad* and *bc* carry current in the opposite direction to that circulating around the field poles, and consequently produce an m. m. f. opposed to that of the main field. The turns enclosed by the lines *ad* and *bc* are known as the *back ampere-turns.*

The breadth of the belt of demagnetizing windings is evidently proportional to the angle of lead, since it subtends double that angle. In such an armature generating 50 amperes, each conductor would carry 25 amperes, since there are two paths in parallel; and as the number of cross-magnetizing turns is 8, and the number of demagnetizing turns is 4, the *cross-ampere-turns* would be $25 \times 8 = 200$; and the number of *back ampere-turns* would be $25 \times 4 = 100$.

This demagnetizing influence, which is proportional to the angle of lead of the brushes, tends to weaken the field in general, while the cross-magnetization, proportional to the ampere-turns not included in the demagnetizing effect, tends to weaken the flux under the hindward pole-horn, and strengthen that under the forward pole-tip, producing the flux distribution shown in Fig. 57. Hence the impressed m. m. f.—that of the field-magnets—must be strong enough to force through the air-gap in the magnetic circuit sufficient flux to permit of sparkless commutation in spite of the demagnetizing and distorting effects on the main field. Since the cross-magnetization is responsible for the distortion which tends to produce sparking, it remains to consider the remedies which limit, compensate for, or overcome it, by maintaining a magnetic field in the right direction and of sufficient value for sparkless operation at the coil undergoing commutation.

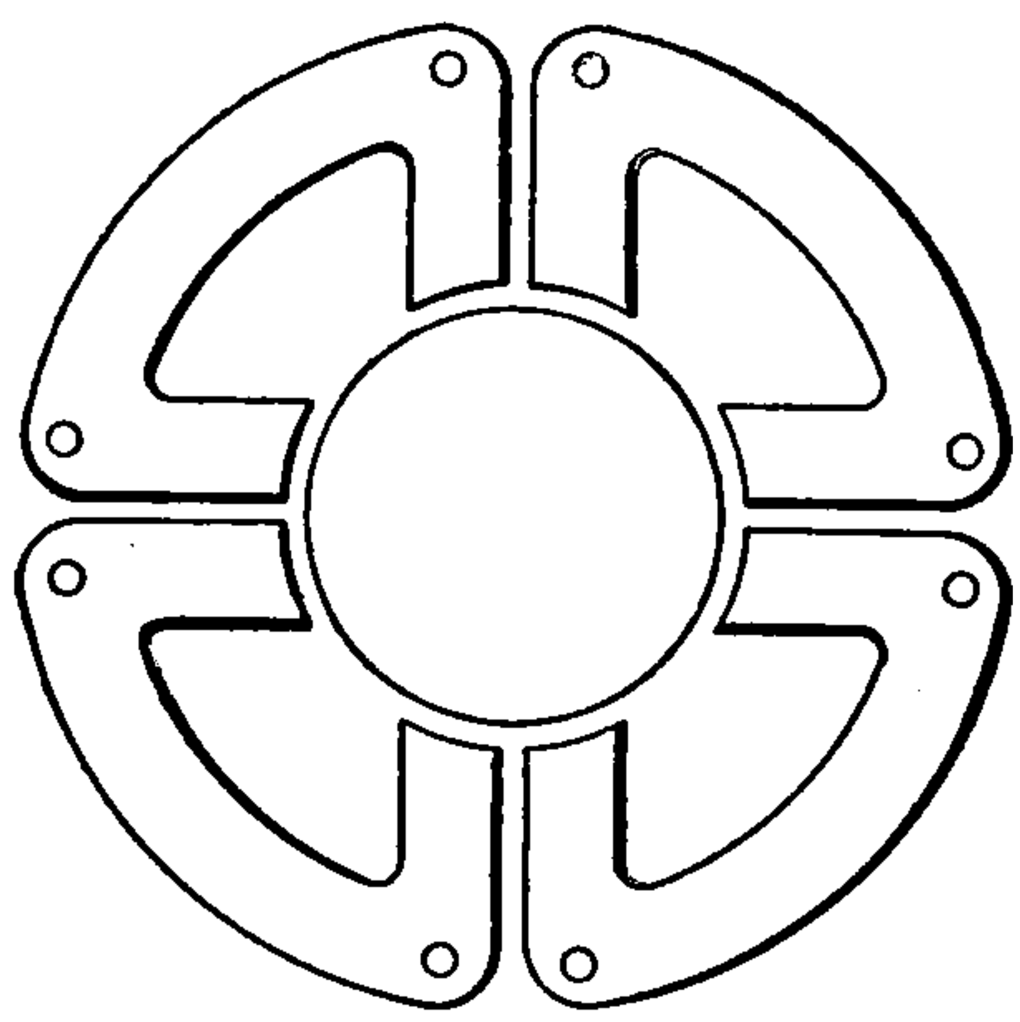


Fig. 67. Clover-Leaf Design of Field Cores

**Constructions for the Elimination of Sparking.**

(1) *To lengthen the air gap.* This will diminish the cross-flux as it increases the reluctance of the armature field path. But this method is somewhat objectionable, as it also increases the reluctance of the field circuit and hence a greater m. m. f. or a larger number of field ampere-turns are required to produce the same field strength as before. This condition implies a higher first cost, constituting the objection.

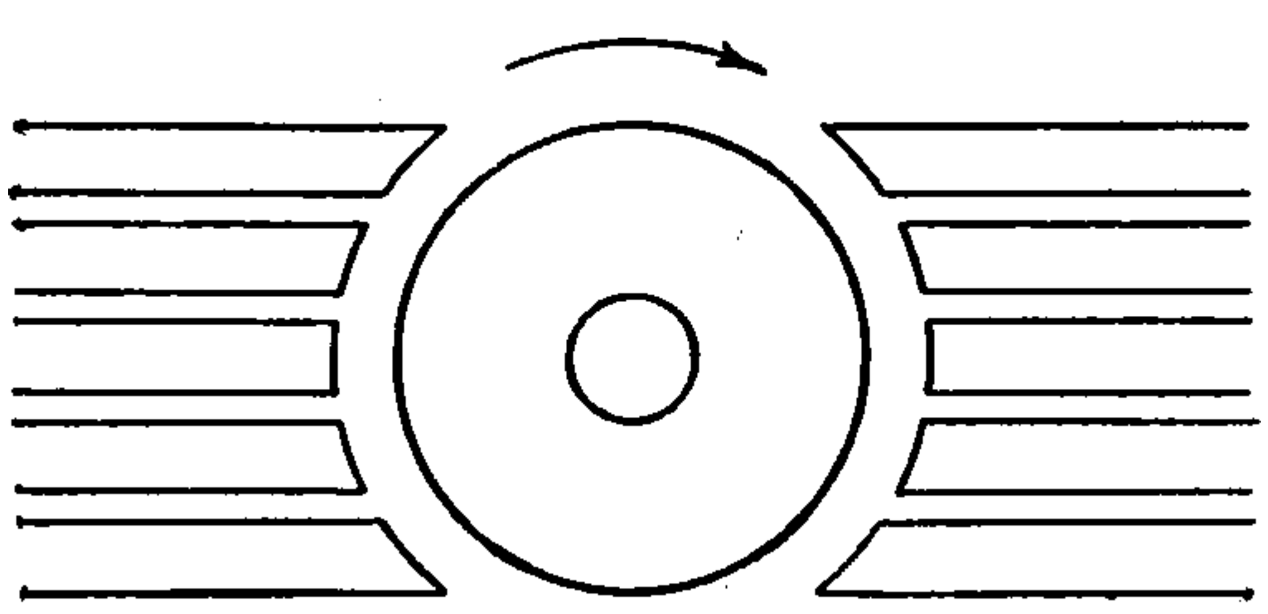


Fig. 68. Thompson's Field Cores with Longitudinal Gaps

(2) *To thin down or to actually separate the two halves of the circuit at any one pole.* This introduces an additional reluctance into the path of the armature cross-flux without increasing the re-

luctance of the main field. This feature has been introduced in the clover leaf design of the Northern Electric Company as indicated in Fig. 67. S. P. Thompson has suggested constructing the field cores of pieces of iron with longitudinal gaps as indicated in Fig. 68, being an extension of the above idea.

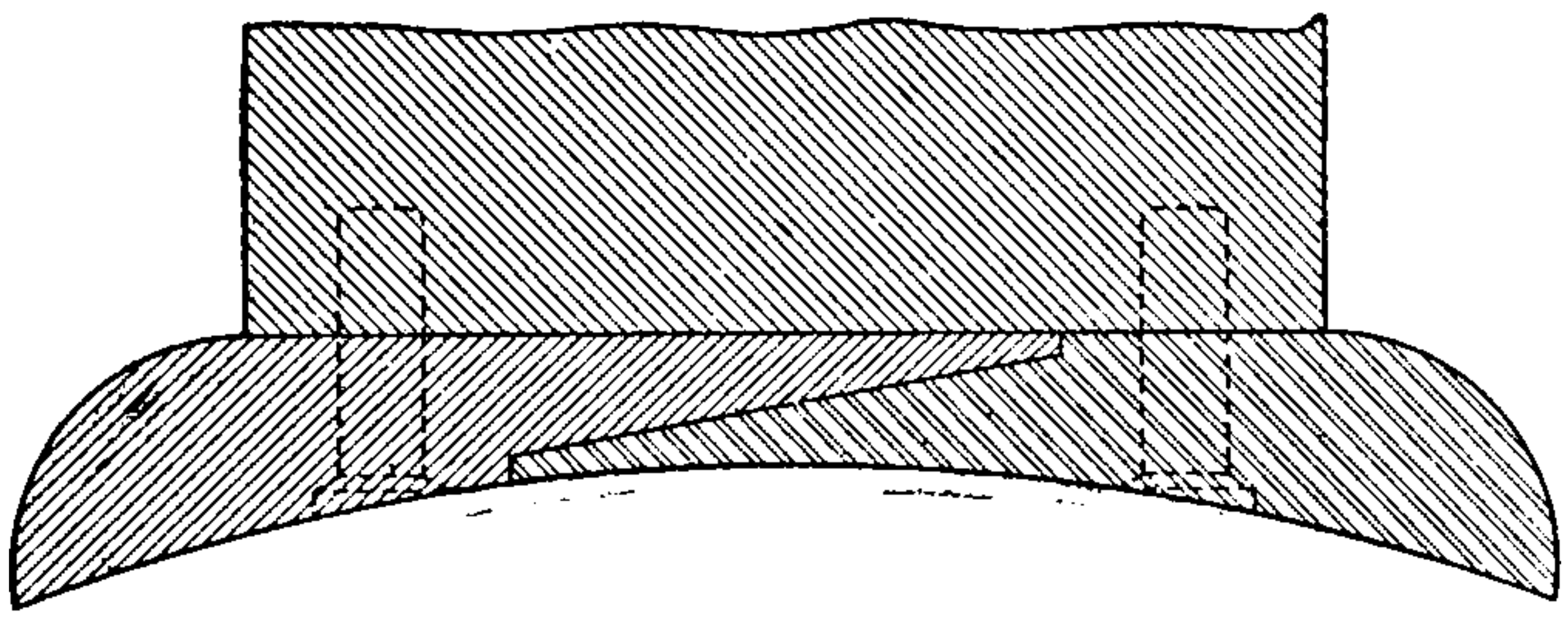


Fig. 69. Pole-Piece Horn of Iron and Steel

(3) *To make the forward horn of the pole-shoe of cast iron, and the rear horn of cast steel.* In this case the joint is oblique, as indicated in Fig. 69.

(4) *Concentration of Field.* Sparkless commutation may also be accomplished if the field is magnetically rigid—*i. e.*, not easily distorted. This stiffness may be partially secured by properly shaping the pole-faces or by making notches in them, as suggested by Sayers, thus concentrating

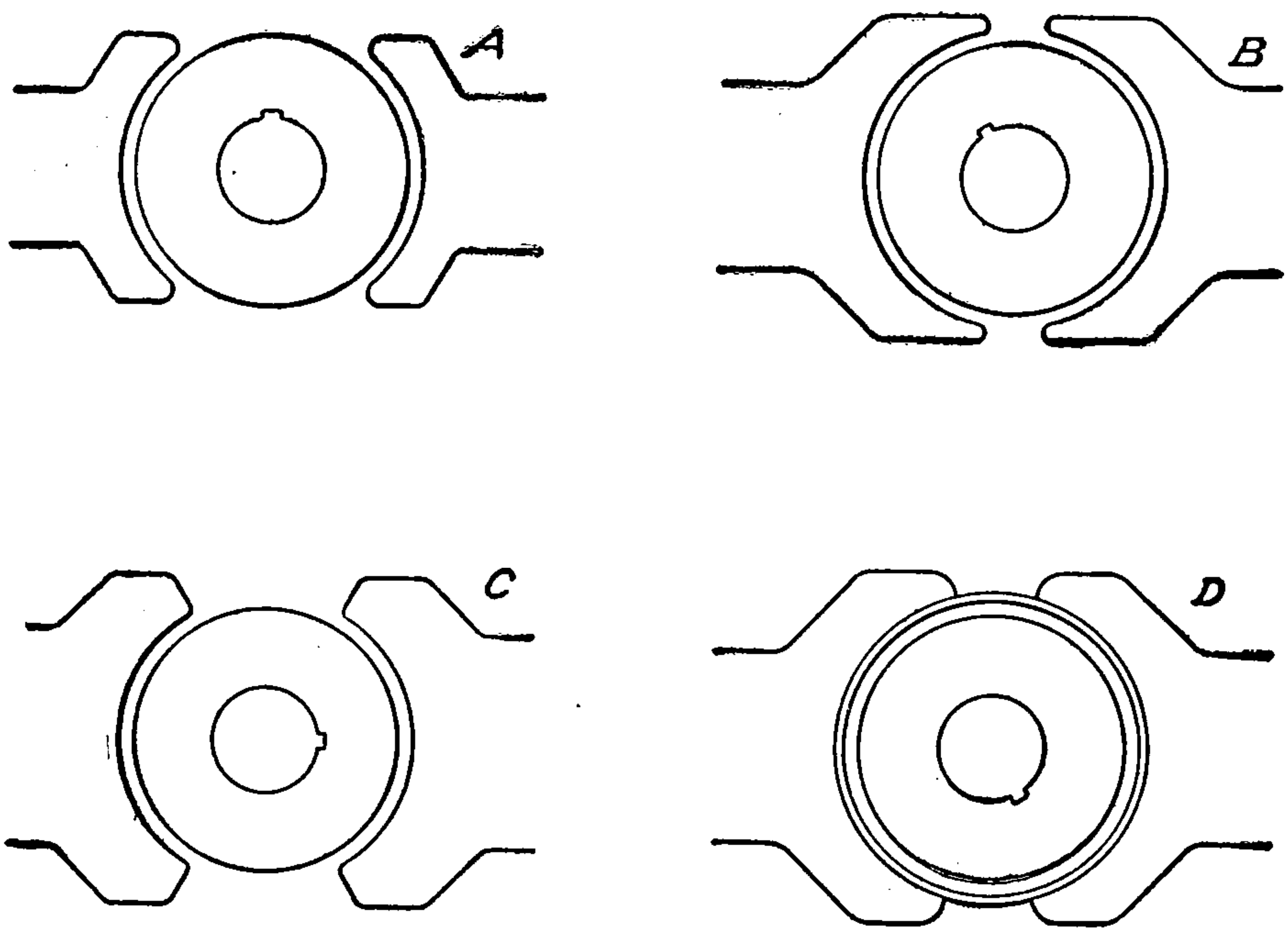



Fig. 70. Various Forms of Pole

the flux at the tip. In Fig. 70 are shown various forms of pole-tips, of which type *A* is not always good, but may be either extended, as in *B*, or cut off, as in *C*. An extreme arrangement, suggested by Dobrowolsky, surrounds the armature completely with iron, as in *D*.

(5) *Unsymmetrical form of poles.* This method was proposed by M. Gravier, and was used as shown in Fig. 71. When the machine is working at small loads, the flux in the gap is nearly uniform; but at large loads, the distortion due to armature current forces the flux forward and saturates the forward pole-horn, thus preventing much change in its flux-density, on account of the saturation and the diminished area. Lundell combines this device with the slotted-pole method, and produces the pole shown in Fig. 72.

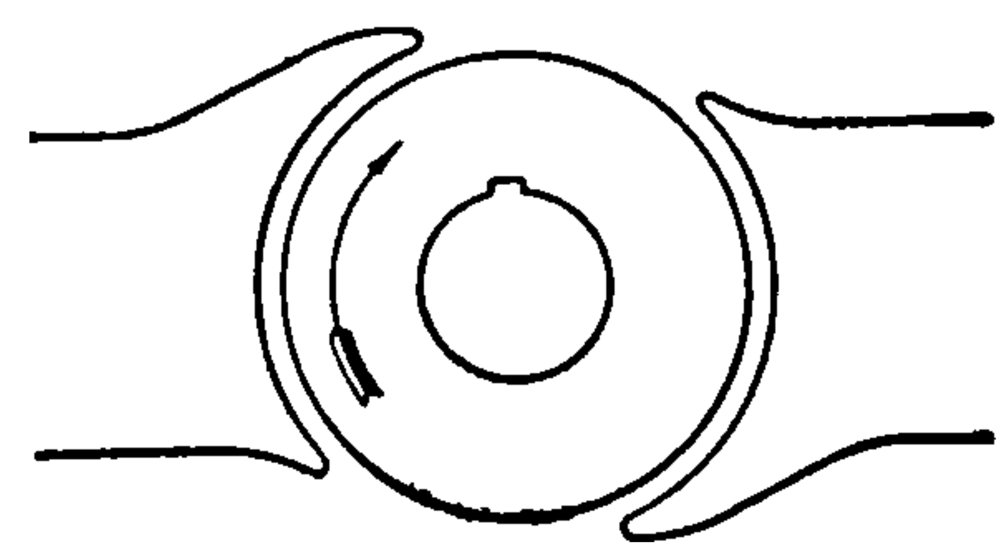


Fig. 71. Unsymmetrical Pole Pieces

(6) *Laminated pole-cores.* Another plan is to make the pole-cores of laminated wrought iron or steel, to which a cast-iron pole-piece is attached. A similar effect is produced by making the poles non-concentric with the armature, as in Fig. 73. This secures a suitable fringe and at the same time maintains a fair magnetic rigidity. Mr. C. E. L. Brown finds that inwardly projecting poles of circular cross-section, without any pole-shoes or extensions, produce excellent results in generators which deliver large current.

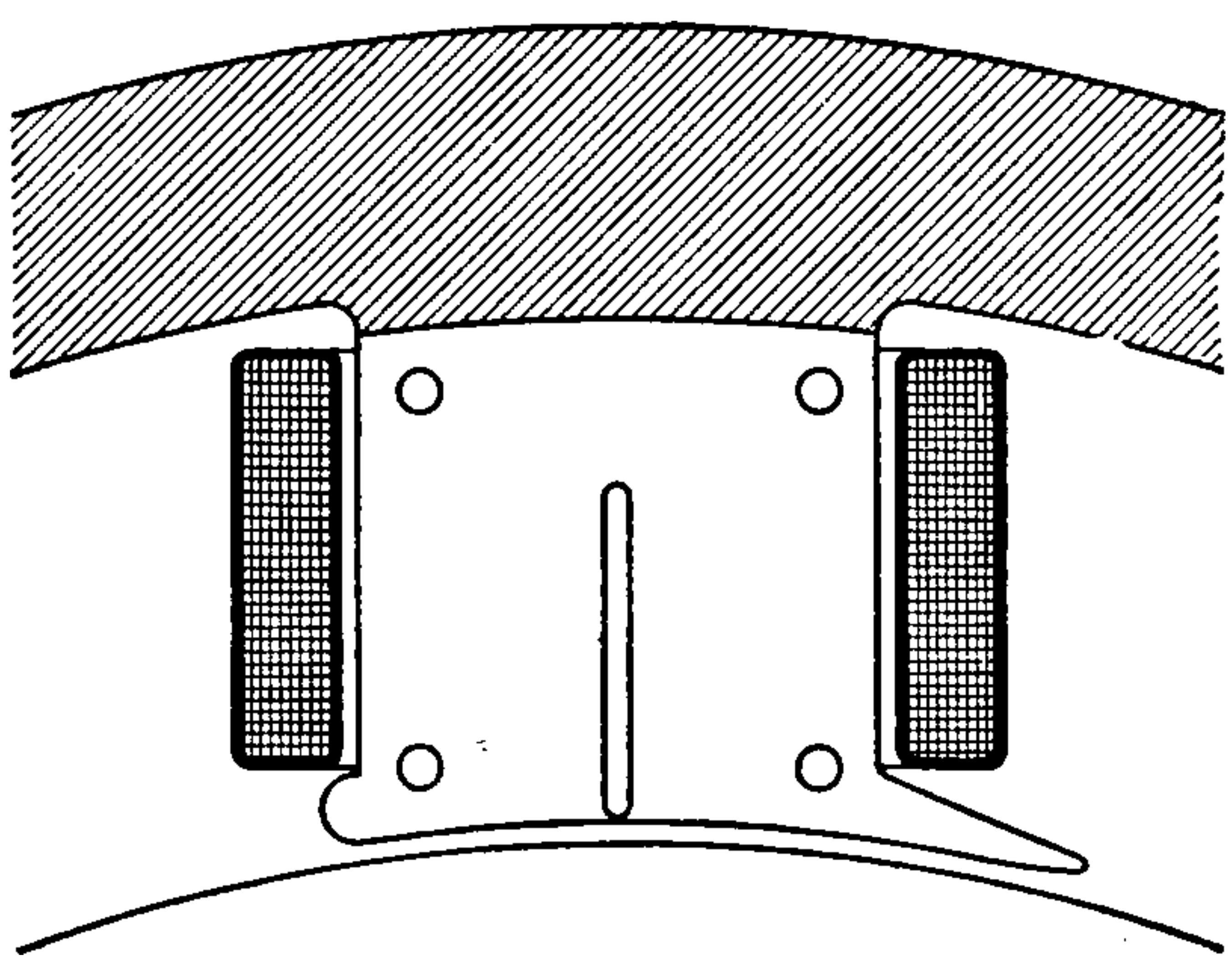


Fig. 72. Lundell Pole Device

Other devices for securing a gradual entrance of the armature conductors into the field, are (7) *to skew the hindward edge of the pole-shoe* as indicated in Fig. 74; (8) *to shape the pole-shoes with circular ends,* Fig. 75; or (9) *to provide pointed ends,* Fig. 76. Some manufacturers leave out every other lamina in the pole-tips, the resulting extra saturation helping to resist the effects of armature distortion.

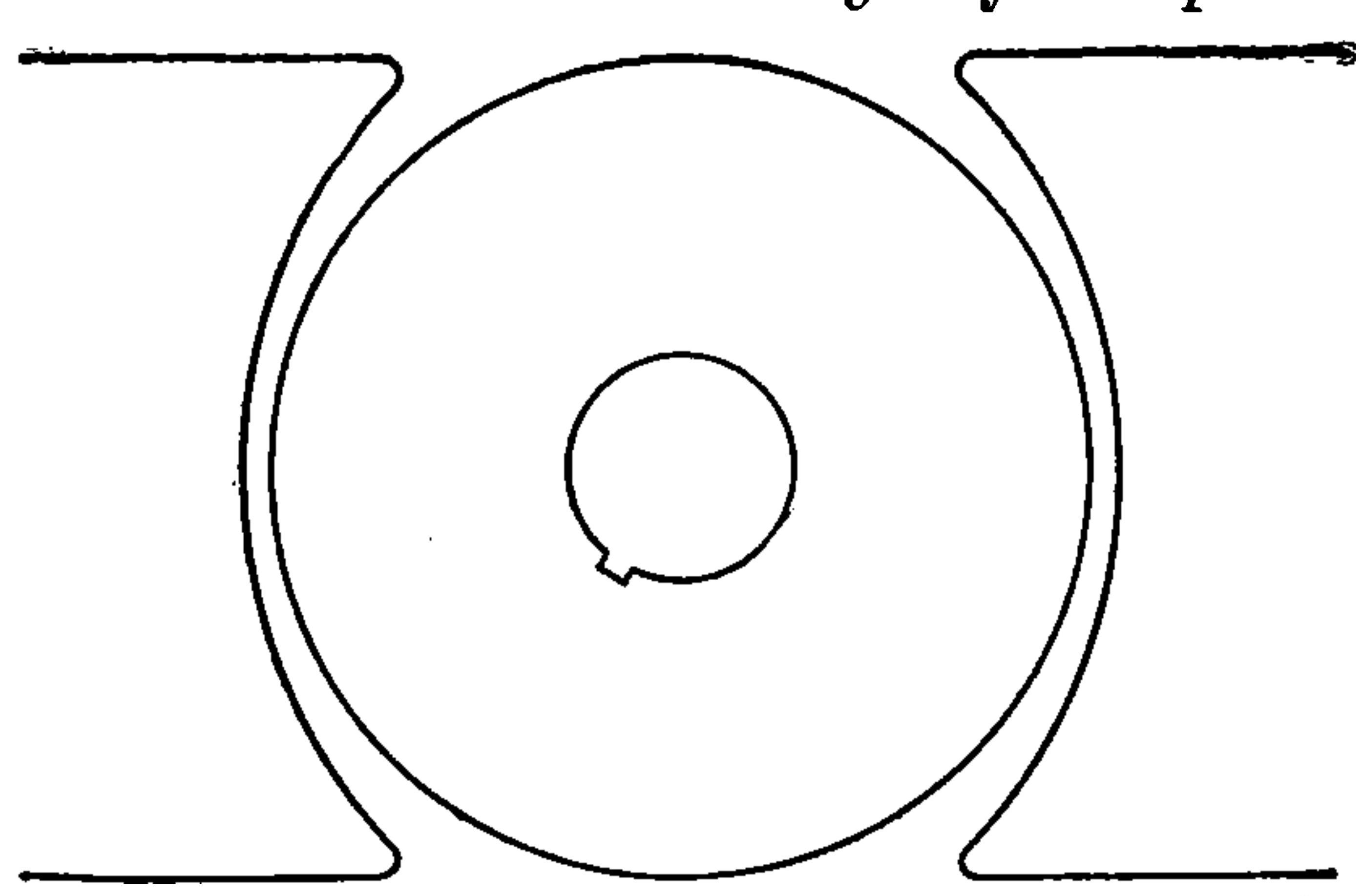


Fig. 73. Pole Pieces Non-Concentric with Armature

(10) *Interpole construction.* Probably the most effective and simple method for the elimination of sparking at the brushes is the

interpole or commutating pole construction variously credited to Mather and Menges. This consists in placing midway between the

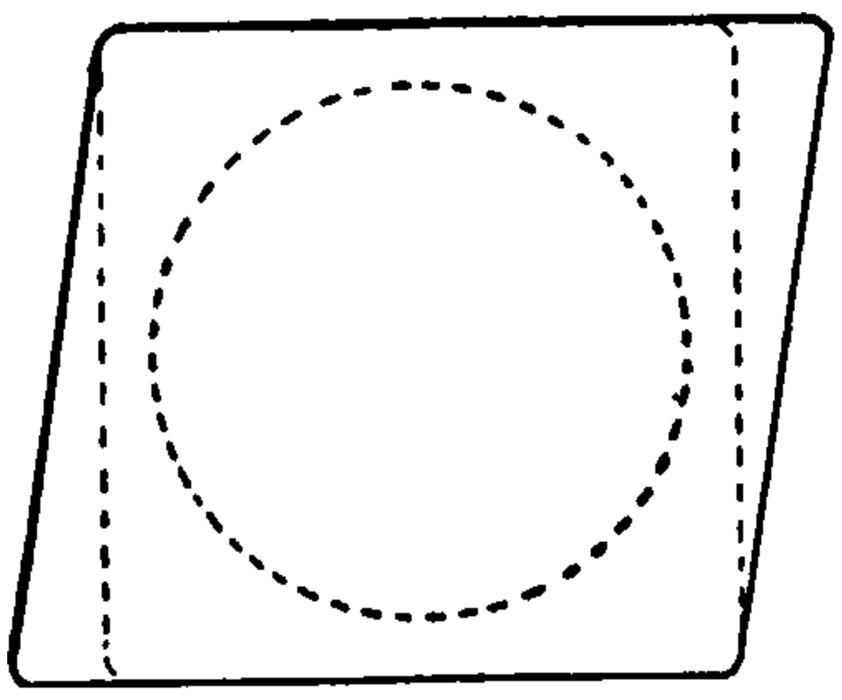


Fig. 74. Skewed Pole Shoe

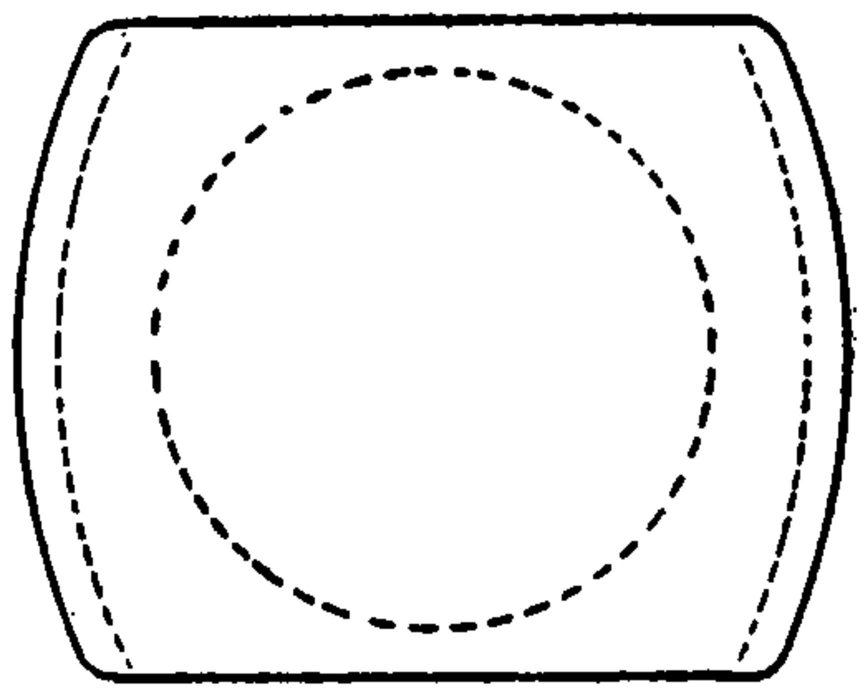


Fig. 75. Pole Shoe with Circular Ends

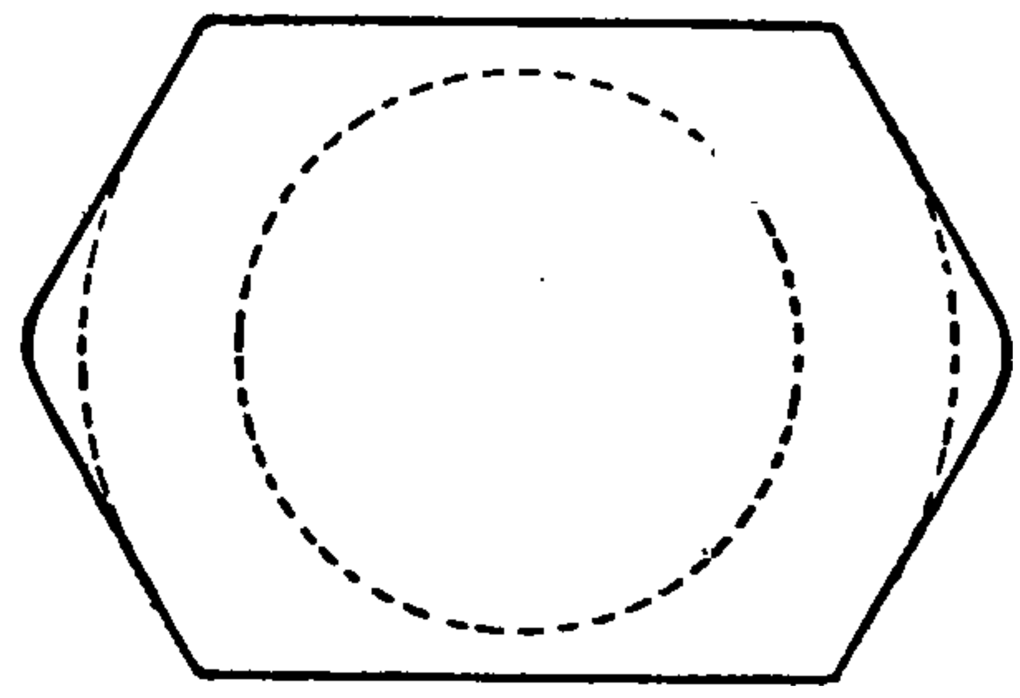


Fig. 76. Pole Shoe with Pointed Ends

various field poles small auxiliary magnet cores connected directly to the yoke and these are provided with windings in series with the armature, Fig. 77. Thus, their magnetic strength is increased with the armature current, while their winding is such that the field set up in them is opposed to the armature field, and, in fact, about 30 per cent in excess. Due to this the flux necessary for reversal of the current in the short-circuited coil is maintained at the coils midway between the main poles and consequently the brushes need not be shifted as the load varies or when the direction of the rotation is reversed. A further advantage of this design is that, since the interpole strength is independent of the main field, the sparkless condition of operation is maintained even if the working field is considerably weakened. This feature was appreciated by Pfatischer and utilized by him in the development of the interpole adjustable-speed shunt motor. It should be noted that this commutating pole construction does not overcome field distortion; in fact, it even increases it, but it maintains a flux for reversal where needed, which is the characteristic desired.

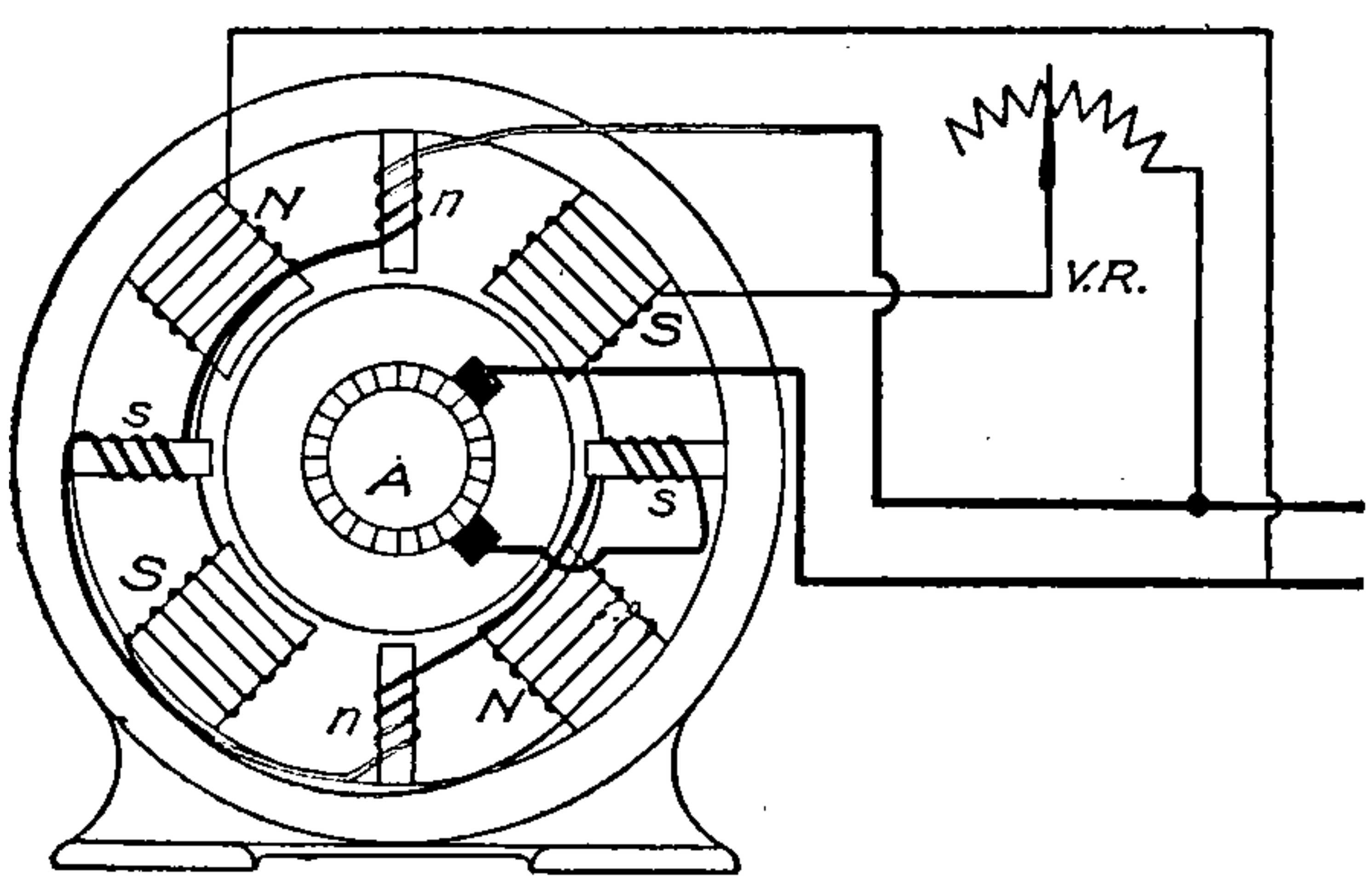



Fig. 77. Interpole Device to Prevent Sparking

**Compensation.** An excellent compensation method was independently proposed by Professor Ryan and Fischer-Hinnen. This consists essentially of introducing a stationary armature *a* around the revolving armature, Fig. 78. This stationary winding is in series

ing the volts between the commutator segments relatively low—2 to 4 volts—employing high-flux densities in the teeth (20,000 to 23,000 *l* of *f* per sq. cm.), and providing the poles with tips or shoes to carry the flux well towards the zone of commutation.

**Dead Turns.** On account of the various internal reactions present in the armature, the terminal voltage is not quite proportional to the speed with constant field-current. Inasmuch as the machine acts as though some of its speed were ineffective, the name *dead turns* has been given to those revolutions by which the actual speed at any output exceeds that determined by strict proportionality.

**Eddy-Currents.** It was shown in discussing the magnetic circuit, that local currents may be produced in the iron parts of dynamo-electric machines if any of these parts form closed electrical circuits and cut flux. The armature core rotates in a magnetic field; eddy-

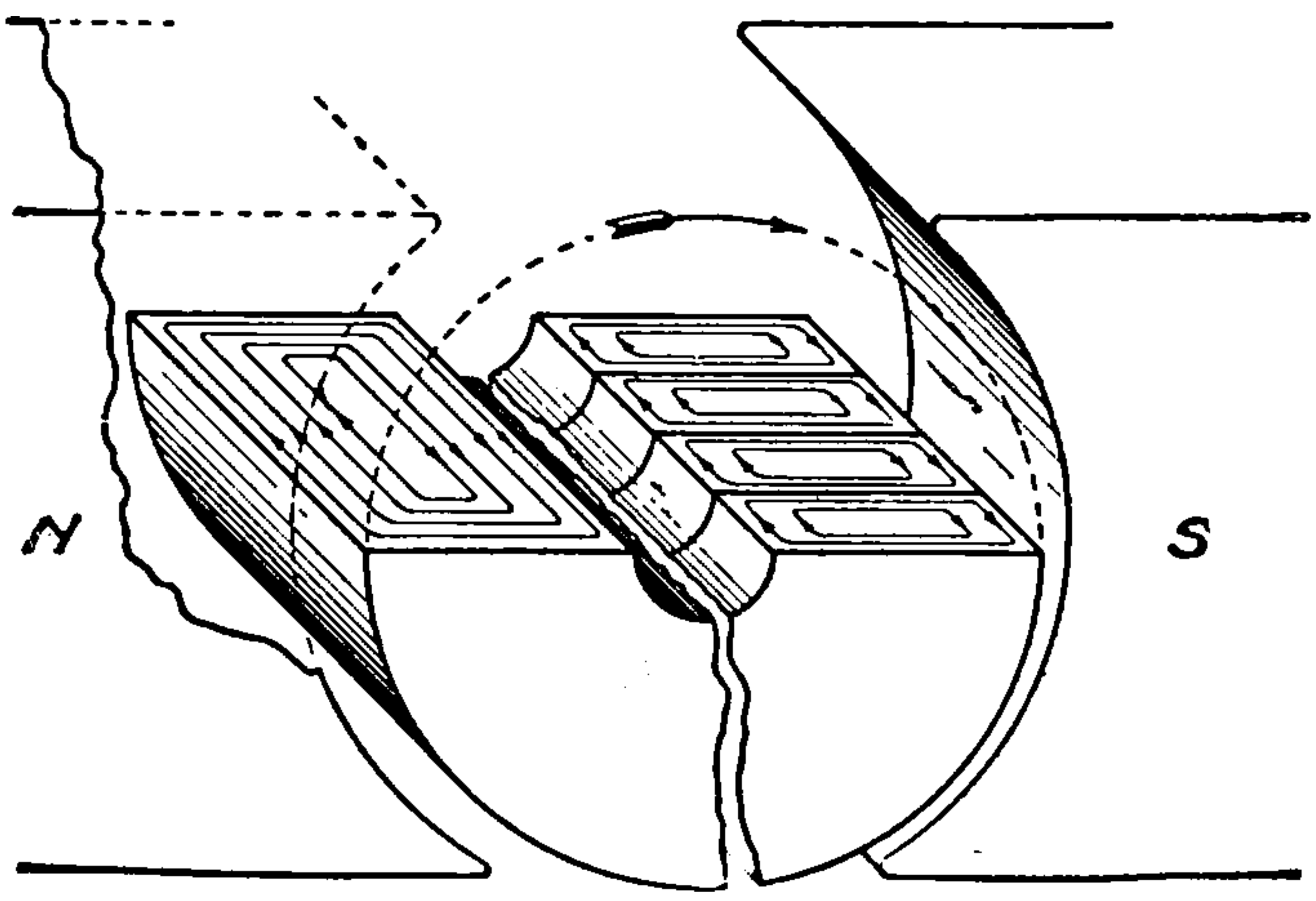



Fig. 80. Eddy-Currents in Armature Core

currents are set up in this core, as shown in Fig. 80, and unless prevented from flowing, these currents will lower the efficiency of the machine. Eddy-currents will also be produced in the pole-faces, due to the variation of the magnetic flux, as shown in Figs. 81–86; and they may in addition manifest themselves in the armature conductors if the latter are large.

In all cases where eddy-currents are likely to be large, the circuits affected are laminated so that the plane of lamination cuts across the path of this parasitic current.

**Drag on Armature Conductors.** A conductor carrying a current is surrounded by a magnetic field, as shown on page 8. If, now, such a conductor be placed in a uniform magnetic field—as, for example, between a large north pole and a large south pole—a compound field will result, having the distorted appearance shown in

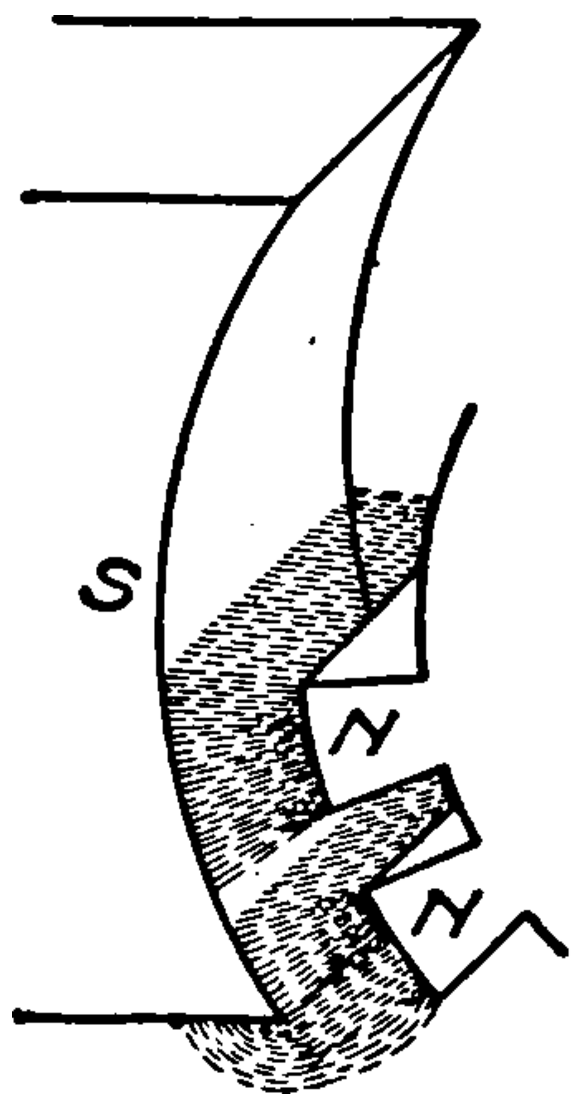


Fig. 81.

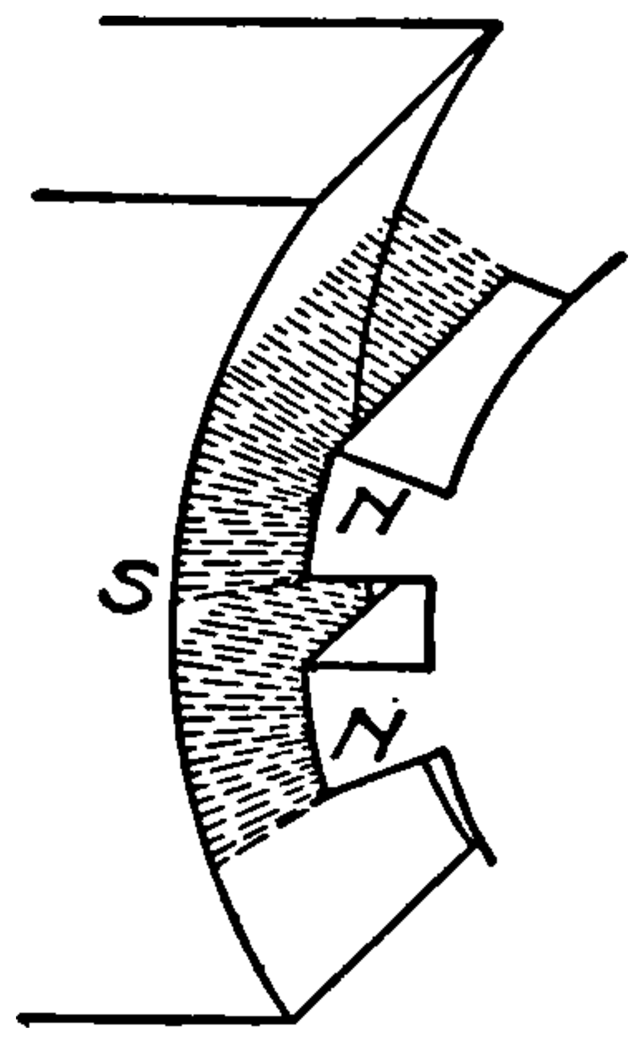


Fig. 82.

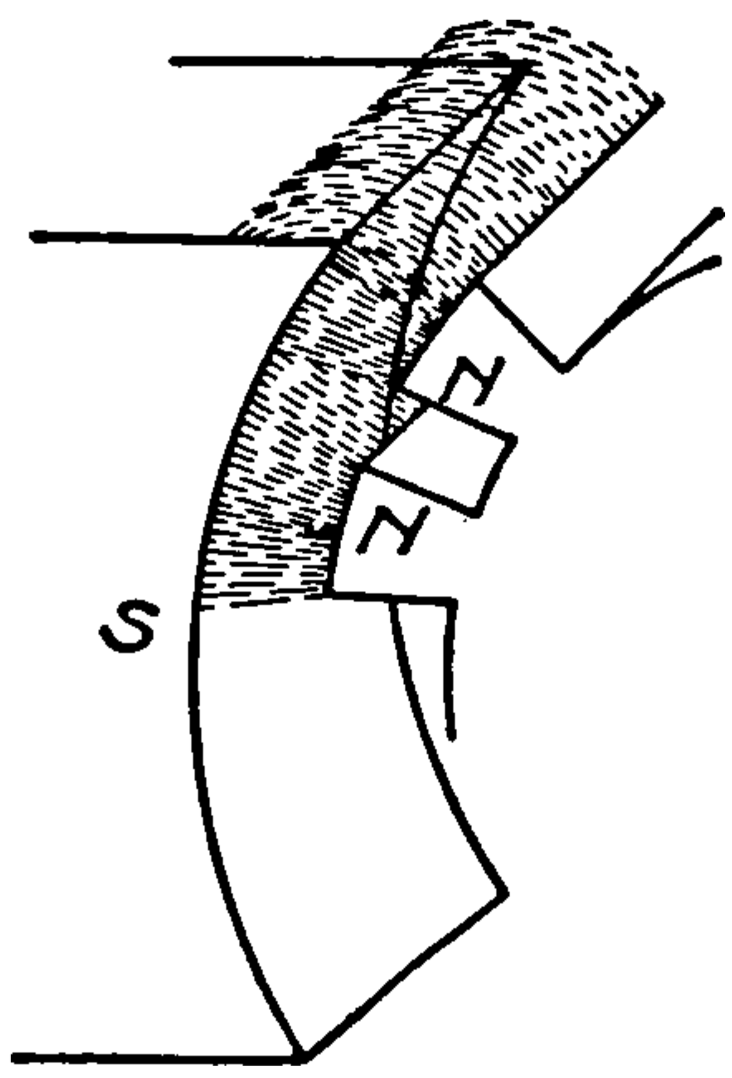


Fig. 83.

Alteration of Magnetic Field Due to Movement of Mass of Iron in Armature

Fig. 87. The direction of the mechanical force exerted may be determined by supposing that the flux acts as a bundle of elastic cords tending to shorten themselves. As a matter of fact, there is tension in the direction of the flux, and stress at right angles to it, proportional at every point to the square of the flux-density. A conductor in which current is supposed to be flowing away from the observer will, therefore, be urged in the direction of the arrow, Fig. 87; so that in every dynamo-electric machine the current generated produces a mechanical reaction which tends to stop the motion producing them.

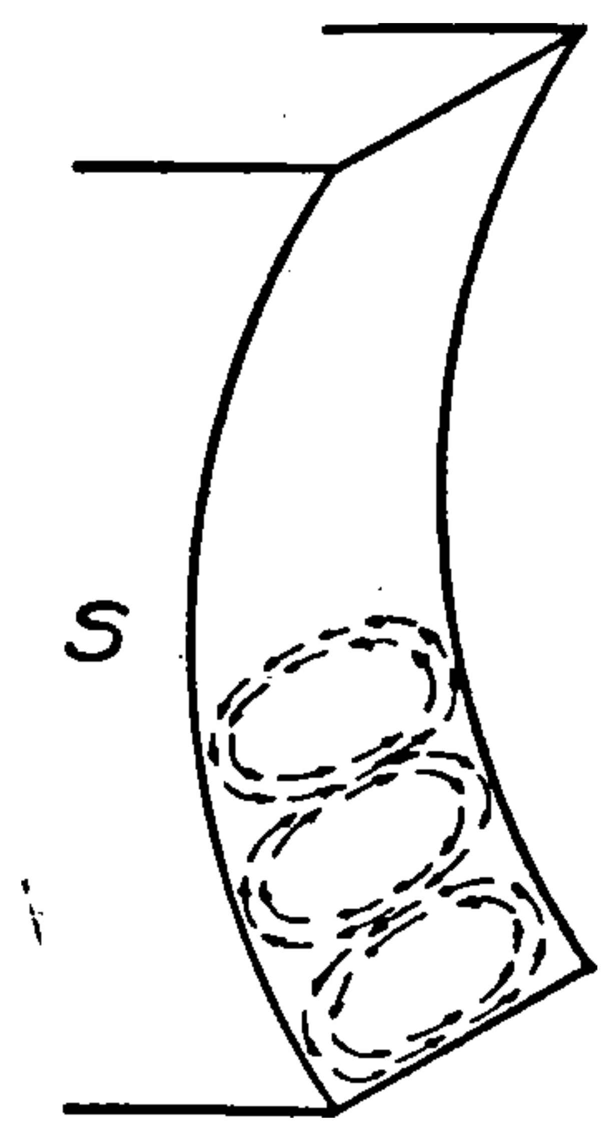


Fig. 84.

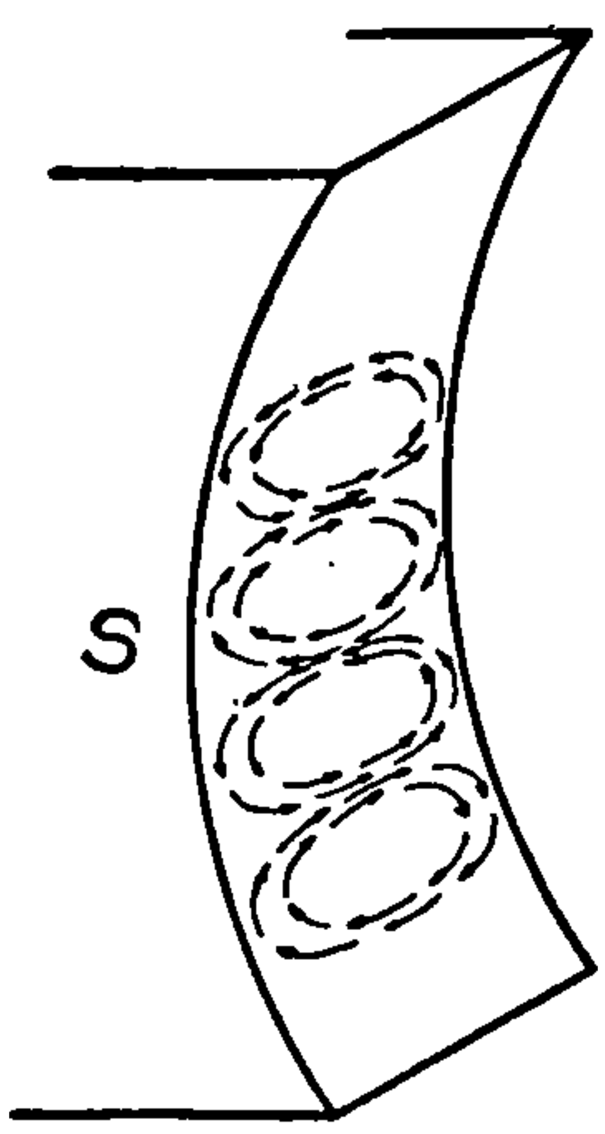


Fig. 85.

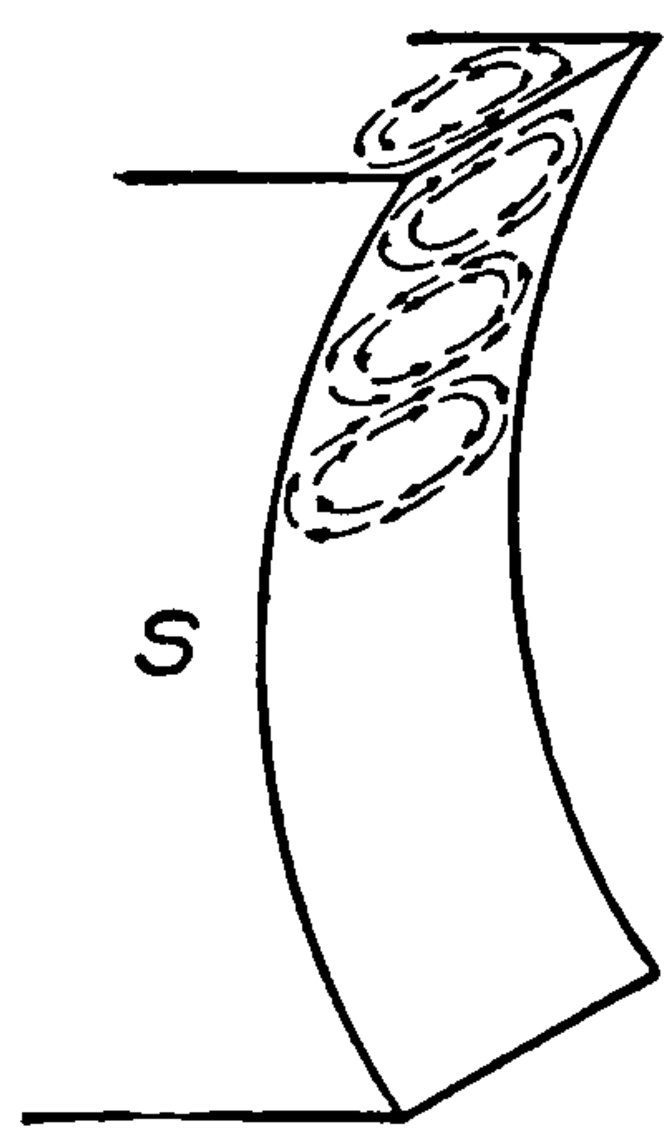


Fig. 86.

Eddy-Currents Induced in Pole-Pieces by Movement of Masses of Iron

If the conductors are imbedded in slots or holes in the armature core, Fig. 88, it is found that the drag comes upon the iron, the magnetic field being distorted as shown. In fact, the flux no longer directly cuts the conductors, but, as it were, snaps from tooth to tooth. In addition to thus relieving the conductors of the drag effect, the teeth permit a much smaller air gap to be used, sometimes reducing it to a mere mechanical clearance. In fact, the advantages accruing from the use of toothed or slotted armature cores are so pronounced that such forms are practically always employed in preference to smooth core types. The advantages of the toothed armature cores, sometimes called the *Pacinotti armature* after its inventor, may be summarized as follows:

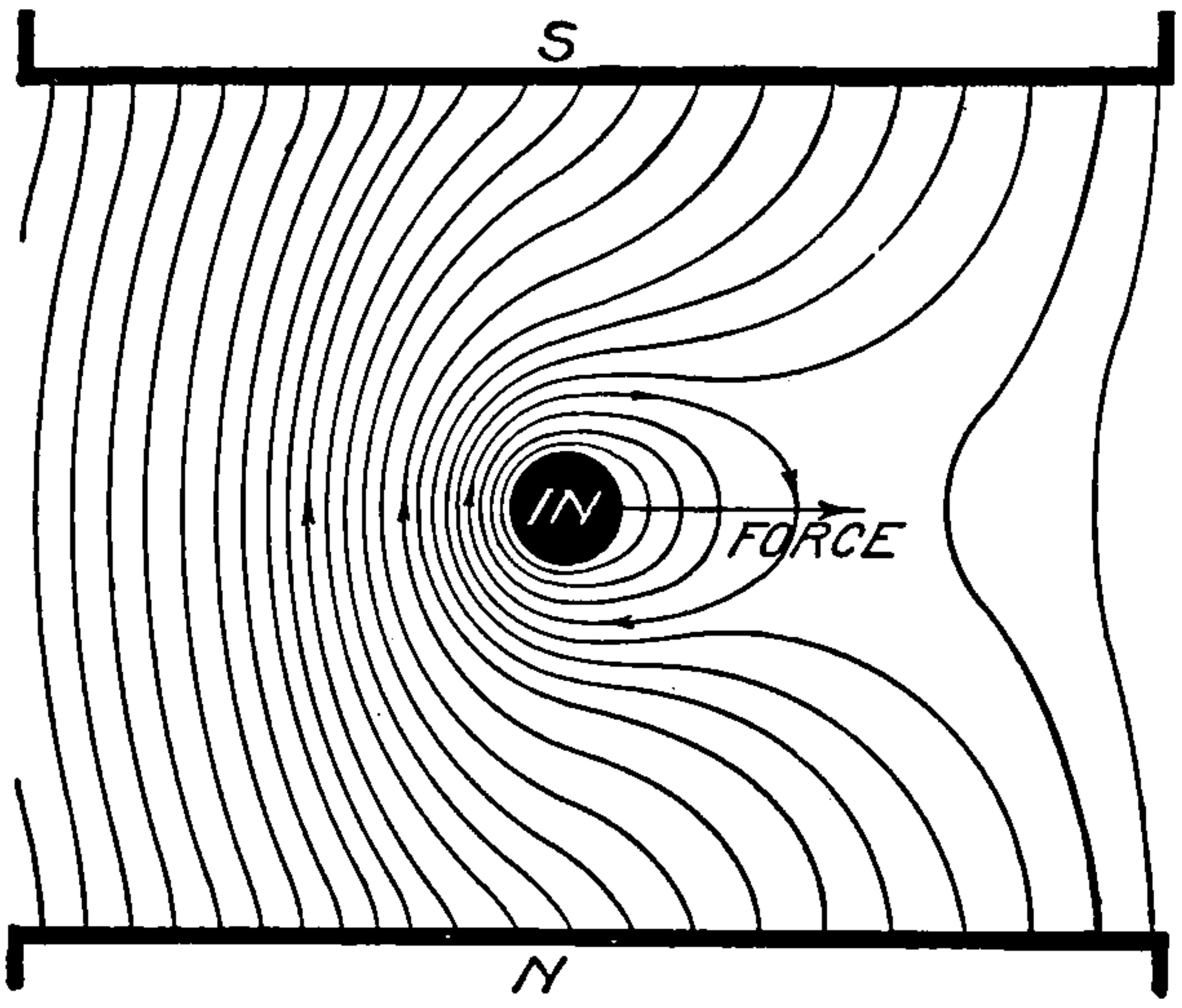



Fig. 87. Distortion Produced by Conductor in a Uniform Magnetic Field

1. The reluctance of the magnetic circuit is reduced to a minimum.
2. The armature conductors are protected from injury.
3. The conductors are held firmly in place and cannot slip on the core, by the action of the electro-dynamic forces.

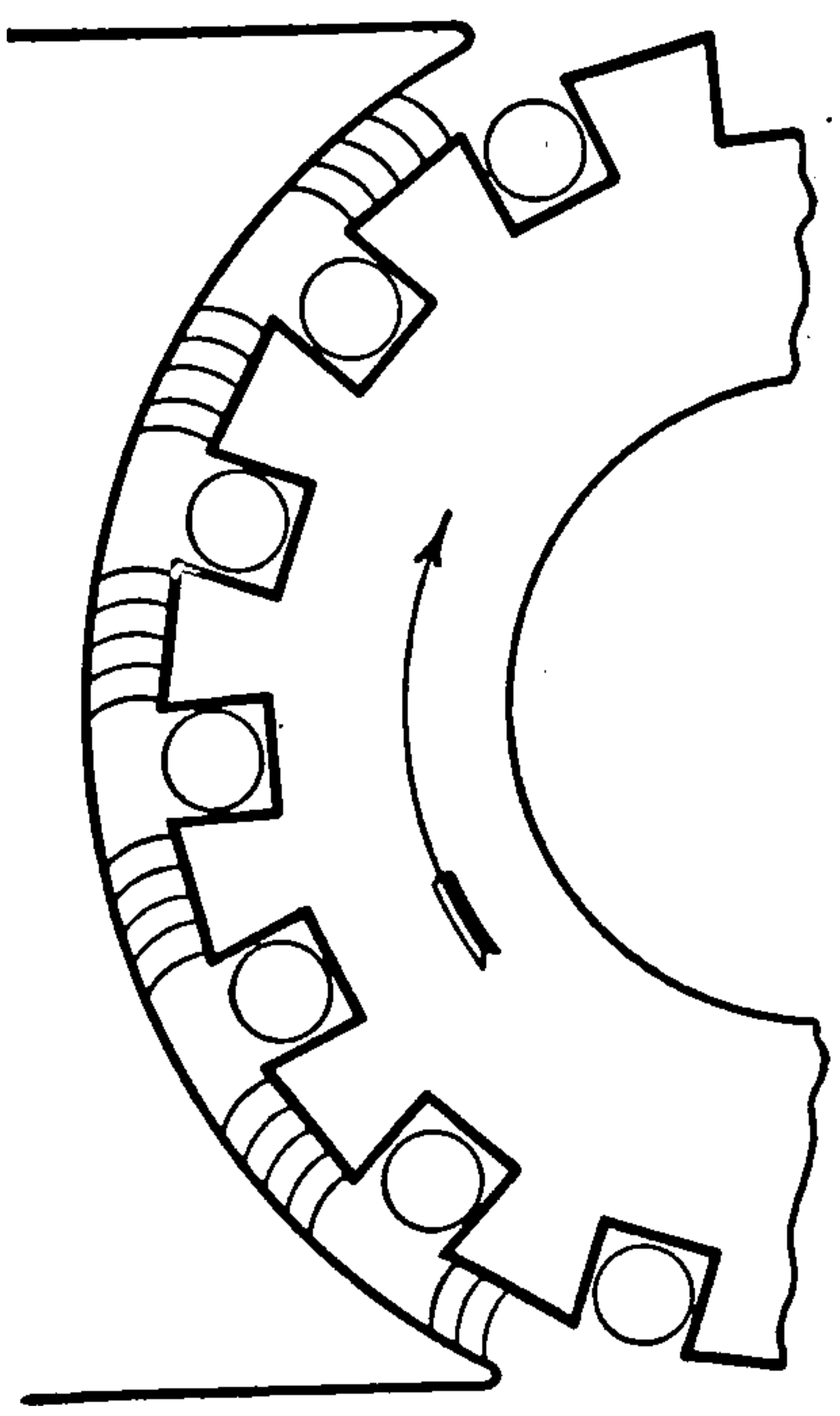


Fig. 88. Section of Slotted Armature

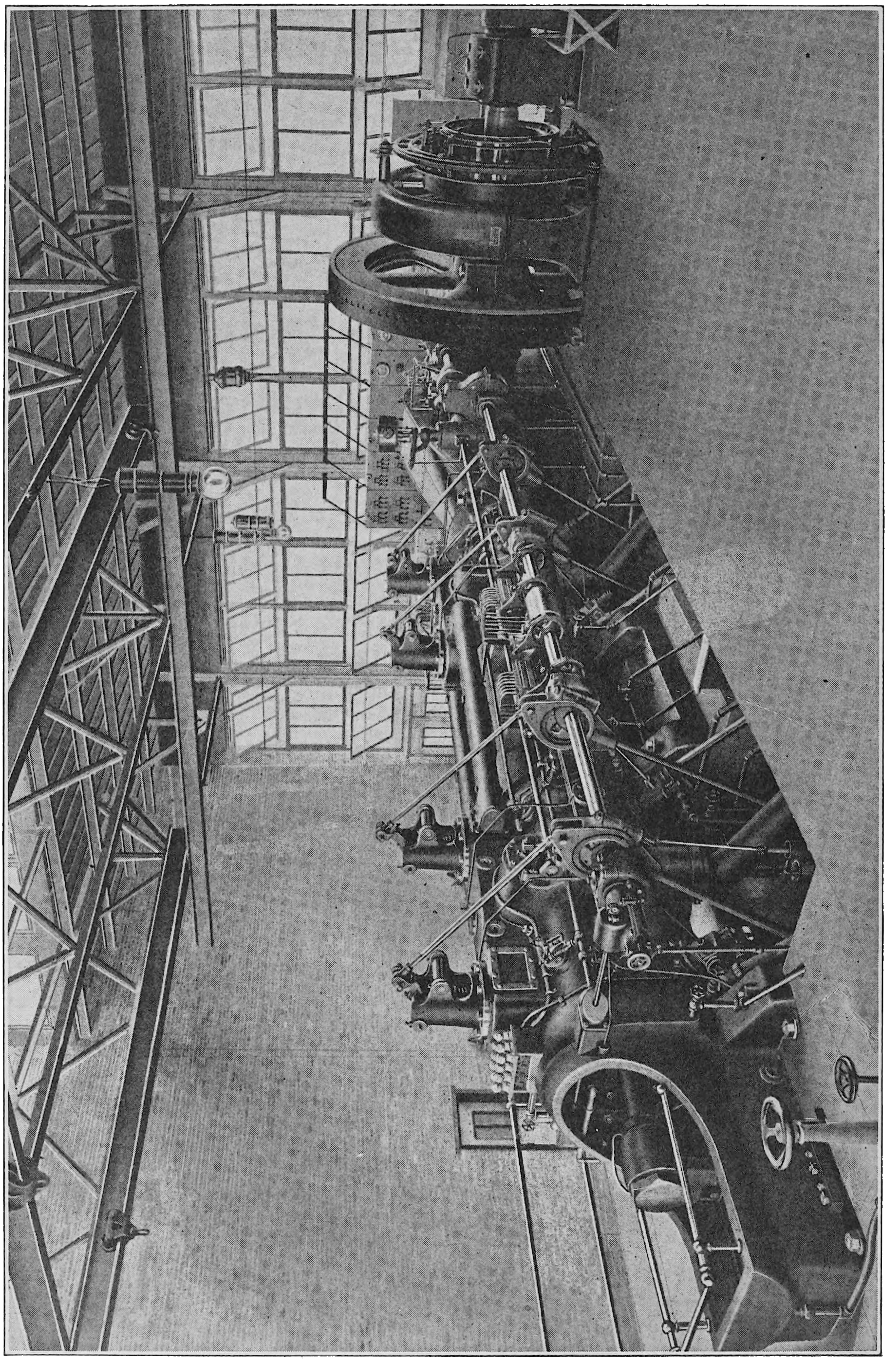
4. Eddy-currents in the armature conductors are avoided because the magnetic lines snap across them instantly.
5. If the teeth are practically saturated by the field magnetization (**B** = 20,000 to 23,000 per sq. cm., or 130,000 to 150,000 per sq. in.), they oppose the shifting of the lines by *armature reaction*.

The disadvantages of toothed armature cores are: they cost more; they may produce eddy-current losses in the polar faces; and they increase armature self-induction. The element of cost is of no account, however, when the advantages are taken into consideration.

**Stray-Power.** In all practical machines there is a difference between the input and the output. In electrical machines, this discrepancy is caused by the following reasons:

1. Armature-resistance drop producing $I^2R$ effects.
2. Friction of bearings and brushes.
3. Air-friction of the rotating armature.
4. Hysteresis in the armature core.
5. Eddy-currents in the armature core, conductors, and polar projections.
6. Energy is also consumed in the field winding, due to $I^2R$ effects

Nos. 2, 3, 4, and 5 are grouped under the head of *stray-power losses,* being from 40 to 60 per cent of the total loss. No. 3 is small, except in those cases where the armature spider is provided with fans to aid ventilation, and where special ventilating ducts are provided in the armature, as in most modern machines. No. 4 is by no means negligible, but never adds more than 1 or 2 per cent to the driving power. No. 5 is the most important of all, especially in large machines. It makes its presence felt even in the metal of the shaft, and there will be power wasted if flux leaks through this portion.



# DIRECT-CURRENT DYNAMOS

## PART II

## CALCULATIONS

**Fundamental Equation.** We have seen, page 23, that an e. m. f. of one volt is generated when $10^8$ lines are cut per second. As most armatures have more than one conductor cutting the field flux, the e. m. f. will be proportional to the number of conductors in series.

Assuming that the sections of the armature winding equal in number the commutator bars $K$, the external conductors all around the armature will be $bK$. The total number of conductors that are in series with each other electrically from brush to brush is $\frac{bK}{c}$, or $\frac{Z}{c}$, where $c$ is the number of paths in the winding. If the armature speed is given in r. p. m., then the revolutions per second $= n = \frac{\text{r. p. m.}}{60} = \frac{N}{60}$.

In order to compute the e. m. f. generated, we have

Number of lines cut by one external wire in one revolution $= 2\,p\,\Phi$

Number of lines cut by 1 external wire in 1 second $= 2\,n\,p\,\Phi$

Number of lines cut by $\frac{Z}{c}$ external wires in series in 1 second $= \frac{2\,pn\,\Phi\,Z}{c}$

Average e. m. f. generated, in C.G.S. units $= \frac{2\,p\,n\,\Phi Z}{c}$

Average e. m. f. generated, in volts $= \frac{2\,p\,n\,\Phi\,Z}{10^8\,c}$

Average e. m. f. generated, in volts $= \frac{2\,p\,\Phi\,Z \times N}{c \times 10^8 \times 60}$ (12)

If the number of circuits through the armature is equal to the number of poles in the field, then

$$(\text{Average})\ E = \frac{N \times Z\Phi}{10^8 \times 60} = Mn \qquad (13)$$

Remember that this e. m. f. is an average, and that the fluctuation during a rotation depends upon the armature construction, pages 25–28.

**TABLE II**

**Relations between Capacity, Speed, and Number of Poles for Continuous-Current Generators**

| Capacity in Kilowatts | High Speed Belt Driven | | Low Speed Belt Driven | | Engine Driven | |
|---|---|---|---|---|---|---|
| | Speed in R. P. M. | No. of Poles | Speed in R. P. M. | No. of Poles | Speed in R. P. M. | No. of Poles |
| 5 | 1100–2100 | 2–4 | 640–1100 | 4 | 400–800 | 4 |
| 10 | 1050–1950 | 2–4 | 610–1050 | 4 | 340–480 | 4 |
| 15 | 960–1770 | 2–4 | 580– 960 | 4 | 305–415 | 4–6 |
| 25 | 850–1550 | 2–4 | 530– 850 | 4–6 | 250–370 | 4–6 |
| 50 | 700–1200 | 2–4 | 470– 700 | 4–6 | 175–325 | 6 |
| 100 | 590– 850 | 4–6 | 440– 590 | 4–6 | 120–290 | 6–8 |
| 150 | 540– 700 | 4–6 | 420– 540 | 4–6 | 110–250 | 6–8 |
| 200 | 495– 625 | 4–6 | 395– 495 | 4–6 | 100–230 | 6–10 |
| 300 | 435– 520 | 4–6 | 360– 435 | 4–6 | 86–180 | 8–12 |
| 500 | 335– 380 | 4–6 | 295– 335 | 4–6 | 70–124 | 10–14 |
| 1000 | | | | | 59– 92 | 12–16 |
| 1500 | | | | | 56– 85 | 12–16 |

EXAMPLE. Assume a 4-pole machine with a 4-circuit armature winding; the flux per pole, 2,000,000 lines of force; the total number of inductors in the armature, 600; and the speed of the machine, 1,200 r. p. m. Determine the generated voltage.

Substituting in equation (12), we have

$$E = \frac{4 \times 2{,}000{,}000 \times 600 \times 1{,}200}{4 \times 10^8 \times 60} = 240 \text{ volts}$$

In the practical application of this formula, certain quantities are fixed by the specifications. For example, the terminal voltage $E$ is decided upon beforehand, the speed is fixed by the prime mover, and the number of poles is largely governed by the current capacity of the machine. If in a generator there are as many parallel circuits through the armature as there are poles, increasing the number of poles will enlarge the current capacity of the machine without affecting its voltage. General relations between kw. capacity, speed, and number of poles for continuous-current generators are given in Table II.

Consequently in preparing the design, the variables in equations (12) and (13) are flux per pole and number of armature conductors. Even these two quantities are to some extent restricted since the

exposing a large surface which materially increases the magnetic leakage. This type is interesting, however, from the fact that it has but a single field-coil. The same form is also arranged with the core horizontal, the armature being either under or over the latter, in which case the supports for the bearings must be of some non-magnetic material such as brass, since they extend from one pole-piece to the other.

These forms, excepting the over-type, are open to the objection that, if set upon an iron base, the base would act as a magnetic short-circuit, and thus rob the armature of a considerable portion of the magnetic flux. In the Edison machines, this difficulty was partly overcome by interposing thick pieces of zinc between the pole-pieces and the base; but Hopkinson* found that even with this arrangement, the leakage through the base was over 10 per cent of the total flux. The over-type, on the other hand, has but small magnetic leakage of this character, since the pole-pieces are far removed from the base bearings or other magnetic conductors.

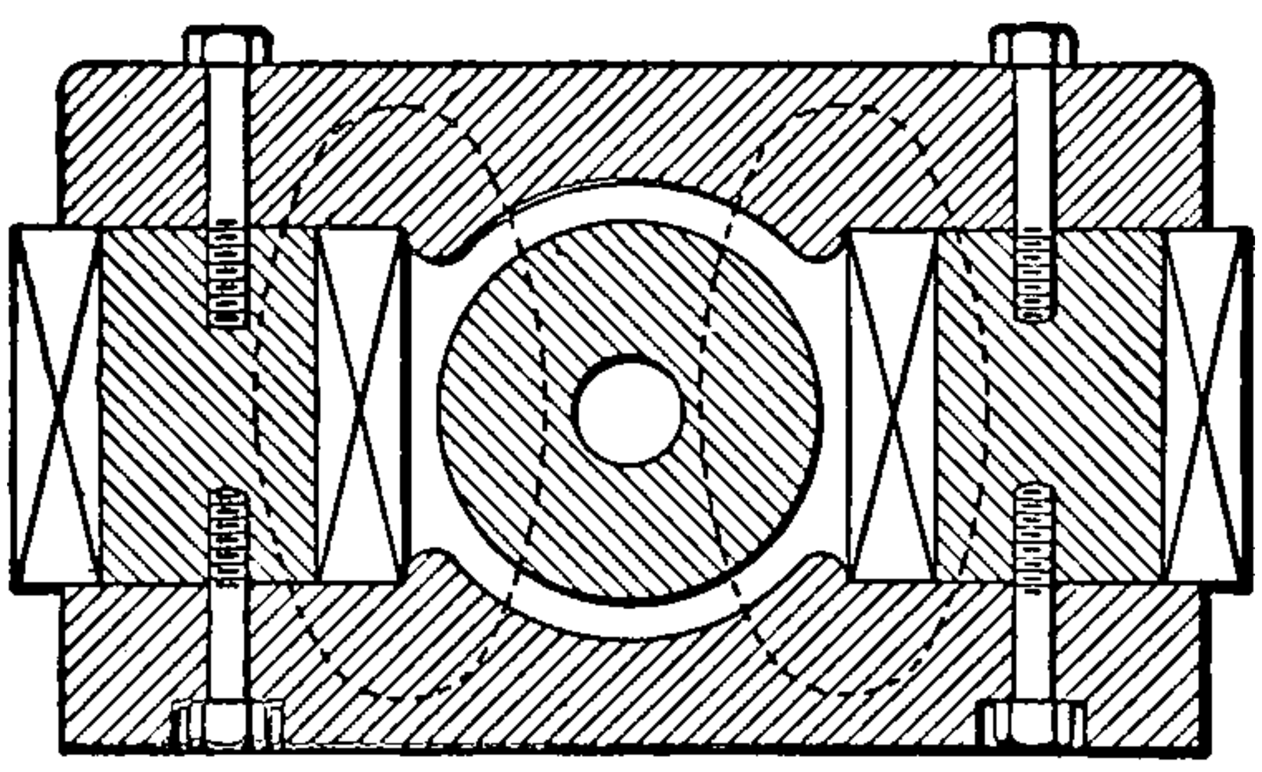


Fig. 92. Manchester Type of Field-Magnet

Fig. 92 represents a radically different form of bipolar magnet, called the *Manchester* type, from its place of manufacture in England. The construction is extremely solid, and offers good protection to the machine; but it has the undesirable feature of having two magnetic circuits in parallel, producing consequent poles and requiring the full number of ampere-turns for each circuit. Hence, the total number is doubled; but each is only $\sqrt{\frac{1}{2}}$ times as long, because the cross-section of each core is one-half that of an equivalent single core. The required length of wire is thus $2 \times \sqrt{\frac{1}{2}} = 1.41$ times as great for the double magnetic circuit. This form also has considerable magnetic leakage, the entire base and bearings being connected to one of the pole-pieces.

The modern tendency has been to draw away from these early designs, and to adopt machines that are wholly or partially enclosed. Figs. 93, 94, and 95 represent, respectively, the bipolar, four-pole,

*Philosophical Transactions of the Royal Society, May 6, 1886.

and multipolar ring arrangements of present-day practice, the bipolar type being restricted to machines of small output, as noted above. This ring arrangement has the advantages of strength, simplicity, symmetrical appearance, and minimum magnetic leakage, since the pole-pieces have the least possible surface and the path of the magnetic flux is shorter, more symmetrical, and more natural.

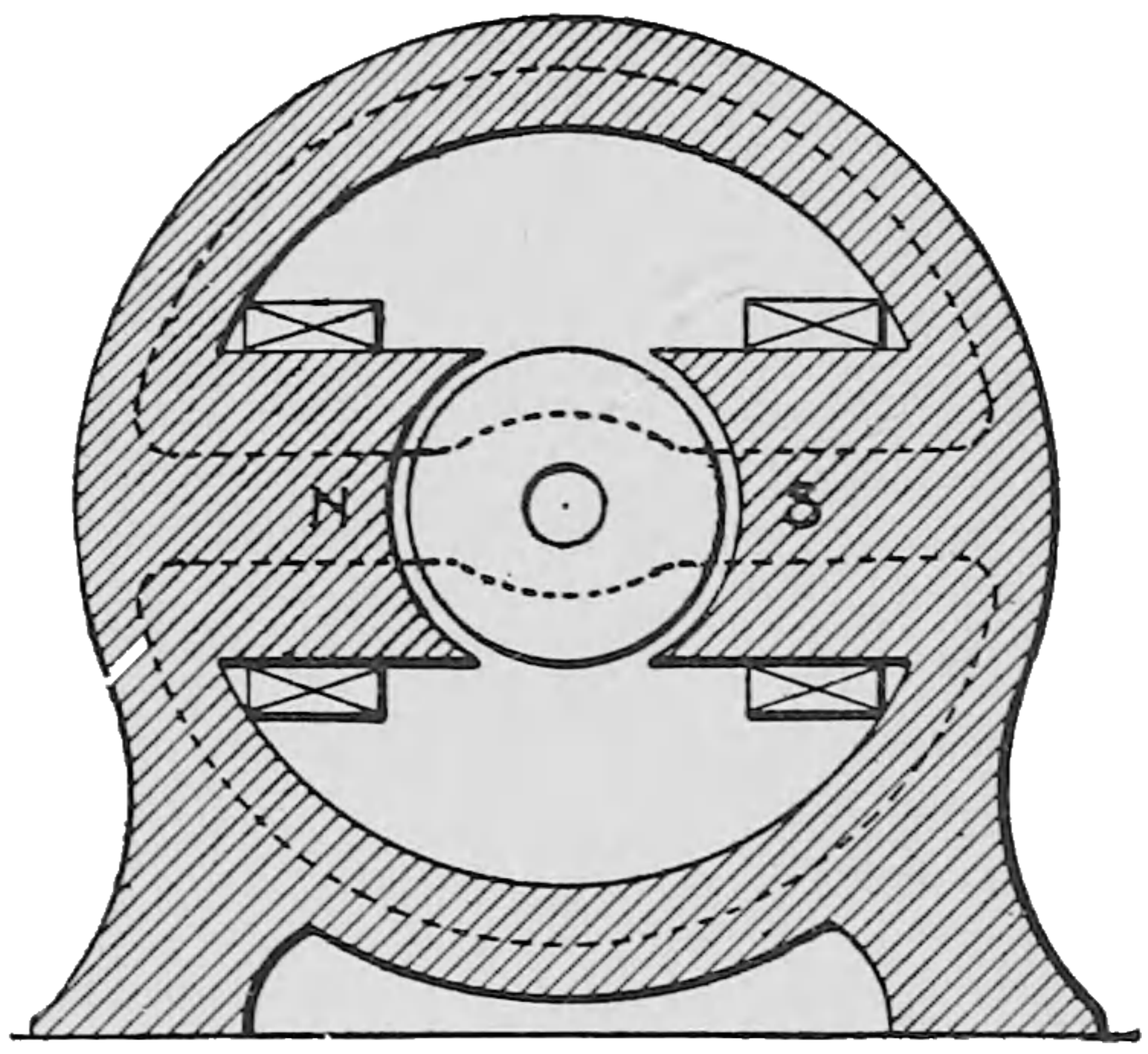


Fig. 93. Bipolar Ring Field-Magnet

**Magnetic Leakage.** The function of the field-magnet is, as we have seen, to produce a flux which the armature conductors cut in order to generate an e. m. f. This flux is called the *useful* flux. In addition to this useful flux, there is a *stray* flux from all parts of the field system, Figs. 96 and 97, the m. m. f. of the exciting ampere-turns having to produce both these fluxes. If we call $\Phi_m$ the flux in the magnet-core, $\Phi_a$ the flux in the armature, and $\Phi_s$ the flux which strays, we have

$$\Phi_m = \Phi_a + \Phi_s$$

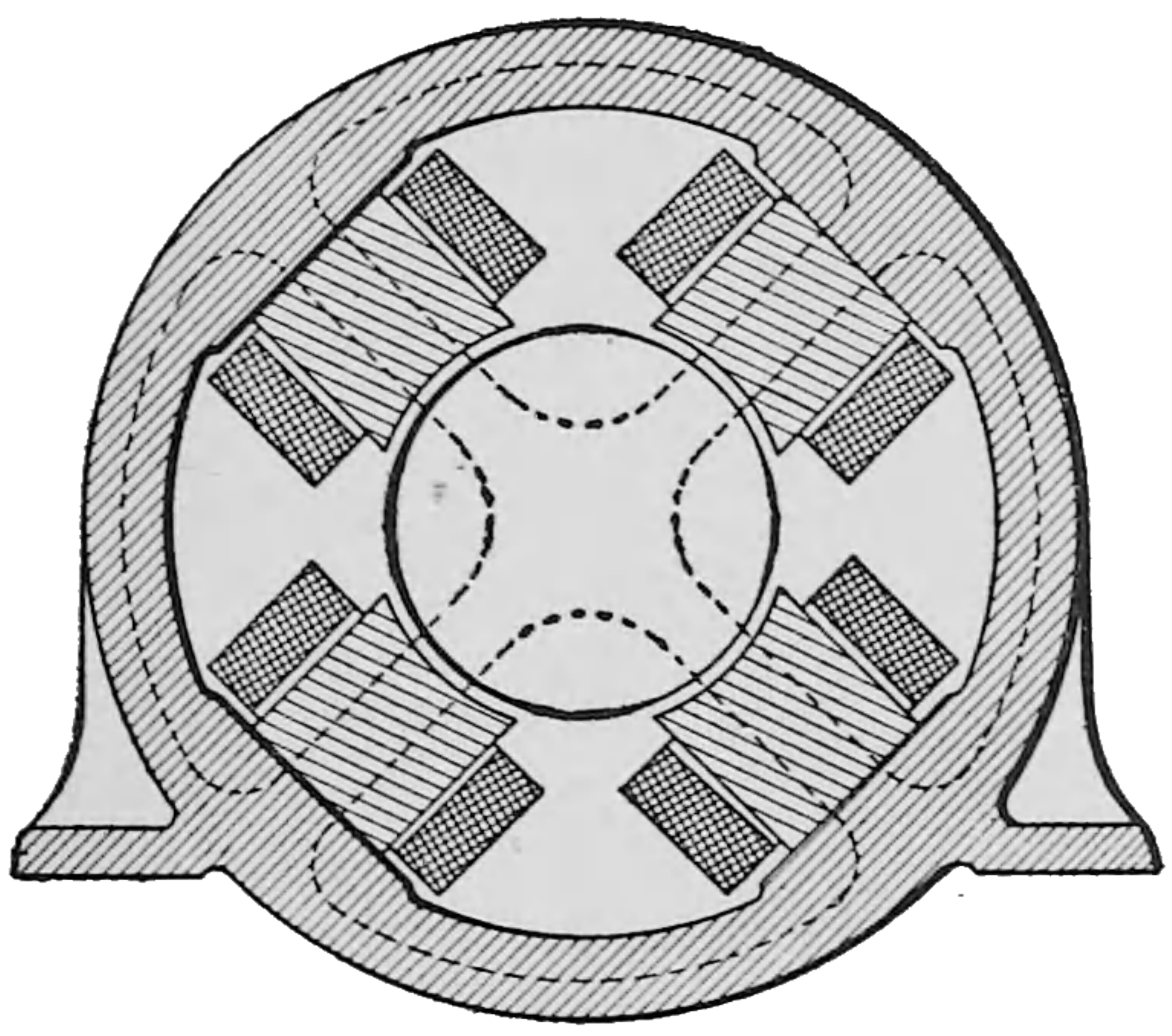


Fig. 94. Four-Pole Ring Field-Magnet

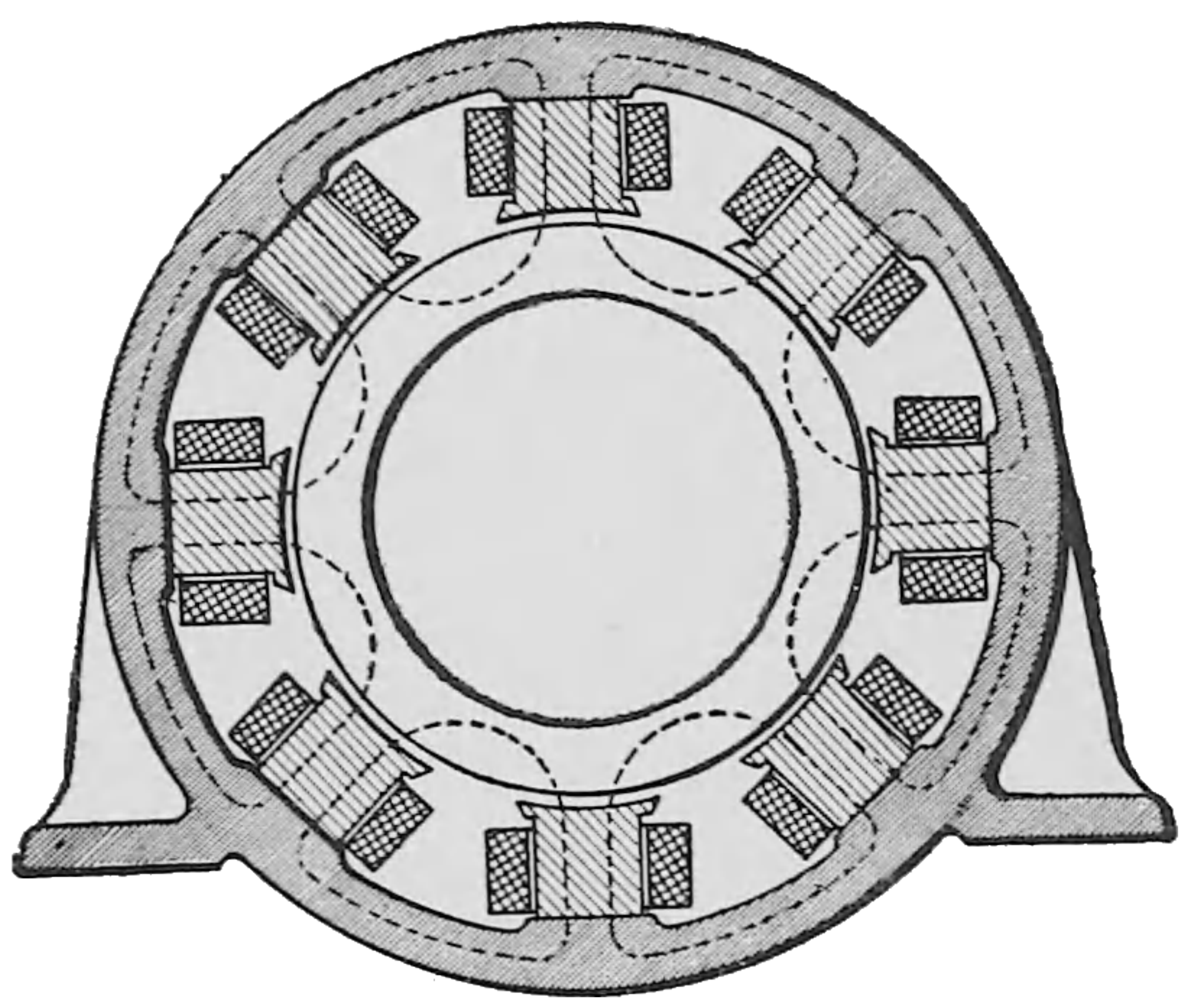


Fig. 95. Multipolar Ring Field-Magnet

The ratio between the total flux and the useful flux is called *the coefficient of magnetic leakage or dispersion*, that is

$$\nu = \frac{\Phi_m}{\Phi_a} \qquad (14)$$

It is a number greater than unity, and varies in value with the size and type of generator.

The magnitude of the stray field depends chiefly (*a*) upon the shape of the magnet-limbs—thus circular cores, for example, will have less leakage than those of rectangular cross-section, on account of the smaller area of the side flanks; (*b*) upon the length of the air gap, because the higher the reluctance of the latter, the greater the tendency of the flux to take alternative paths; (*c*) upon the degree of saturation to which the field system is pushed, because the magnetic conductivity of the leakage paths in air is constant, while that of the iron cores decreases as the saturation point is approached. It is evident, therefore, that the coefficient of dispersion not only varies with different types of machine, but is not generally constant even in a given machine, since it rises with the excitation. Moreover, when a large armature current flows, the demagnetizing action of the latter directly aids dispersion, as it usually produces an m. m. f. opposed to that of the main flux, which tends to blow aside the latter.

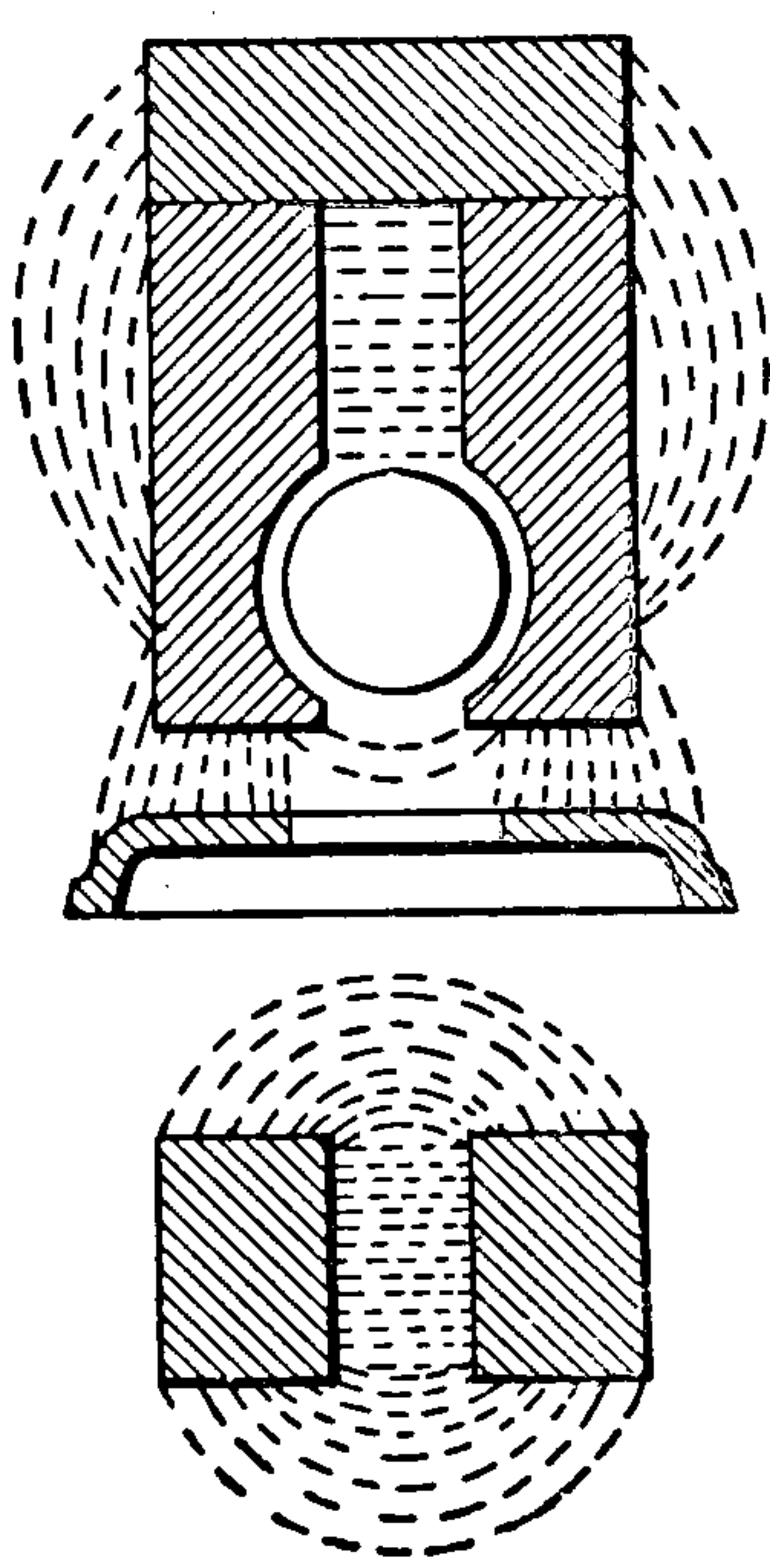


Fig. 96. Magnetic Leakage or Stray Flux in Bipolar Field

The only accurate method of determining the dispersion factor of any machine is by direct test.* For purposes of design, however,

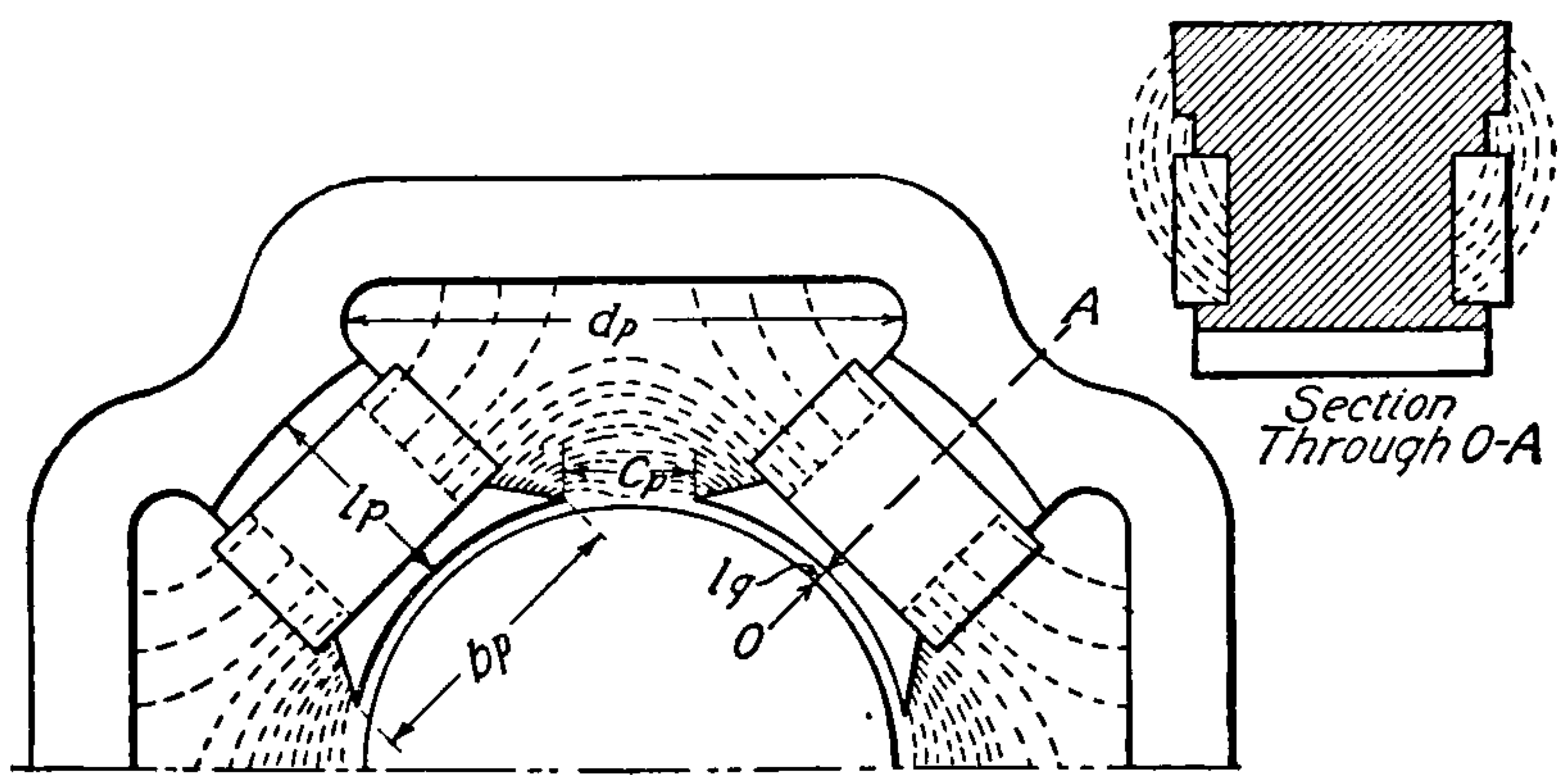



Fig. 97. Magnetic Leakage or Stray Flux in Four-Pole Field

one must resort to the results of experiments performed on machines similar to the one being designed. Table III gives approximate values of dispersion coefficients for machines of the modern type, *i. e.*, mul-

*For various methods of procedure, see S. P. Thompson's "Dynamo-Electric Machinery," Vol. I, p. 134, New York, 1904.

**TABLE III**

**Dispersion Coefficients**

| Output in Kilowatts | Ring Type Figs. 93-95 | Over-type Fig. 90 | Under-type Fig. 89 | Single-Magnet Type Fig. 91 | Manchester Type Fig. 92 |
|---|---|---|---|---|---|
| 1 | 1.25–1.60 | 1.30–1.65 | 1.35–1.65 | 1.30–1.65 | 1.35–1.80 |
| 2.5 | 1.20–1.50 | 1.25–1.55 | 1.30–1.60 | 1.25–1.55 | 1.30–1.70 |
| 5 | 1.18–1.40 | 1.20–1.45 | 1.25–1.55 | 1.23–1.50 | 1.25–1.60 |
| 10 | 1.16–1.35 | 1.20–1.40 | 1.22–1.50 | 1.20–1.45 | 1.20–1.55 |
| 25 | 1.15–1.32 | 1.15–1.35 | 1.20–1.45 | 1.18–1.40 | 1.18–1.50 |
| 50 | 1.13–1.30 | 1.15–1.30 | 1.18–1.40 | 1.15–1.35 | 1.16–1.45 |
| 100 | 1.11–1.28 | 1.15–1.30 | 1.16–1.35 | 1.15–1.35 | 1.15–1.40 |
| 200 | 1.08–1.25 | | 1.14–1.30 | | |
| 300 | 1.08–1.22 | | 1.12–1.25 | | |
| 500 | 1.08–1.20 | | | | |
| 1000 | 1.08–1.18 | | | | |
| 2000 | 1.08–1.15 | | | | |

tipolar frames, and, for comparison, values for corresponding machines of the other types mentioned.

It is seen that the magnetic dispersion is greater with the smaller sizes of machines, because the surfaces from which it occurs are relatively longer compared with the total flux. It is also greater with cast-iron magnets and pole-pieces than with mild steel or wrought-iron ones, because the leakage areas are proportionally larger. Similarly the dispersion is more marked with smooth than with toothed core armatures on account of the greater length of air gap.

It is theoretically possible to predetermine the dispersion of a given machine from the working drawings,* the calculations being based upon the principle that where a circuit offers alternative paths, the flux will divide itself between the paths in the proportion of their relative magnetic conductance, or permeance. In fact, the theory of parallel electrical circuits is here applicable. Various rules have been devised for this purpose, and one easily applied, which gives a close approximation, is

$$\text{Coef. of leakage} = 1 + .5\left[\frac{l_p \times l_g}{b_p \times \frac{d_p + c_p}{2}}\right] \qquad (15)$$

*"Dynamo-Electric Machines," A. E. Wiener, 2d ed., p. 217.

wherein, $l_p$, $l_g$, etc., are shown in Fig. 97. The designer, however, usually contents himself with referring to tables.

**Exciting Ampere-Turns.** The determination of the exciting ampere-turns for a machine is a simple matter if we know the dispersion coefficient and the magnetic properties—as shown by the **B-H** curve—of the materials forming parts of the magnetic circuit, Fig. 100.

The simplest mode of procedure is to fix approximately the flux necessary to pass through the armature in order to produce the required e. m. f.* Knowing this value, and also the size of the machine, we may select from Table III a suitable dispersion coefficient and thus find the flux required to be produced by the field winding, that is

$$\Phi_m = \nu \, \Phi_a$$

The next step is to allow a sufficient cross-section of material in the various parts to carry this flux at a reasonable flux-density. Knowing the latter at once fixes the reluctance, and the necessary number of ampere-turns is found by solving the equation connecting the flux, m. m. f., and reluctance of each portion of the circuit, discussed on pages 13-18, that is

$$\text{Ampere-turns} = IT = \frac{\Phi l}{1.257\, A\mu} = \frac{\mathrm{B} A\, l}{1.257\, A\mu} = \frac{\mathrm{B}\, l}{1.257\, \mu}$$

The sum of the ampere-turns required for the different parts will then give the total ampere-turns for that circuit.

$$\text{Ampere-turns} = \frac{\mathrm{B}_y\, l_y}{1.257\, \mu_y} + \frac{\mathrm{B}_p\, l_p}{1.257\, \mu_p} + \frac{\mathrm{B}_c\, l_c}{1.257\, \mu_c} + \frac{\mathrm{B}_t\, l_t}{1.257\, \mu_t} + \frac{\mathrm{B}_g\, l_g}{1.257} \quad (16)$$

Wherein $\mathrm{B}_y$, $\mathrm{B}_p$, $\mathrm{B}_c$, $\mathrm{B}_t$, and $\mathrm{B}_g$ are the flux-densities per sq. cm. in the yoke, pole-pieces, armature core, teeth, and air gap, respectively, and $l_y$, $l_p$, $l_c$, $l_t$, and $l_g$ the lengths of the respective parts in centimeters.

The magnetic path from one pole to its neighbor of opposite polarity and return, is alone considered, as indicated in Figs. 93, 94, and 95, assuming a ring-type yoke. Hence, the total ampere-turns for this circuit will be those necessary per pair of poles. In other words, each field-coil must have one-half of this total value.

*See Equations (12) and (13), page 65.

As average values for the magnetic densities in the various parts of continuous-current generators, we may take those given in Table IV, departures from which are, however, often necessitated by circumstances.

If the particular solution thus arrived at is not suited to the various conditions, a slight change in the original assumptions will bring one nearer to the proper value. In fact, the *more* preliminary calculations that are made, the more nearly perfect and the more reliable will be the final figures; furthermore, it is always wise to make assumptions both sides of the accepted value, to assure its correctness.

As these assumptions carry with them the selection of the magnetic dimensions of the machine, it will be well to consider these here.

**TABLE IV**

**Average Flux-Densities in Various Parts of Continuous-Current Generators**

| Flux in Density | Lines per Square Inch | Material |
|---|---|---|
| Armature body | 50,000 to 95,000 | Soft sheet iron or mild steel |
| Armature teeth | 100,000 to 130,000 | Soft sheet iron or mild steel |
| Air gap | 40,000 to 55,000 | Air |
| Magnet-cores | 75,000 to 100,000 | Cast steel or wrought iron |
| Magnet-yoke | 70,000 to 90,000 | If cast steel or wrought iron |
| | 35,000 to 50,000 | If cast iron |

(*a*) *Yoke.* In all machines of the ring (yoke) type, the yoke carries only one-half the total flux, as may be seen by reference to Figs. 93-95. The magnetic length is the mean length of path.

(*b*) *Magnet-Cores.* As each core carries the whole flux for one pole-face, the entire section of one core is considered. The length of the magnetic path in the magnet cores is, however, twice the length of one core.

(*c*) *Air Gap.* Since slotted armatures are used almost exclusively at present, the magnetic area of this portion will equal the mean of pole-face area and tooth surface of armature under the pole. The total magnetic length of these gaps is twice the distance from iron to iron, measured perpendicular to the armature periphery.

(*d*) *Armature Core.* Here, also, the magnetic flux divides into two or a multiple of two paths (for the ring-yoke design), so that the magnetic area carries only one-half the flux entering the armature from one pole-face. The magnetic section is also less than the gross section, on account of the insulation of the core-disks* and the presence of ventilating ducts. If the latter are absent, it is usual to allow 10 per cent as space loss if the insulation is varnish, and 15 per cent if it is paper. When the air ducts are present, 25 per cent may be assumed for preliminary calculations with varnish insulation, and 35 per cent with paper insulation. The magnetic length is the length of the mean path lying between the roots of the teeth and the periphery of the internal hole.†

(*e*) *Teeth.* The total length traversed by the flux in this portion of the circuit is equal to twice the depth of one tooth. The width of one tooth may be taken as the width at the root, the teeth being generally trapezoidal in shape. The number of teeth receiving the flux from one pole may be taken as the number lying immediately under the pole-face, *plus* one or two, depending upon the allowance for fringing.** The magnetic area of the teeth will, therefore, be the number so determined, *multiplied by* the product of the mean width of one tooth and the mean length of the armature, where the latter is the gross length *minus* the percentage allowed for insulation and air-ducts. Account must also be taken of the fact that when the teeth are operated at densities of 100,000 lines per square inch or more, part of the flux from the poles will take the alternative air paths through the slots to the armature core, since at this high density their permeance is not insignificant compared with that of the teeth themselves. In other words, the ampere-turns calculated to force the flux through the teeth alone at high flux-densities would be in excess of the correct amount.

An equation from which the actual flux-density in the teeth can be calculated if the apparent density is known, is

$$\text{Actual flux-density in teeth} = B_t = B_a \left( \frac{\alpha\, b_t\, \mu}{b_t + b_s - \alpha\, b_t + \alpha\, b_t \mu} \right)^{\dagger\dagger} \qquad (17)$$

*See page 60 for reason for laminating and insulating core-disks.

†The "internal hole" is that portion of the armature between the center and inner edge of the core.

**"Fringing" means spreading of flux issuing from a pole-shoe.

††"Dynamo-Electric Machinery," S. P. Thompson, page 146.

**Example of Calculation.** In order that the foregoing rules may be clearly understood, and to exemplify the use of the curves and the method of calculation, we shall take a concrete case of dynamo design. In Fig. 99 is given a dimensioned sketch of a modern six-pole continuous-current generator having a capacity of about 200 kw.

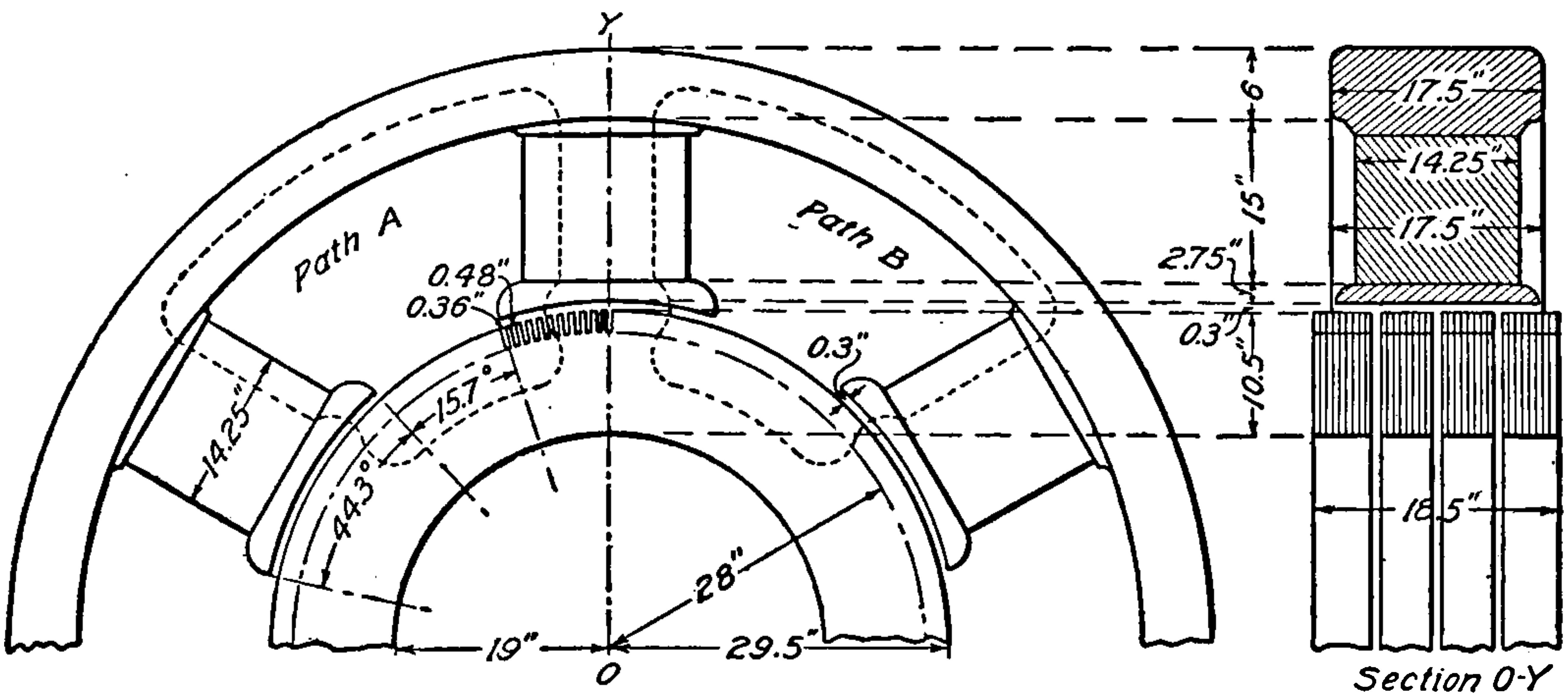



Fig. 99. Part of Magnetic Circuit of a Six-Pole Machine

Assuming that 12,500,000 lines are required to produce the rated e. m. f. in the armature, let us determine the ampere-turns required per pair of poles to produce this flux in the armature. Taking a mean value for the dispersion coefficient from Table III, we have $\nu = 1.18$ approximately, and the data of the magnetic circuit around path *A* or path *B* is found in Table V.

**TABLE V**

**Magnetic Flux in Armature Parts**

| PART | MATERIAL | TOTAL FLUX |
|---|---|---|
| Yoke | Cast steel | 7,375,000 |
| Pole-cores | Cast steel | 14,750,000 |
| Pole-shoes | Cast steel | 14,750,000 |
| Air gap | Air | 12,500,000 |
| Armature teeth | Sheet steel | 12,500,000 |
| Armature core | Sheet steel | 6,250,000 |

We now estimate the magnetic lengths and areas as follows:

*Yoke.* From Table IV, we assume a flux-density of 80,000, hence, the cross-section of the yoke is

$$7{,}375{,}000 \div 80{,}000 = \text{approximately } 92 \text{ sq. in.} = A_y$$

Consequently the dimensions of the yoke would be, say 5.5 inches by 17.5 inches to allow for rounded corners, making the actual flux-density in the yoke

$$\mathbf{B}_y = 7{,}375{,}000 \div 92 = 80{,}200 \text{ lines per sq. in.}$$

The length of magnetic path, scaled off from the drawing, is

$$l_y = 48 \text{ in.}$$

*Magnet-Cores.* Assuming, from Table IV, the flux-density as 90,000 lines per square inch, we have as the required area of cross-section of the magnet-cores

$$14{,}750{,}000 \div 90{,}000 = 163.9 \text{ sq. in.}$$

Selecting a circular section for the pole-cores, let us assume a diameter of, say 14.25 inches, as giving an area of cross-section nearest to that above computed. This gives

$$A_p = 159.5 \text{ sq. in.}$$

and

$$\mathbf{B}_p = \frac{14{,}750{,}000}{159.5} = 92{,}500 \text{ lines per sq. in.}$$

The length of magnetic path in the pole-cores is twice the length of one; so that

$$l_m = 2 \times 15 = 30 \text{ in.}$$

*Pole-Shoes.* These are cast-steel extensions affixed to the magnet-cores to increase the air-gap area. The mean area of each shoe is the average of the upper and lower faces.

$$\text{Area of upper face} = 159.5 \text{ sq. in.}$$

The circumference of the armature being $2\pi \times 29.5$, the polar embrace 44.3°, and the width of the pole-shoe 17.5 inches, then the lower polar-face area is

$$2\pi \times 29.5 \times \frac{44.3^\circ}{360^\circ} \times 17.5 = 402.9 \text{ sq. in.}$$

$$A_s = \frac{159.5 + 402.9}{2} = 281.2 \text{ sq. in.}$$

so that

$$B_s = \frac{14,750,000}{281.2} = 52,400 \text{ lines per sq. in.}$$

The mean length of magnetic path per shoe is 2.75 inches. Hence, we have

$$l_s = 2 \times 2.75 = 5.5 \text{ in.}$$

*Air Gaps.* The magnetic area of the air gap is the average of the areas of the polar face and of the effective tooth surface below the same.

$$\text{Polar-face area} = 402.9 \text{ sq. in.}$$

As there are 220 teeth upon the armature core, there will be $220 \times \frac{44.3°}{360°} = 27$ teeth under each pole. With fringing correction this becomes 28 teeth. The width of each tooth on top is 0.36 inch, and as 75 per cent of the 18.5 inch gross length of the armature core is effective, we have as the area of the teeth below the polar face

$$28 \times 0.36 \times 18.5 \times .75 = 139.8 \text{ sq. in.}$$

Hence, the effective air-gap area is

$$\frac{402.9 + 139.8}{2} = 271.4 \text{ sq. in.}$$

Then

$$B_g = 12,500,000 \div 271.4 = 46,100 \text{ lines per sq. in.}$$

The magnetic length through air in path *A* or *B* is twice the length of an air gap, that is

$$l_g = 2 \times 0.3 \text{ in.} = 0.6 \text{ in.}$$

*Armature Teeth.* The iron area of the 28 teeth acted upon by one pole, if the mean width of one tooth is 0.34, becomes

$$A_t = 0.34 \times 28 \times 18.5 \times 0.75 = 132.1 \text{ sq. in.}$$

Therefore

$$B_t = \frac{12,500,000}{132.1} = 94,600 \text{ "apparent" lines per sq. in.}$$

Since the flux-density is below 100,000 lines in this case, we can

By reference to the magnetization curves, Fig. 100, the ampere-turns per inch of length for the various materials at the flux-densities determined may be found, and the ampere-turns for total length of path computed. The results are tabulated in Table VII.

**Coil Winding Calculations.** In series field-coils the whole of the external current, or a definite part of it, is used for the production of a m. m. f., so that the number of turns of wire or strip is found by dividing the requisite number of ampere-turns at any given load by this current. Furthermore, this wire or conductor must be of sufficient size to carry the given current safely, efficiently, and without overheating.

If the machine were to be separately excited, it is probable

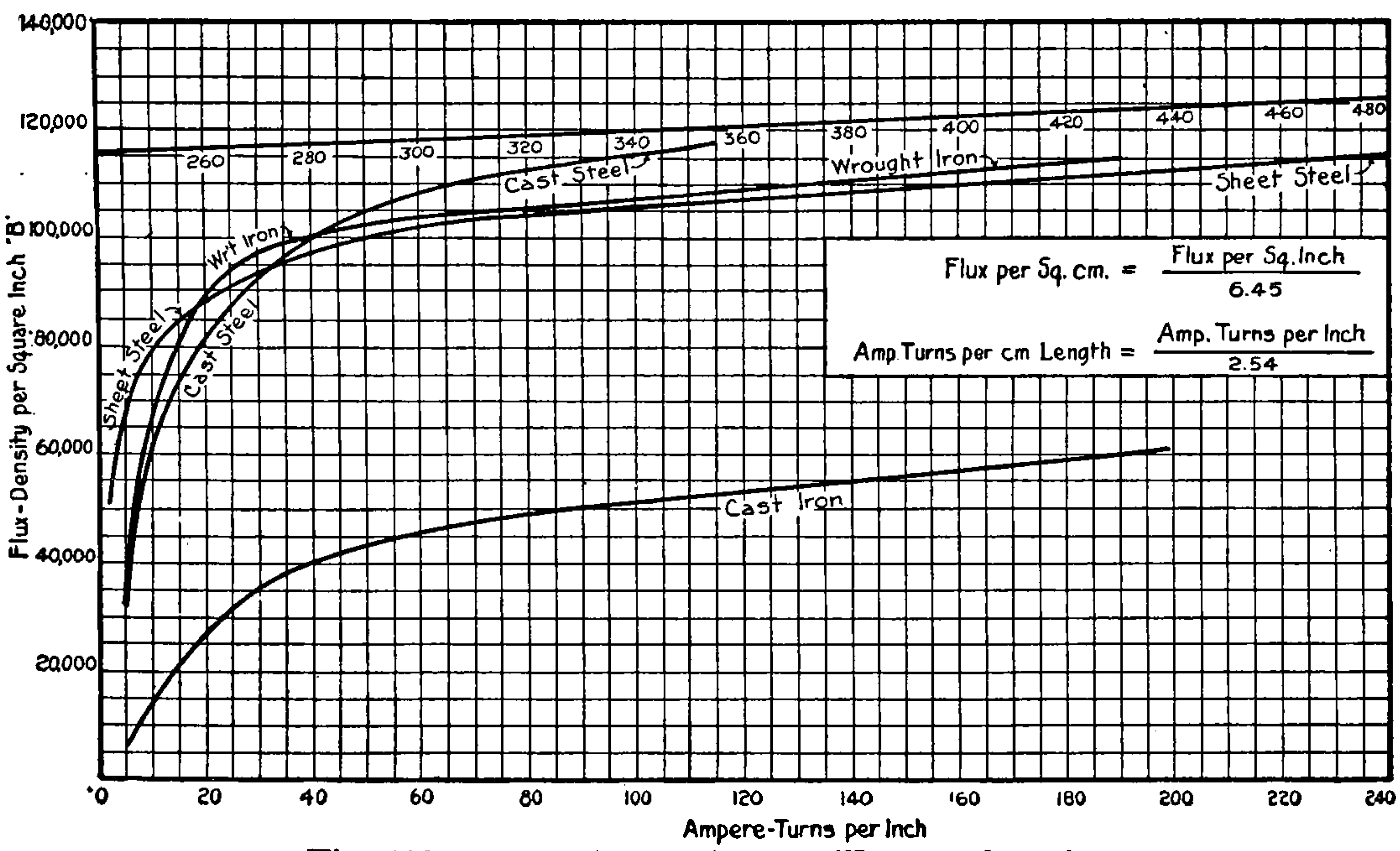
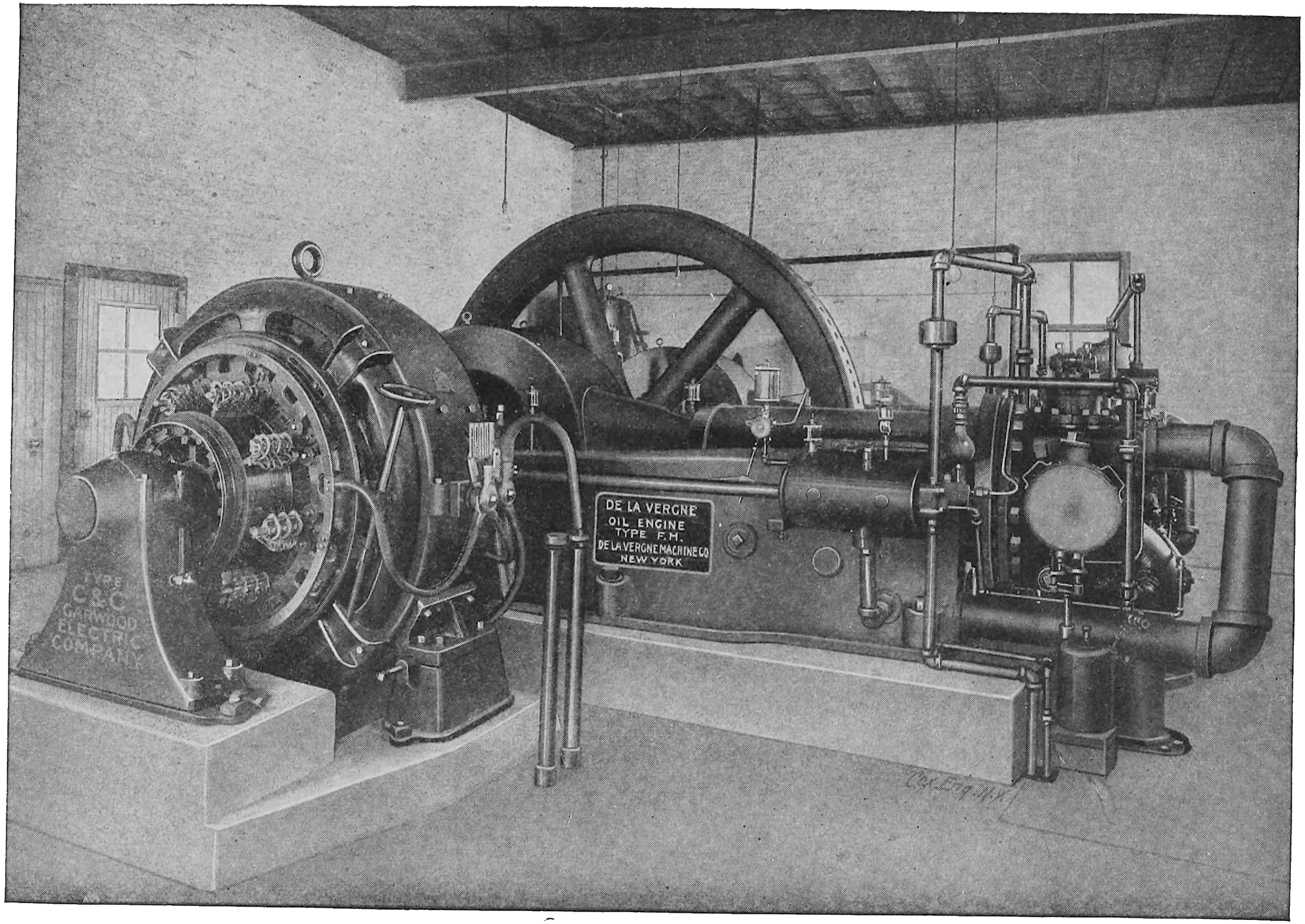



Fig. 100. Magnetization Curves of Irons and Steels

that the e. m. f. of the exciter would be specified, and we should have practically the shunt case. If, however, the current were given, the determination would be the same as in the case of the series winding above.

**Shunt Winding Calculations.** The determination of the best size of wire for a shunt winding is far more difficult than for a series one, in that merely the ampere-turns and the voltage applied to the terminals of the coil are given, while the space allotted to the winding and the heating limits must be kept within definite bounds. Various methods have been suggested, but none are very satisfactory. One




INSTALLATION OF 170 HORSEPOWER De La VERGNE OIL ENGINE DIRECT CONNECTED TO GARWOOD GENERATOR FOR HEEDEN IRON WORKS

*Courtesy of De La Vergne Machine Company*

In applying the above formula to the shunt winding for a dynamo, allowance must be made for the resistance of the rheostat which is usually put in the shunt circuit to regulate the e. m. f. This resistance will consume from 20 to 30 per cent of the no-load voltage, and the value of $V''$ to be substituted in the formula should, therefore, be a corresponding amount lower, unless the rated load voltage be used. In this case the resistance of the rheostat is determined by the resistance which it is necessary to add to that of the field-winding in order to keep the generated e. m. f. at the proper point for all other loads.

**Space-Factor.** In all cases where insulated conductors, whether strip or wire, are used, the space taken up by the conductor proper is always a fraction of the whole space occupied by the entire winding. This fraction will obviously depend upon the shapes of the conductors and the space set apart for the winding, and also upon

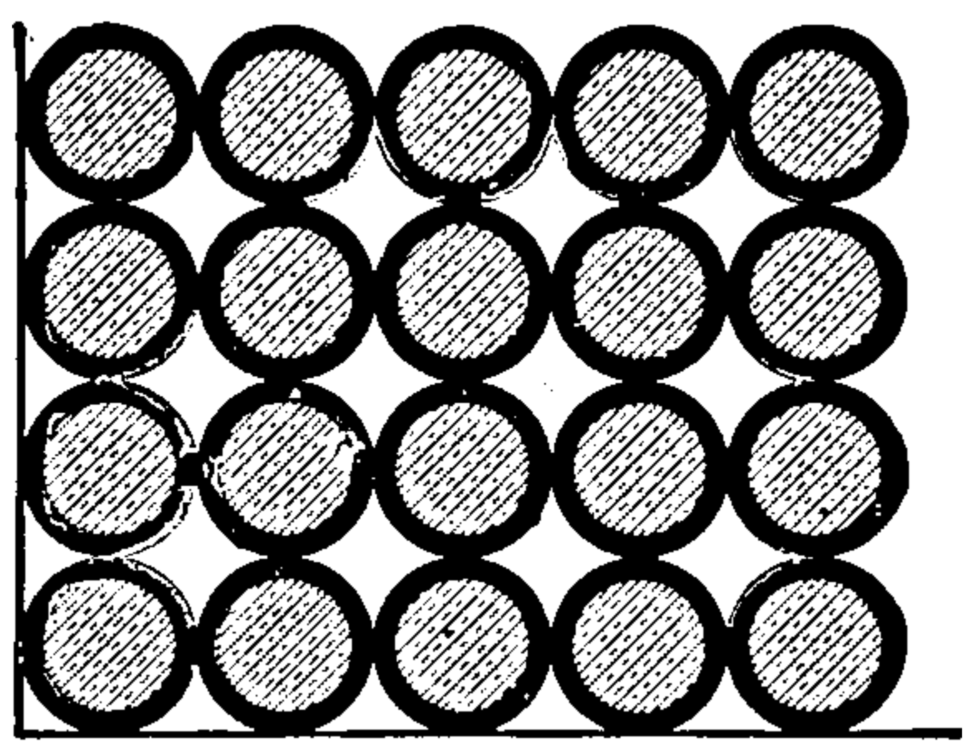


Fig. 101. Square Order of Bedding

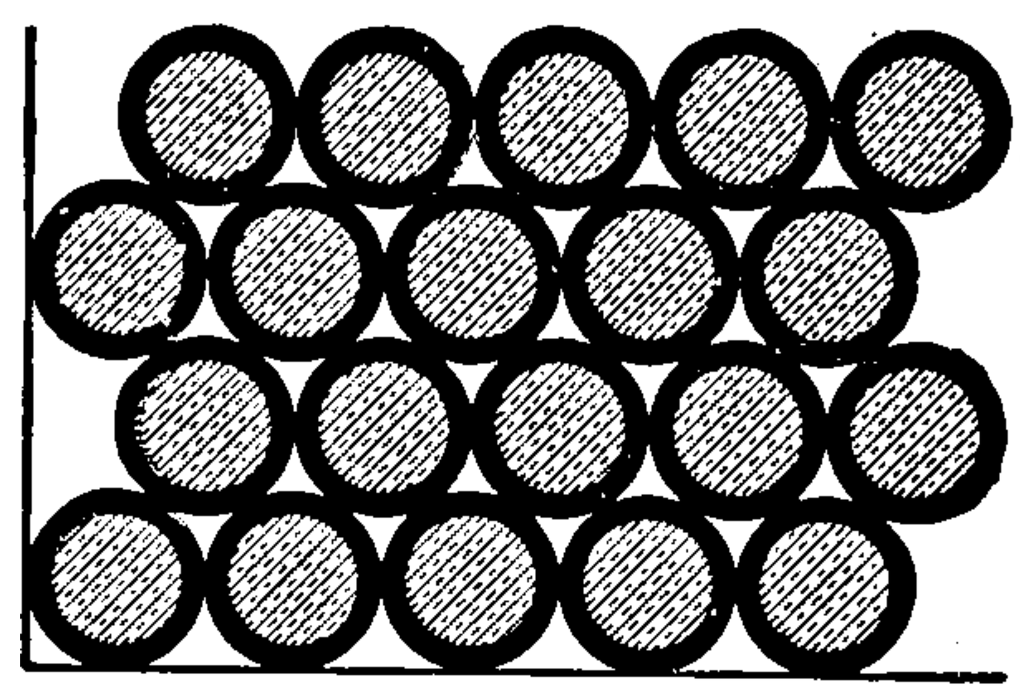


Fig. 102. Hexagonal Order of Bedding

the thickness of the insulation. The ratio of net cross-sectional area of copper in any such space to the gross section, is called the *space-factor*.

In winding bobbins for field-magnet coils, the space-factor depends largely upon whether square or round wire is used. If the former, the space wasted is less, and the heating of the coil is reduced —for a given number of turns carrying a given current, etc.—since there is less cross-section filled with air or insulation, either of which is a bad conductor of heat. If round wires are used, as is generally the practice, the space-factor will be determined chiefly by the ratio between the relative thicknesses of the wire and its insulation, and also by the partial bedding of one layer of wires between those of the layer below.

Suppose the round wires to be wound so as to lie in the square order without any bedding, as in Fig. 101. Then, if the diameter of the bare wire is $d$, and the insulated diameter is $d_1$, the ideal space-factor would be

$$S = 0.7854 \frac{d^2}{d^2_1} \qquad (20)$$

because the area of each small circle is $\pi \frac{d^2}{4} = 0.7854\ d^2$, and the area of the small square enclosing each outer circle is $d^2_1$. Suppose,

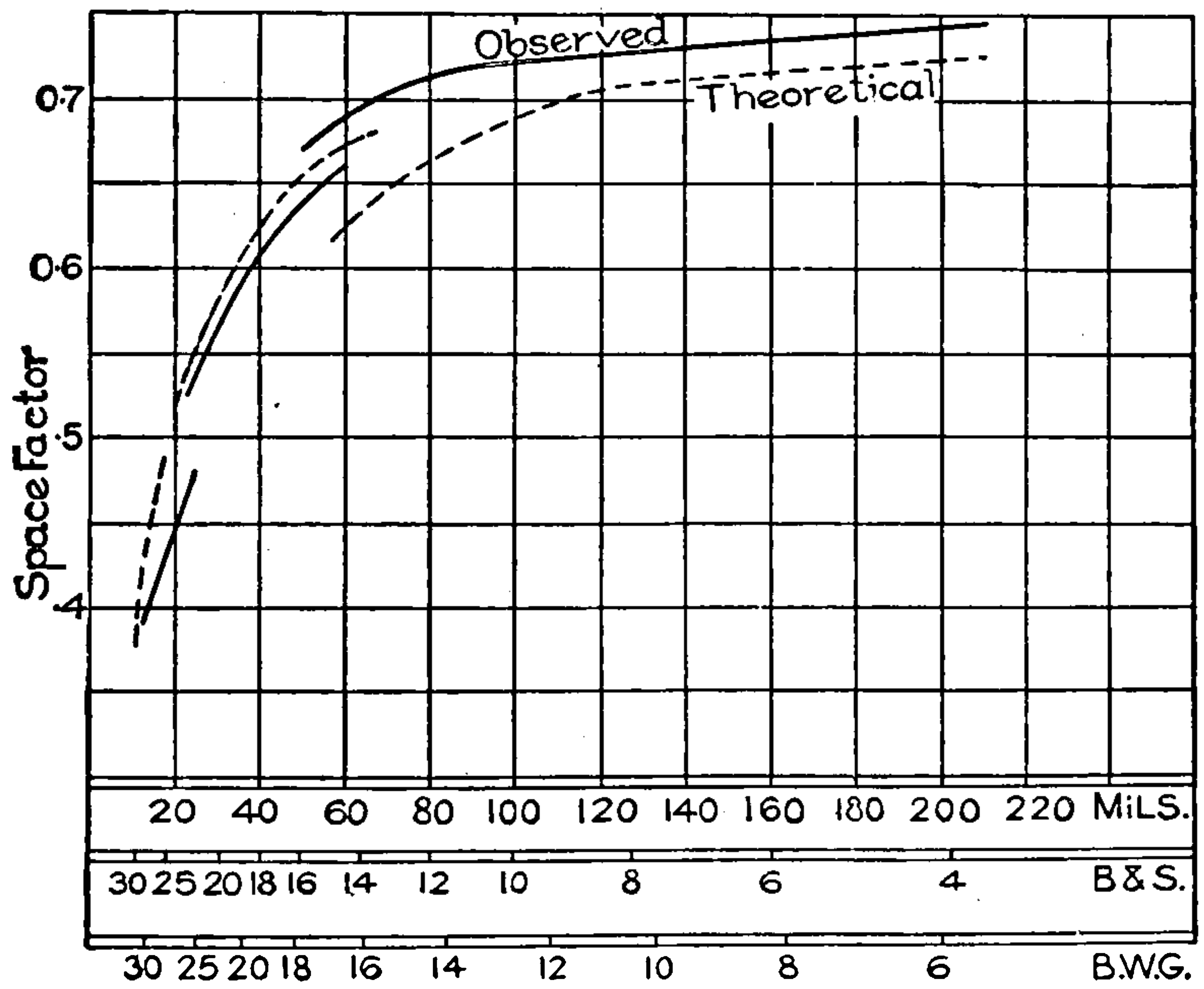



Fig. 103. Curves Showing Space-Factors for Round Wires of Various Gauges

however, an extreme case of bedding, as in Fig. 102, where the wires lie in hexagonal order. By similar reasoning, the space-factor would then be

$$S = 0.906 \frac{d^2}{d^2_1} \qquad (21)$$

If rectangular strip is used, there is no bedding, and no wasted space except where the end of one layer of a coil extends to the layer above. If the area of cross-section of the bare conductor is $ab$, and the area of the same, insulated, is $a'\ b'$, the space-factor is simply $ab \div a'\ b'$. In practice it has been found that edge-wound strip gives the highest space-factor, ranging from 0.83 to 0.93.

In practice, with round wires, it is found, however, that even the most experienced winders produce a bedding of seldom over 3 per cent; so that the safest course is to assume no bedding, and to take the space-factor as given above unless it is actually known.

Some actual figures have been put into graphical form by Dr. S. S. Wheeler, and these are given in Fig. 103. Here the broken lines represent the values by the formula assuming the square order; and the full lines, the observed values. It is seen that the larger sizes of wire do actually bed a little, while with smaller sizes the bedding is negative.

**Connections of Exciting Coils.** It is the almost invariable custom to connect all the field-magnet exciting coils of the same type in series with each other, so that the magnetizing current is the same throughout. Then, if the number of turns per spool is the same, the flux per pole will be uniform. They must also be connected up so as to produce alternate north and south poles, so that if all the coils are wound in the same direction, and similarly placed, the connections

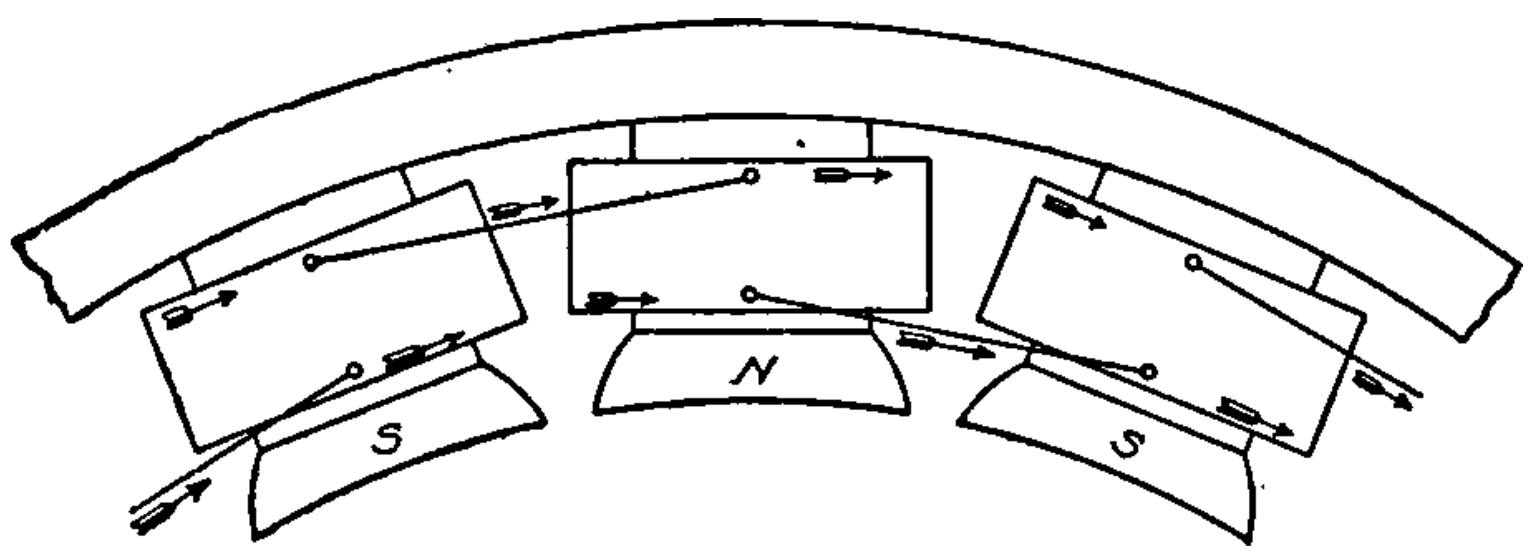



Fig. 104. Connections of Field-Magnet Coils

will come alternately at the yoke-end and the pole-face end of the bobbin, as in Fig. 104. Particular methods of winding field coils are shown in detail on pages 163—167.

**Excitation Losses.** Having computed the resistance of the shunt winding $r_{sh}$ by the previously explained method, we have $\frac{V}{r_{sh}} \times V = \frac{V^2}{r_{sh}}$ as the watts actually expended in the shunt field-coils, $V$ being the terminal voltage of the generator. To this loss must be added the one in the shunt-regulating resistance, and also the loss in the series-regulating coils, if any, in order to give the total watts required in excitation. For shunt-wound machines, the watts required in excitation vary in practice from 1 to 8 per cent or more of the output, depending upon the capacity of the machine. As a guide in this direction, Table VIII has been constructed, giving the *maximum permissible* excitation losses.

**Heating of Magnet-Coils.** The heat developed in field-magnet coils is dissipated in two ways: It is either carried by conduction through the copper and the insulation, and then by radiation and

## TABLE IX

**Specific Temperature Increase in Magnet-Coils of Various Proportions at Unit Energy Loss per Sq. In. of Core Surface**

| CYLINDRICAL MAGNETS | | | | | | | | RECTANGULAR AND OVAL MAGNETS | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Increase of Magnet Temperature for Each Watt per Square Inch of Core Surface — Radiating Surface Consisting of | | | | |
| Ratio of Winding Depth to Core Diameter | Winding Depth in Parts of Core Diameter | Ratio of External Coil Surface to Core Surface | Ratio of Cylindrical Surface plus One End Surface of Coil to Core Surface | Ratio of Cylindrical Surface and Both End Surfaces of Coil to Core Surface | Cylindrical Coil Surface | Cylindrical Surface plus One End Surface | Cylindrical Surface and Both End Flanges | Ratio of Radiating Surface to Core Surface | Temperature Increase for Unit Energy Dissipation |
| 1 : 100 | .01 | 1.02 | 1.03 to 1.05 | 1.04 to 1.07 | 75° | 74° to 72° | 73° to 71° | 1.02 | 75° |
| 1 : 50 | .02 | 1.04 | 1.05 " 1.10 | 1.07 " 1.12 | 73 | 72 " 69 | 71 " 68 | 1.05 | 72 |
| 1 : 30 | .033 | 1.067 | 1.07 " 1.15 | 1.10 " 1.20 | 71 | 70 " 65 | 69 " 63 | 1.1 | 69 |
| 1 : 20 | .05 | 1.1 | 1.12 " 1.20 | 1.15 " 1.30 | 69 | 68 " 63 | 65 " 58 | 1.25 | 60 |
| 1 : 15 | .067 | 1.133 | 1.15 " 1.25 | 1.20 " 1.40 | 67 | 65 " 60 | 63 " 53.5 | 1.5 | 50 |
| 1 : 12 | .083 | 1.167 | 1.20 " 1.30 | 1.25 " 1.45 | 65 | 63 " 58 | 60 " 51.5 | 1.75 | 43 |
| 1 : 10 | .1 | 1.2 | 1.25 " 1.40 | 1.30 " 1.55 | 63 | 60 " 53.5 | 58 " 48 | 2 | 37.5 |
| 1 : 9 | .11 | 1.22 | 1.28 " 1.45 | 1.35 " 1.60 | 61.5 | 59 " 51.5 | 55.5 " 47 | 2.25 | 33 |
| 1 : 8 | .125 | 1.25 | 1.30 " 1.50 | 1.40 " 1.70 | 60 | 58 " 50 | 53.5 " 44 | 2.5 | 30 |
| 1 : 7 | .143 | 1.286 | 1.35 " 1.55 | 1.45 " 1.80 | 58.5 | 55.5 " 48.5 | 51.5 " 41.5 | 3 | 25 |
| 1 : 6 | .167 | 1.33 | 1.40 " 1.60 | 1.50 " 1.90 | 56.5 | 53.5 " 39.5 | 50 " 39.5 | 3.5 | 21.5 |
| 1 : 5 | .2 | 1.4 | 1.50 " 1.75 | 1.60 " 2 | 53.5 | 50 " 43 | 47 " 37.5 | 4 | 19 |
| 1 : 4 | .25 | 1.5 | 1.65 " 2 | 1.80 " 2.5 | 50 | 45.5 " 37.5 | 41.5 " 30 | 5 | 15 |
| 1 : 3 | .33 | 1.67 | 1.85 " 2.5 | 2 " 3 | 45 | 40.5 " 30 | 37.5 " 25 | 6 | 12.5 |
| 1 : 2 | .5 | 2 | 2.25 " 3 | 2.5 " 4 | 37.5 | 33 " 19 | 30 " 19 | 8 | 9.5 |
| 1 : 1 | 1 | 3 | 3.5 " 5.5 | 4 " 8 | 25 | 21.5 " 13.5 | 19 " 9.5 | 10 | 7.5 |
| 3 : 2 | 1.5 | 4 | 5 " 8.5 | 6 " 12 | 19 | 15 " 9 | 12.5 " 6 | 12 | 6 |
| 2 : 1 | 2 | 5 | 6.5 " 12 | 8 " 18 | 15 | 11.5 " 6 | 9.5 " 4 | 15 | 5 |

Experience has shown that a certain rise in temperature is allowable, this being usually put at 50° C. or 90° F. above the temperature of the surrounding air. Tests have also demonstrated that this rise in temperature is not usually exceeded if a certain surface of coil is allowed for each watt converted into heat. The difficulty in fixing this is due to the way in which the heat is dissipated, as before noted. Also, authorities differ in regard to what surface shall be considered as radiating, in some cases going so far as to count only the external cylindrical surface of the coil. As a matter of fact, the internal surface of the coil, next to the poles, usually dissipates more heat in a given time than the external surface, so that the total area should be reckoned. This may be done by assuming a proper value of $h$, which, according to W. B. Esson, is about 55, and, according to Esterline, 83, for ordinary bobbins; or by relying upon the experimental results given in Table IX. Esson, in using this figure, counts as radiating surface only the external heat-radiating area and not the end flanges and internal surfaces. Esterline includes in the radiating surface the external and internal areas and the flanges, counting the last two as radiating only one-half as much as a corresponding external area.

## ARMATURE WINDINGS

We have seen in equation (12) the relations existing between the number of armature inductors ($Z$) and the other factors, such as speed (r. p. m.), field strength ($\Phi$), and voltage ($E$), and, although the number of inductors may be varied, the designer will always follow certain methods in placing these upon the armature core.

These *inductors*—or *conductors*, as they are sometimes called—are almost universally made of copper. Their arrangement upon the armature, and the order in which they are connected together to form a complete winding, constitute one of the most involved subjects in the design of dynamo-electric machinery.

**Classification.** Armature windings may be classified according to the way the inductors are placed upon the armature core, as follows:

*Ring Windings* are those in which the inductors are wound upon a ring-shaped core, passing around the ring in the form of a helix.

*Drum Windings* are those having the inductors placed entirely upon the surface, or in slots upon the surface, of a cylindrical core.

*Disk Windings* are those where the conductors are arranged in a plane like the spokes of a wheel, the end connections being similar to those of drum armatures.

*Pole Windings* are those in which the conductors are wound around radial iron cores projecting outward from a central hub.

Of all these types, the drum is almost exclusively used at the present time for the armature windings of continuous-current machines, since, in contradistinction to the ring winding, there are no internal return conductors to increase the amount of armature copper needed, and for the greater reason that formed coils are applicable, greatly reducing the first cost and facilitating insulation and repairs.

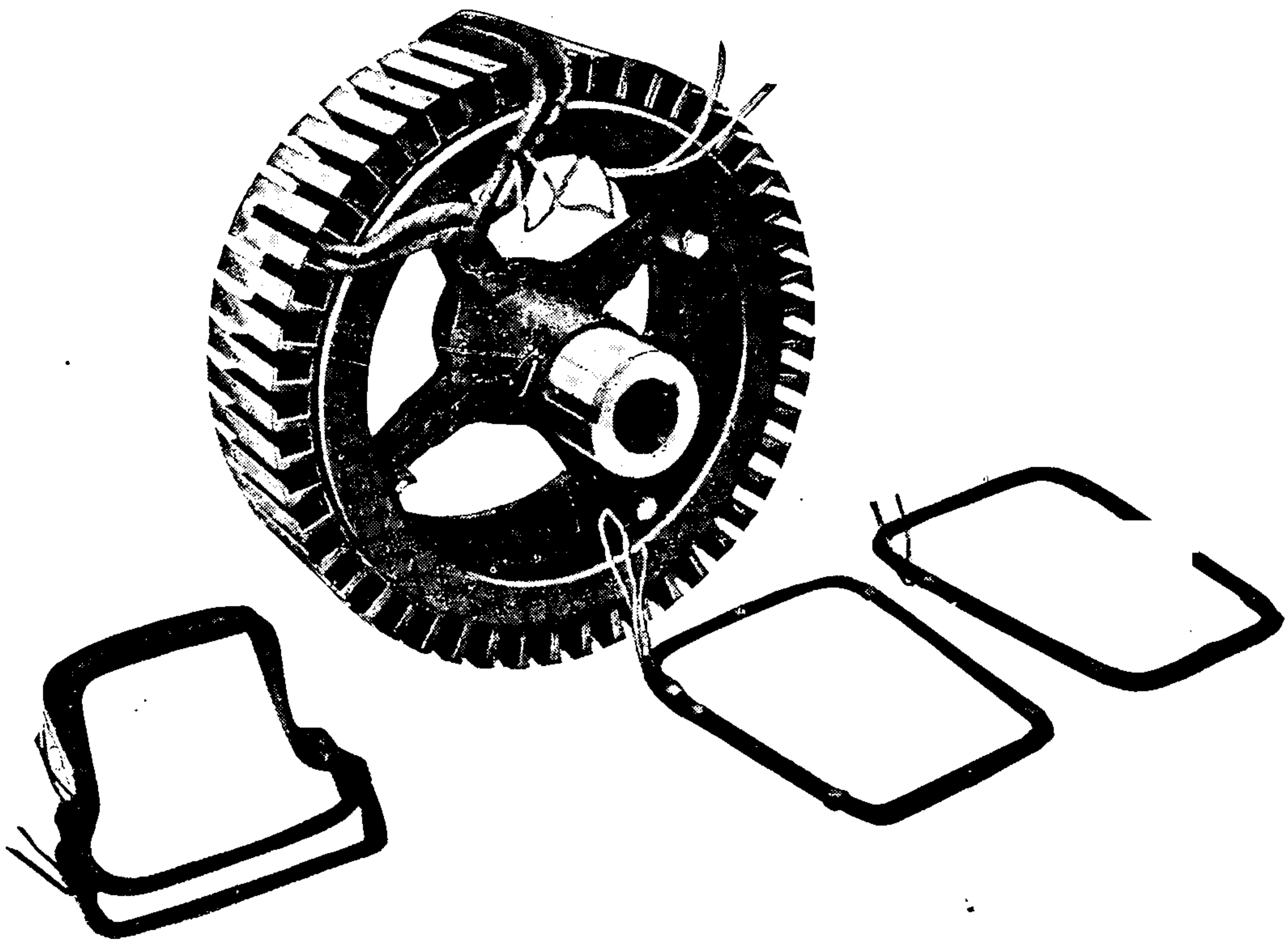


Fig. 105. Showing Method of Winding and Applying Formed Coils for an Armature Core

A drum armature partly wound with formed coils is illustrated in Fig. 105. Disk and pole armatures are almost never used in modern machines, and no further attention will be paid to them.

Besides this grouping, we may also divide windings into *closed-coil* and *open-coil* types, depending upon whether the winding constitutes a closed or an open circuit. Closed-coil armatures are in almost general use for direct-current machines, since they give a steadier current and spark considerably less at the collecting brushes than the open-coil types. The latter are used for direct-current arc-lighting machines and for star-wound alternators.

Similarly, the resistance of an element may be reduced by connecting several conductors in parallel, Fig. 110; but this also does not affect the end connections of the coil as an element of winding; it merely increases the current-carrying capacity. In either case the *method* of winding is not altered by putting more turns of wire in series or in parallel in each section.

The whole theory of armature winding may, therefore, be said to resolve itself into a study of end connections; and in discussing drum windings, we shall consider an element consisting of two armature conductors with their end connections only.

**Possible Number of Commutator Bars.** We have seen that at each end of a section of winding there is a commutator bar. In the simplest form of ring-wound armature, each element of the winding contains only one armature conductor, so that $K$, for maximum number of commutator bars, is equal to $Z$, the total number of armature inductors upon the core, the rest of each element being equivalent to an end connection. The number of commutator bars in a ring winding may also be less than $Z$; but in any case it is $Z \div f$ where $f$ is 1 or an integer factor of $Z$.

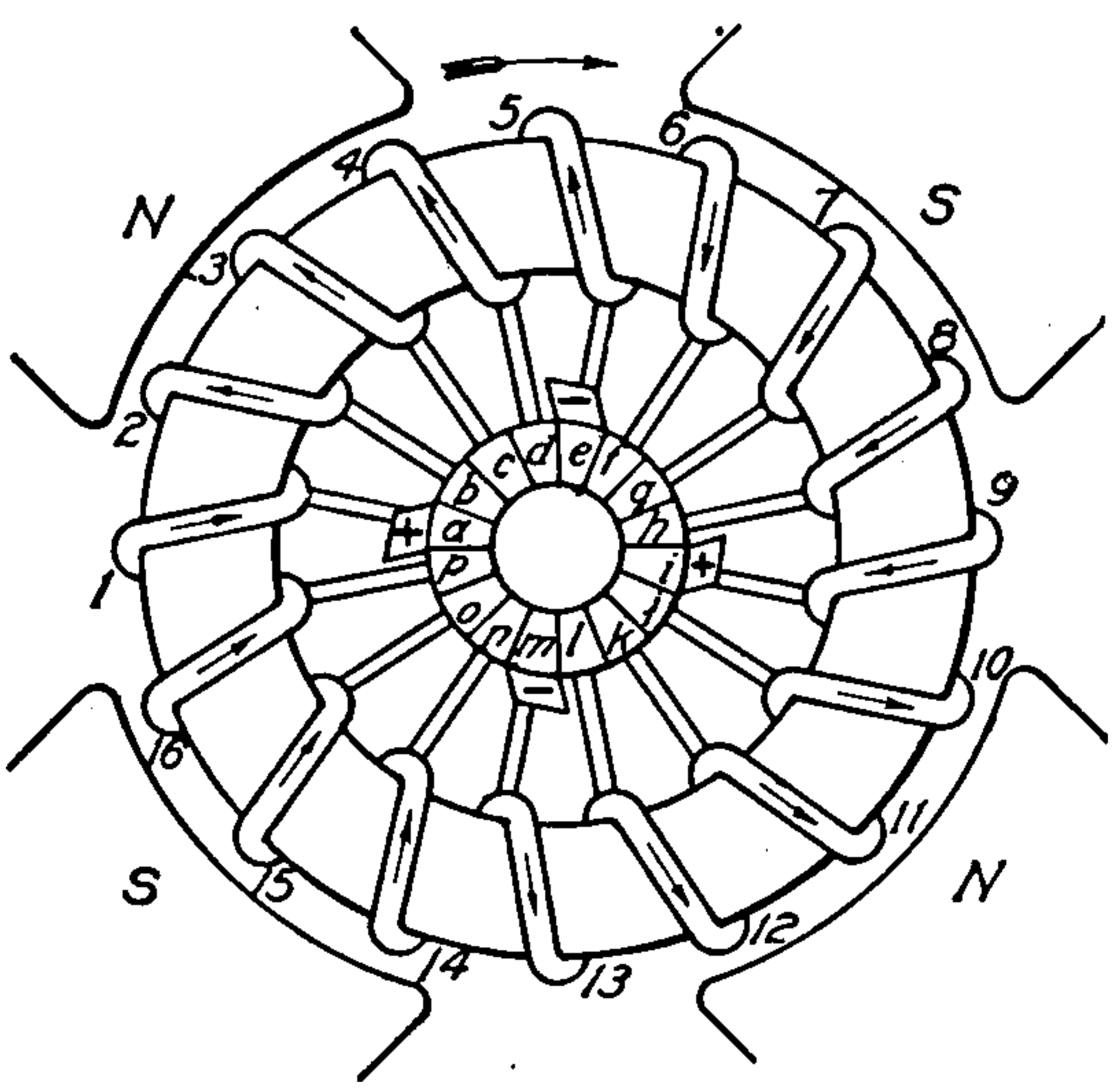



Fig. 111. Ring Winding for 4-Pole Machine

In closed-coil drum windings, $K$, the number of commutator bars, has for its maximum value $Z \div 2$, and it may be $Z \div 2f$.

**Pitch.** The distance between the beginning of one winding element and the beginning of the next element connected to the first one is called the *winding space*, or simply *pitch*. This pitch may either be measured by the number of inductors passed over or by the number of commutator bars passed. In the former case it is designated as *winding pitch*, $y$, while in the latter case it is called *commutator pitch*, $y_k$. Figs. 113 and 114 will make this clear.

**Ring Windings.** Ring windings may be divided into two classes: the *spirally-wound* ring, and the *series-connected wave-wound* ring.

The first type, shown in Figs. 111 and 112, forming in itself a single closed helix, is unaffected by the number of poles ($2p$); by merely placing $2p$ sets of brushes on the surface of the commutator at equal distances apart, the winding is at once divided into as many equal and symmetrical paths through the armature, and we have $c = 2p$. A multipolar armature is thus obtained, having as many parallel circuits and as many points of collection of the current as there are poles. The equation of the e. m. f. of such a *multipolar parallel-wound* or *multiple-circuit* armature is similar to that for a bipolar machine, that is

$$E = \frac{2p \times \Phi \times Z \times \text{r.p.m.}}{c \times 10^8 \times 60} = \frac{\Phi \times Z \times \text{r.p.m.}}{10^8 \times 60}$$

since $c = 2p$. This multipolar winding has greater current-carrying capacity than the bipolar, since there are more paths in parallel. The

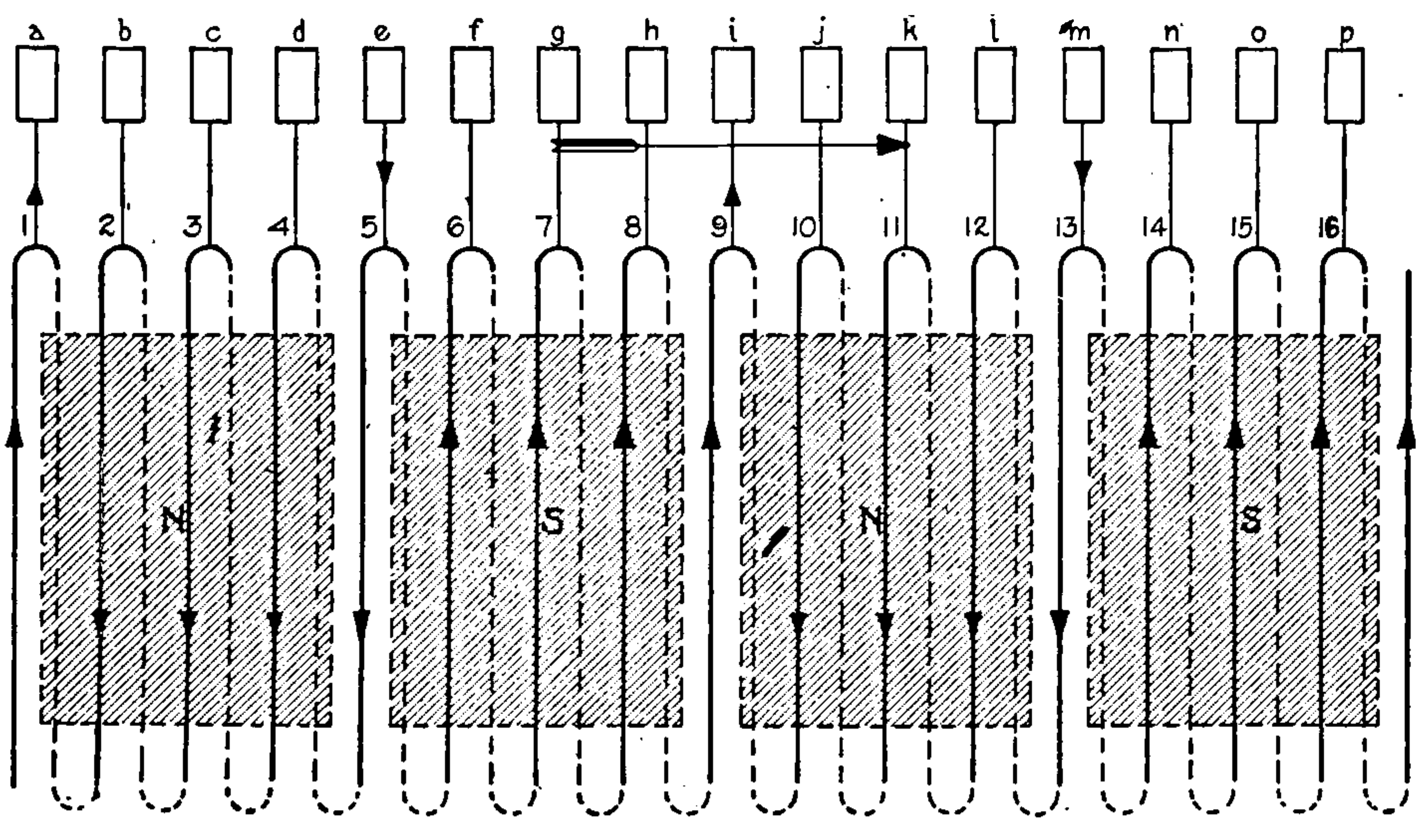



Fig. 112. Development of Ring Winding for 4-Pole Machine

multipolar winding is, therefore, equivalent to several bipolar dynamos in parallel, just as the bipolar machine was shown to be equivalent to two sets of cells in parallel, Fig. 48, Part I. In the cases just considered the winding and commutator pitches are both 1, or $y = y_k = 1$.

In Fig. 113 is shown a series-connected wave-wound ring armature. If we start at commutator bar *1*, and trace the circuit, it will be seen that it leads through coil *1*, commutator bar *9;* coil *8*, bar *2;*

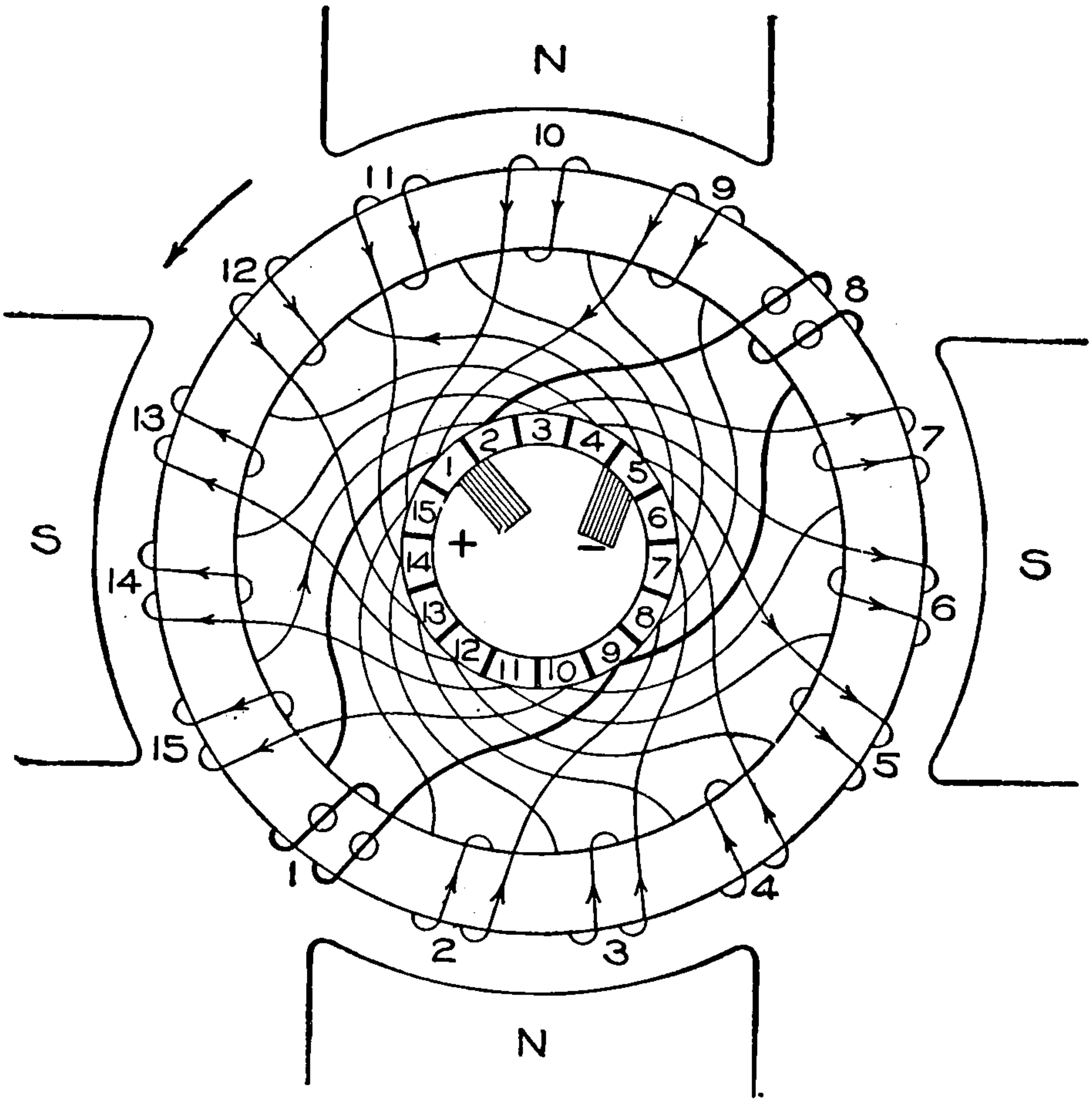



Fig. 113. Series-Connected Wave-Wound Ring Armature

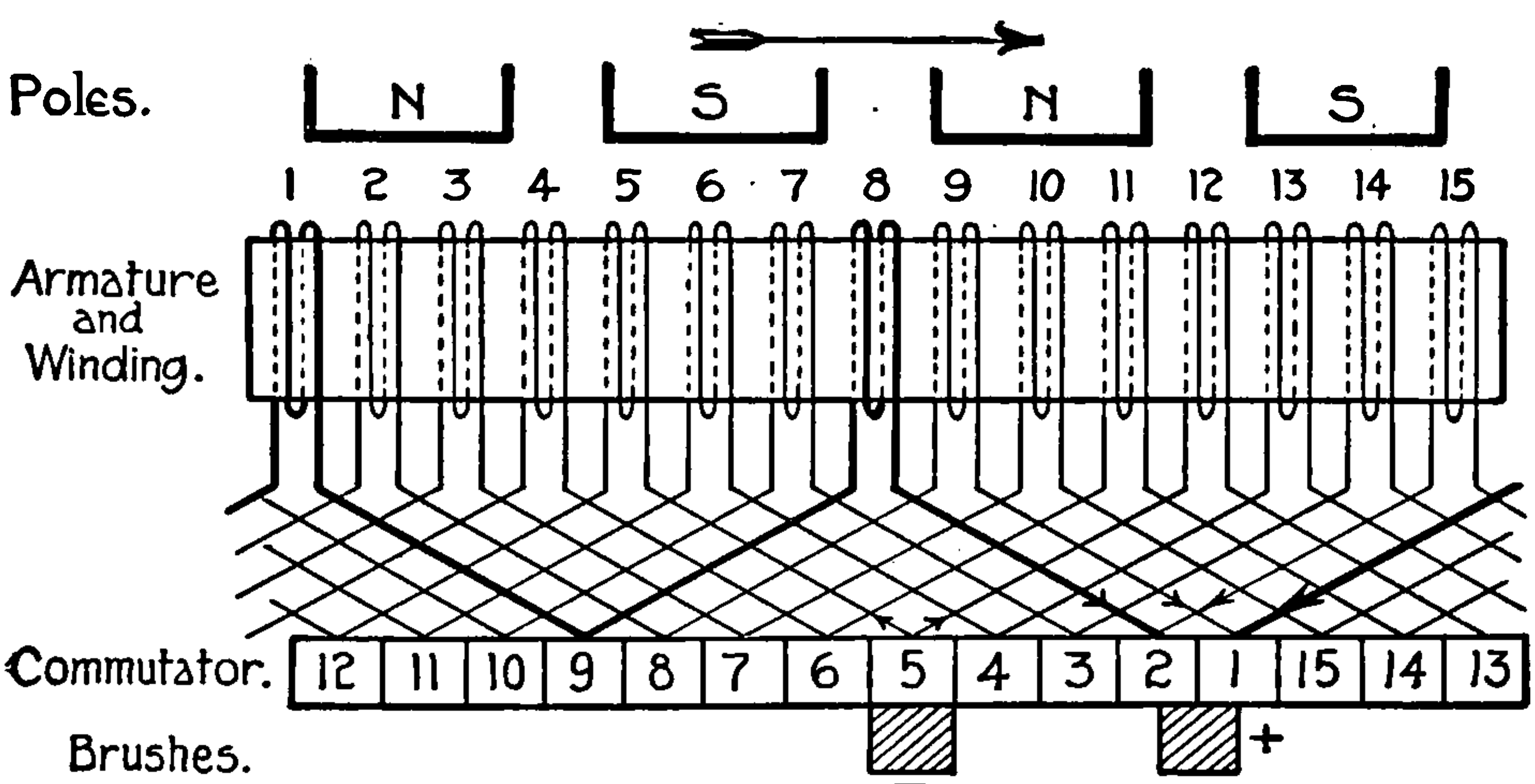



Fig. 114. Development of Winding Shown in Fig. 113

coil *15,* bar *10;* etc. The two circuits through the armature are then as follows:

Coils *5 – 13 – 6 – 14 – 7 – 15*

– Brush on bar *5*     Coils *1 – 8*     + Brush on bars *1–2*

Coils *12–4–11–3–10–2–9*

Coils *1* and *8* (drawn heavy) are short-circuited and, for the instant shown, theoretically carry no current. Upon close examination of Figs. 113 and 114 it will be seen that coils 5, 6, 7, 13, 14, and 15 are all under south poles, while the other ones are directly under north poles. The winding thus connects half of the armature sections in series and the two halves in parallel, and only two brushes are required. Another way of obtaining the same result is illustrated by Figs. 115 and 116; here each end of every section is connected to a separate commutator bar and the bars connected to put the coils in series, as in the preceding example.

Referring again to Fig. 113, we see that proceeding in a clockwise direction the winding pitch is *14,* while the commutator pitch is *7.* If there had been only one inductor per section, the winding pitch would have been *7,* the same as the commutator pitch. The winding pitch is *16* and the commutator pitch *16* in Fig. 115 (proceeding in a counter clockwise direction), there being two commutator bars per section or one per inductor.

The general winding formula for series wave ring windings for any number of poles is $y = (Z \pm c) \div p;$ wherein $y$ is the winding pitch, $Z$ the number of inductors, $c$ the paths in parallel, and $p$ the pairs of poles.

In Fig. 113, $Z = 30,$ $c = 2,$ and $p = 2,$ therefore, $y$ can be either *14* or *16.* The value $y = 14$ has been chosen. The only precaution in determining the pitch for wave-wound series-connected ring windings is that all the conductors joined together must cut flux under poles of like sign.

*Multipolar Parallel-Connected Ring Windings.* In a bipolar machine, there are two points on the commutator where the e. m. f. is zero, *i. e.,* where proper commutation may occur, so there will be $2p$ points in a multipolar parallel-connected ring winding where the current is commutated, and $2p$ brushes will be needed. If, however, the increased number of points of collection be regarded as a disadvantage, they may again be reduced to two, by joining all commutator bars which are situated $360 \div p$ degrees apart, so that sectors which are at any moment in the same polar position and, therefore, at the same voltage, are connected together. These connections are termed equipotential or cross-connections. Thus, in a four-pole machine, each commutator bar must be connected to that diametrically opposite, and there is a choice between two positions for the brushes at right angles to one another. In a six-pole machine

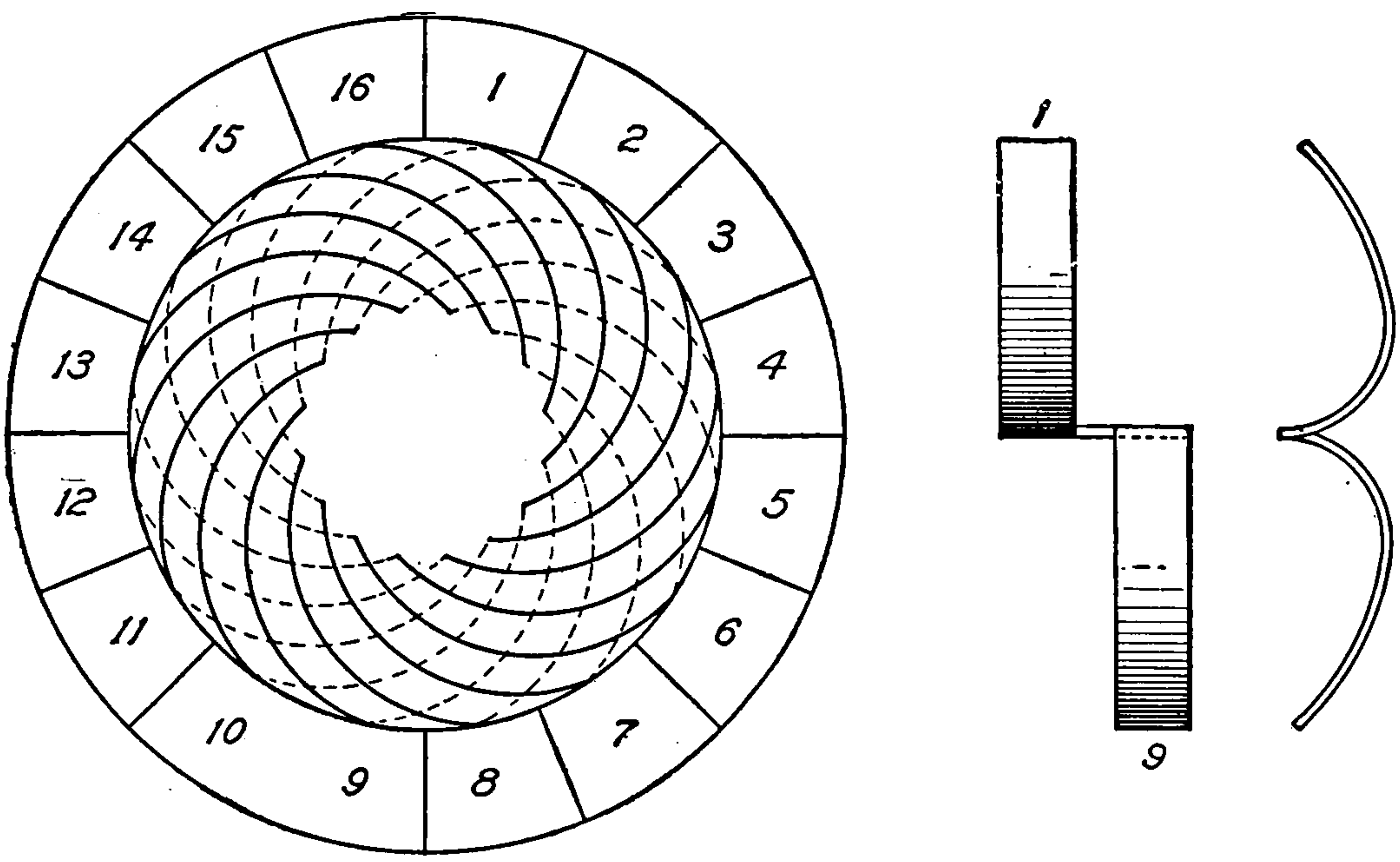



Fig. 117. Commutator Connections for a 4-Pole Cross-Connected Winding

each cross-connection must unite three bars situated 120° apart, and the brushes may be either 60° or 180° apart; in an eight-pole machine, four commutator bars 90° apart must be joined, and the brushes may be either 45° or 135° distant from each other. Thus in general the angle between the brushes of unlike sign must be $180° \div p$ or any uneven multiple of this angle. The commutator connections for a four-pole cross-connected winding of the type described are shown in Fig. 117, while Fig. 118 illustrates the same for a six-pole machine. When thus cross-connected, the commutator must be made $p$ times as long as before, in order to provide sufficient surface of contact to collect the current by the two sets of brushes; also, the number of commutator segments must be divisible by $2p$.

A reduction of the number of brushes by means of equipotential connections is only permissible when the current density at the brushes is small. It is possible to make the commutator longer and the brush area per set larger, but this is expensive.

Equipotential connections are used to a large extent in modern generators, however, not for the purpose of reducing the number of brushes, but to *equalize the distribution of current* throughout the armature winding and between brushes of the same polarity. With equipotential connections, owing to their added resistance one circuit will be overloaded, if only two sets of brushes are used, causing

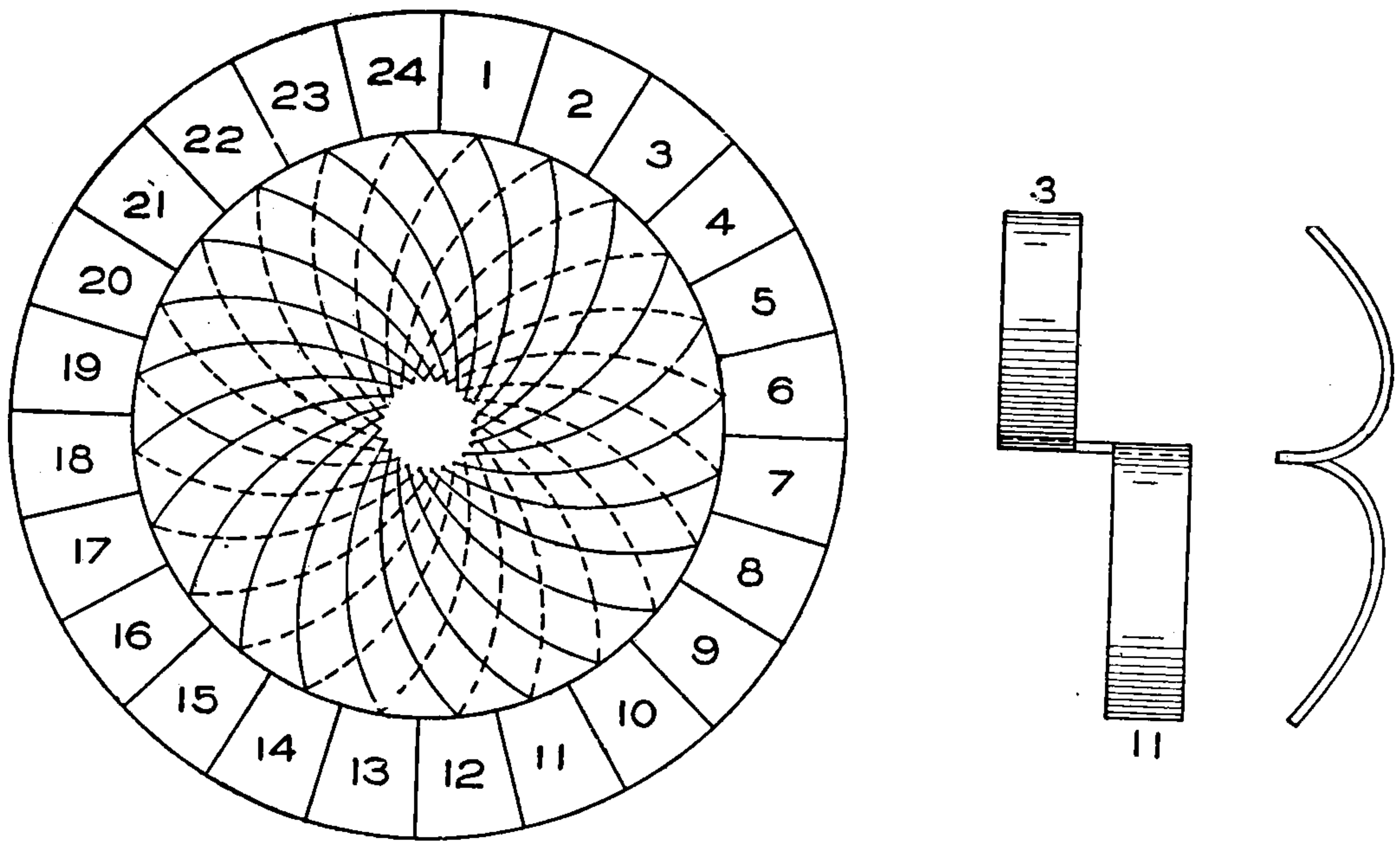
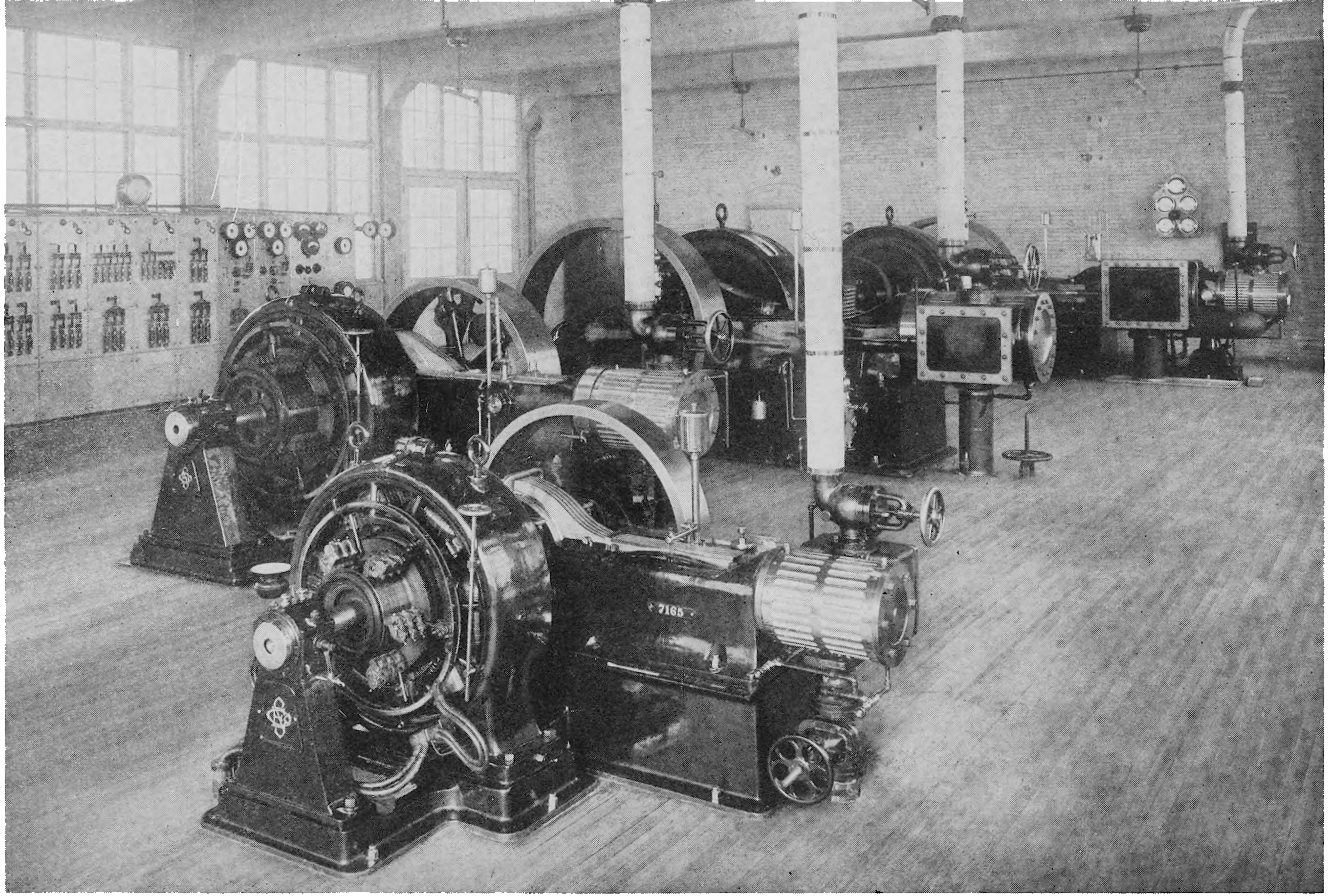



Fig. 118. Commutator Connections for a 6-Pole Cross-Connected Winding

sparking, etc. General practice is to have the full number of brush sets, together with the additional cross-connections, which now equalize the currents in the armature sections as well as between the brushes and are, therefore, known as *equalizing* connections.

*Re-entrancy of Windings.* An armature winding which closes upon itself, *i. e.*, returns to its beginning, is known as a *closed-coil* armature winding, and since such a winding re-enters itself it is called *re-entrant.*

Armature windings may be *singly, doubly,* or *multiply* re-entrant. A single re-entrant winding is one in which the *whole* winding must be traced through before it closes upon itself or before the first inductor is re-entered. Fig. 111 illustrates a singly re-entrant ring



INSTALLATION OF SKINNER ENGINES DIRECT CONNECTED TO GENERATORS. TOTAL HORSEPOWER 2000

*Courtesy of Skinner Engine Company*

winding, while Figs. 130 and 135 illustrate, respectively, singly re-entrant lap and wave drum windings. In the case of Fig. 131, tracing through the winding shows that *every* inductor must be passed through after starting from *1*, going thence to *52* to *3* to *54*, etc., before *1* is reached again. While in case of Fig. 136, after starting from *1* the winding passes to *12*, then to *21* to *32*, etc., all inductors being connected before *1* is re-entered. Hence, as per definition, these windings are singly re-entrant.

A *doubly* re-entrant armature winding is one in which after tracing through the consecutive inductors, in order of winding, only *half* of the winding is passed through before the starting inductor is re-entered; the other half of the winding is of the same character.

A doubly re-entrant lap winding is shown in Fig. 132, wherein it may be noted that in tracing through inductors in the order of connection, *1-8-57-4-53*, etc., only one-half of the inductors are connected before *1* is re-entered. In the same manner Fig. 137 illustrates a doubly re-entrant wave winding, because in this example we find upon tracing the winding in order of connection, *1-12-21-32-41*, etc., that only half the inductors on the core are encountered before the first is again reached.

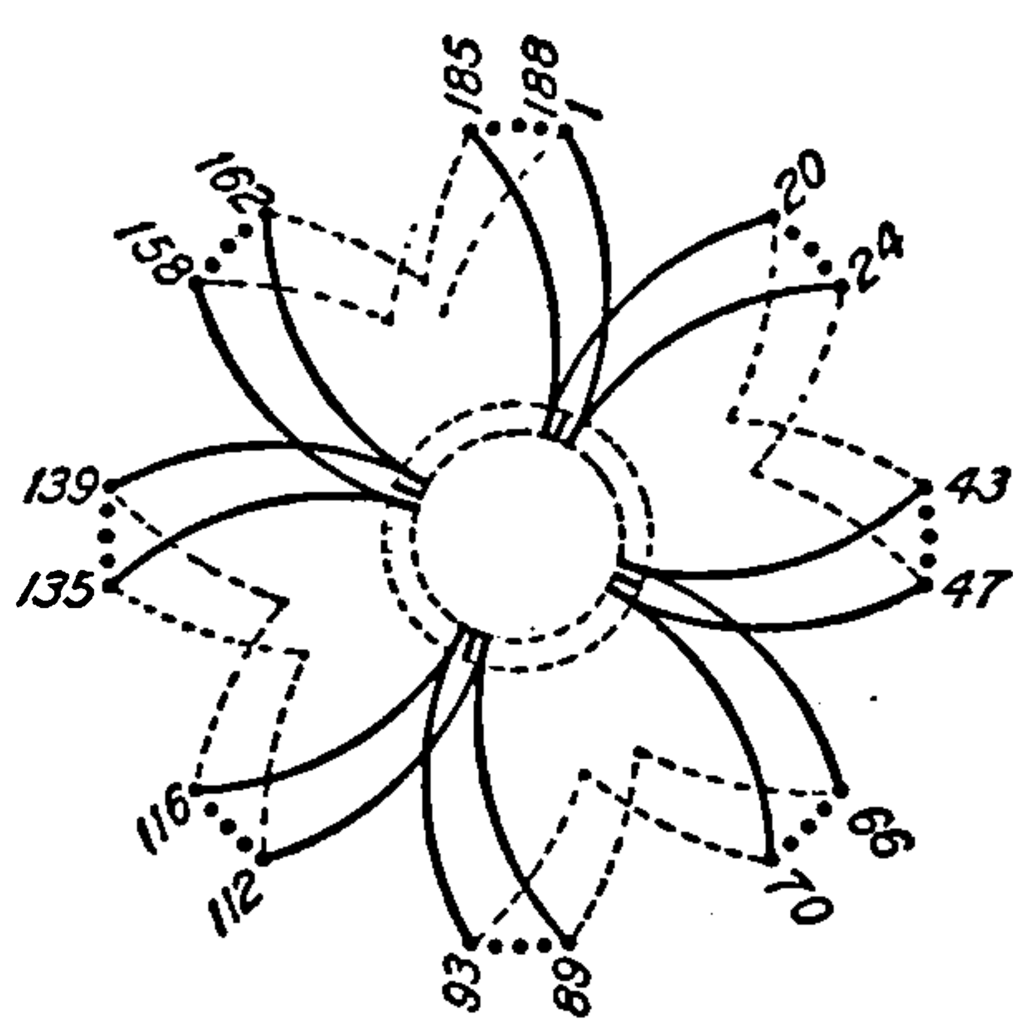



Fig. 119. Wave Winding, 8-Pole, 2-Circuit, Singly Re-entrant

A *triply* re-entrant winding, similarly, is one which connects together only *one-third* the total number of the inductors on the core before re-entering the starting one, thus two-thirds still remain to be connected up in a like manner.

In tracing through the successive inductors of an armature winding, in order of connection, one may pass around the core once, twice, or any number of times before closing or re-entering the winding. The number of times one thus passes around the core before closing the winding has nothing to do with the degree of re-entrancy. For example, the winding illustrated in Fig. 119 is only singly re-entrant, yet we pass around the core twenty-three times before all the inductors are connected, the closing of the winding at *1* not occurring until after this number of travels around the core. The order of re-entrancy of windings may be predetermined by means of formulas for the winding pitch, an example of which is given upon pages 101 and 103.

*Multiplex Windings.* An armature may be wound with two or more independent windings, each of which may be singly re-entrant, as shown in Fig. 120. These two windings might be furnished with two independent commutators situated at each end of the armature; but usually there is one with the number of its segments doubled, the two sets of bars being alternated between one another. In this case the brushes must be made broad enough to overlap at least two and one-half commutator bars, so as to collect current from both windings simultaneously. Such a winding is known as a *duplex singly re-entrant winding. Triplex-wound armatures* have three independent windings, with three sets of commutator bars similarly arranged. It is, of course, possible to have duplex doubly re-entrant windings, and so on.

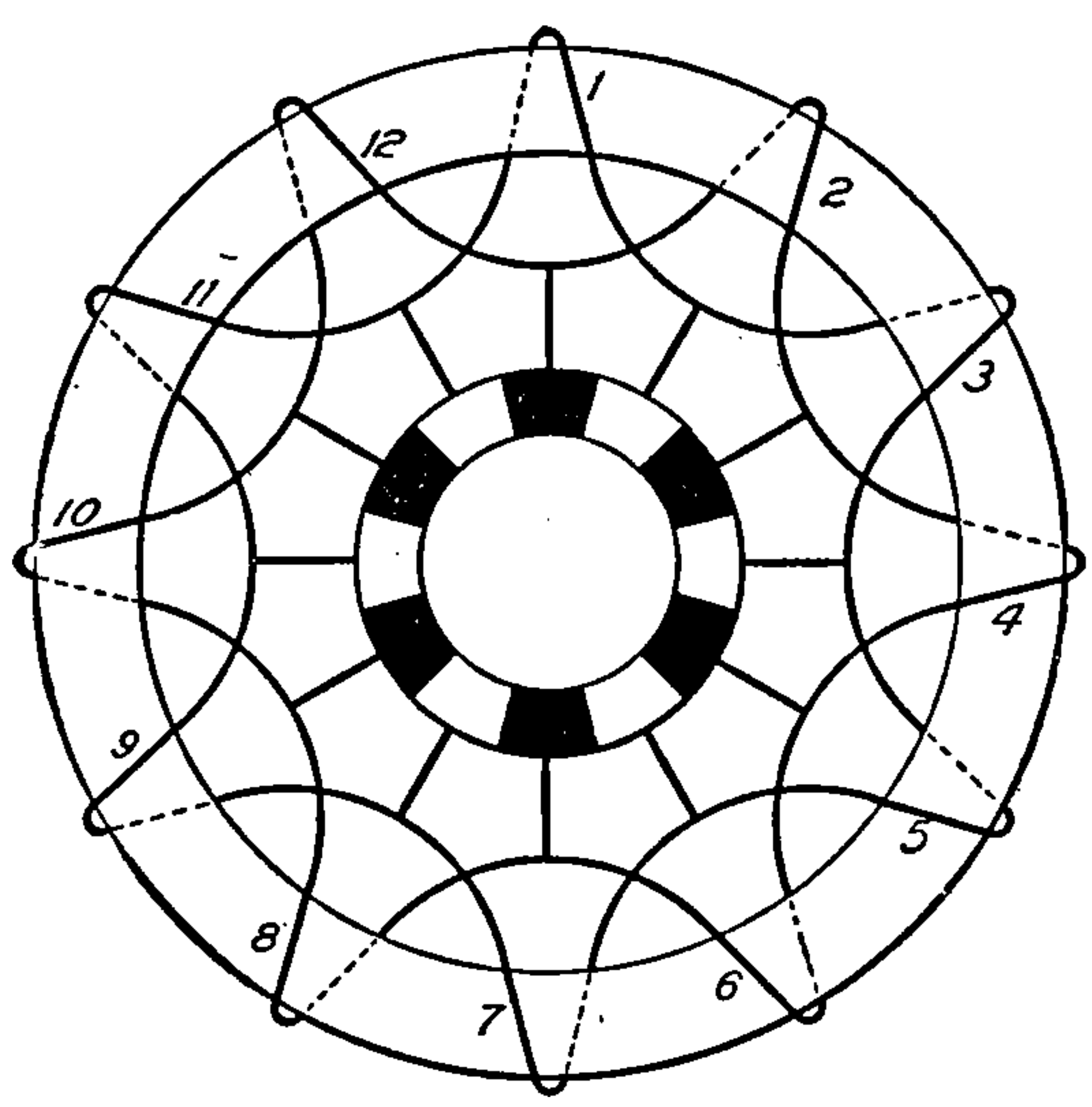



Fig. 120. Duplex Winding Consisting of Two Singly Re-entrant Ring Windings

The advantage of multiplex windings is that sparking at the brushes may be considerably lessened as the reactance voltage is much less and there is a longer brush-resistance path. Hence, multiplex windings may be used in machines intended to supply large currents at small voltages, such as generators for electrolytic work.

**Drum Windings.** The characteristic feature of drum windings is that the conductors are arranged only on the circumference and the sides of the armature core. Starting out from the commutator

Upon examination of Fig. 121 it is seen that as a winding starts out under a north pole it proceeds to the adjacent south pole and then returns under influence of the north pole at which it originated. This arrangement of inductors is called a *lap winding.* The winding illustrated in Fig. 123 after leaving the south pole does not return to the north pole from which it started but advances to the next north pole and would thus proceed around the core passing successively under each pole. This arrangement is called a *wave winding.*

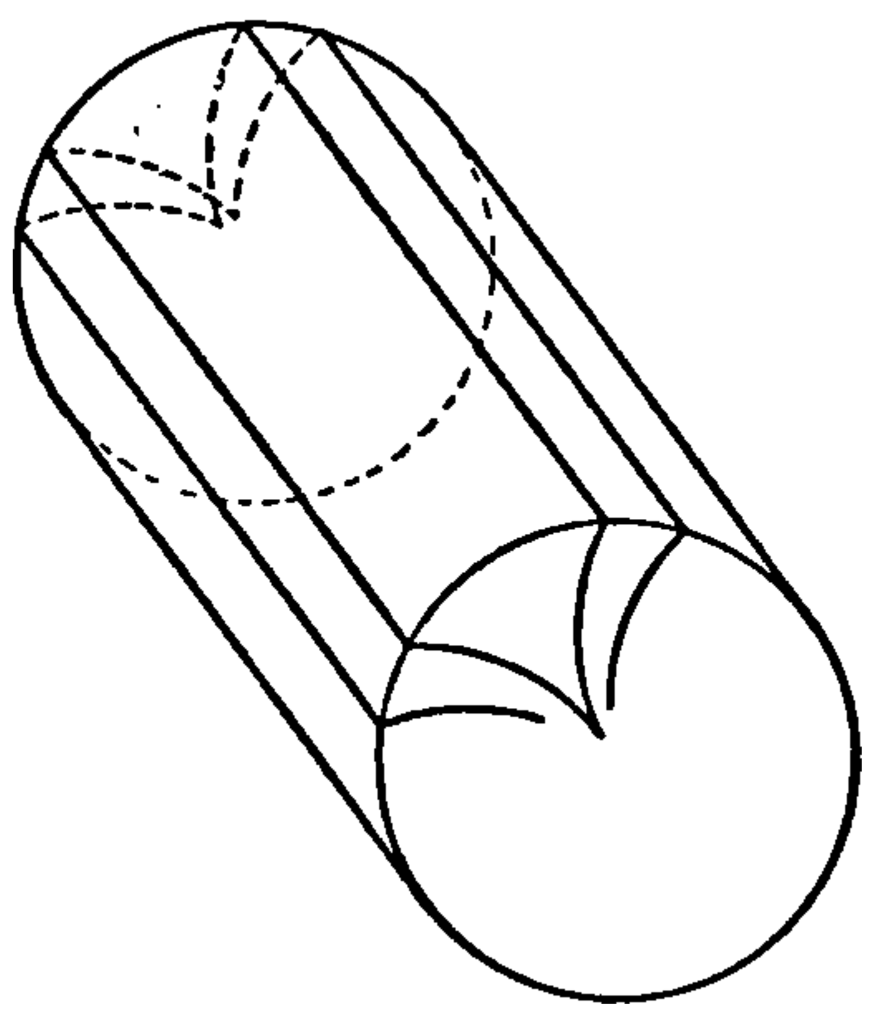


Fig. 124. Diagram of Lap Winding

We can then define a *lap winding* as one in which the conductors are so connected with each other as to form loops. Starting from one commutator bar the winding passes successively under adjacent poles and returns to the commutator section next to the one from which it started, Fig. 124.

A *wave winding* is one in which the winding advances continually in one direction, successively passing under each pole and each coil connected to a commutator section which is at a considerable distance from that at which the winding started, Fig. 125.

Just as in ring windings we may have several turns in series per coil to increase the e. m. f. of the coil or we may place several turns in parallel to increase the current-carrying capacity.

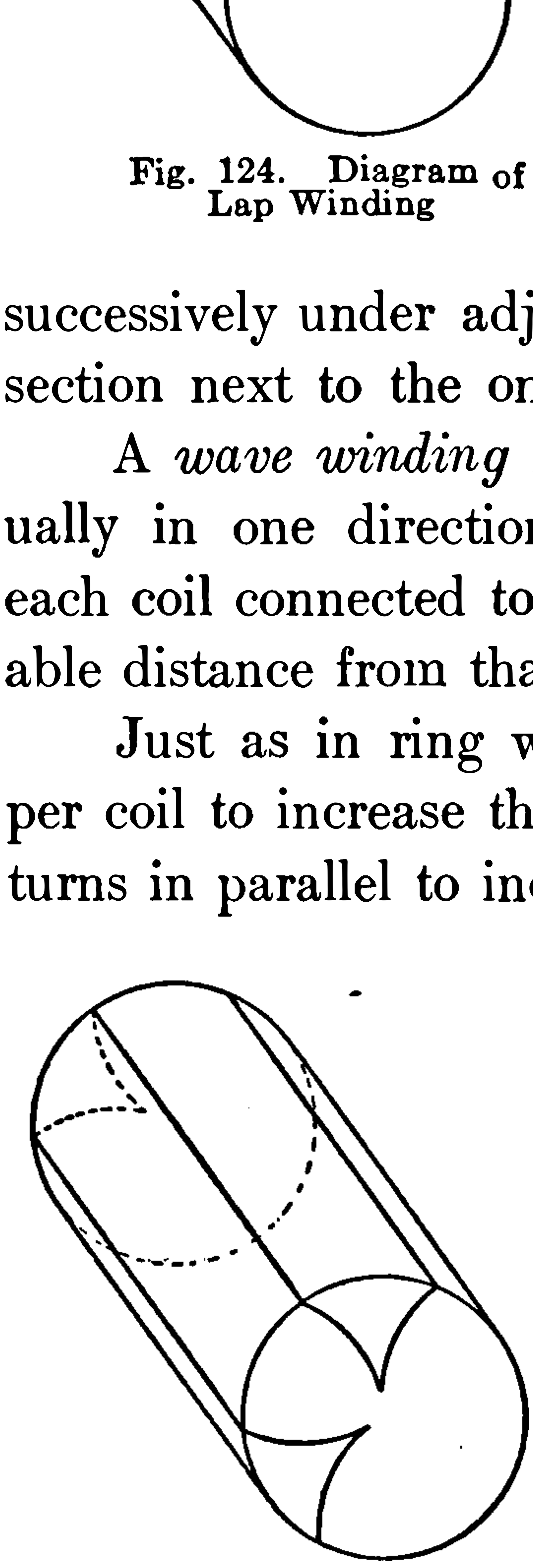
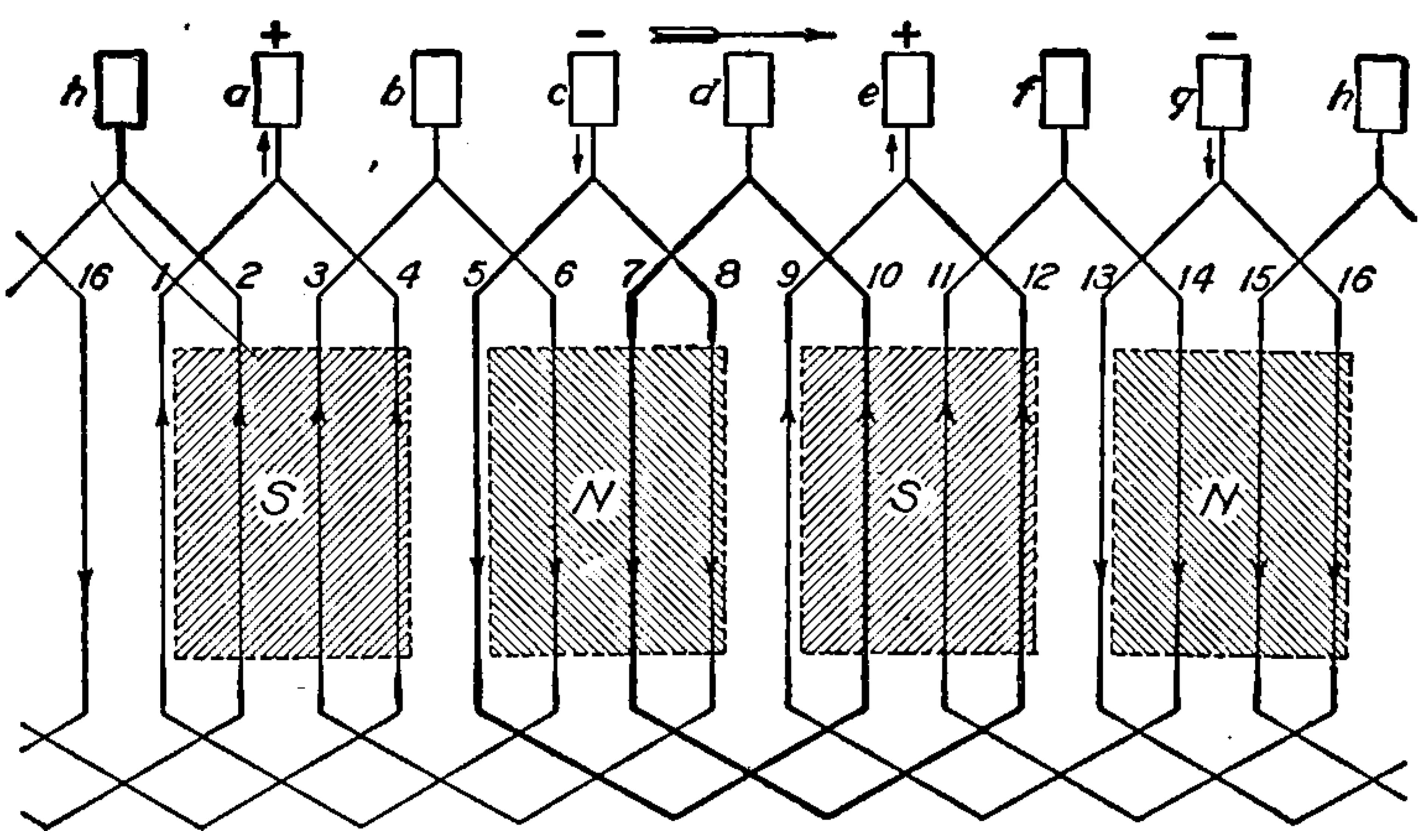


Fig. 125. Diagram of Wave Winding

*Lap Windings.* Let us now consider a simple lap winding as is shown in Fig. 126. Following through this winding and starting at segment *a,* we pass along conductor *1* to the rear of the armature, then by an end connection skip over to conductor *6,* which leads to commutator bar *b.* This commutator bar is then connected to conductor *3* which leads to the rear, and is there connected to *8,* which in turn is connected to bar *c.* Following on in this manner to bar *h* by conductor *2,* and from here via conductor *15,* we finally reach bar *a* through *4,* thus closing the winding on itself without traversing each conductor more than once, thus forming a simplex lap winding.

The winding elements are thus *a-1-6-b*, *b-3-8-c*, *c-5-10-d*, etc., to *h-15-4-a*. Calling the interval between the conductors connected at the rear of the armature the *back pitch*, $y_b$, and the interval between those connected together at the front end the *front pitch*, $y_f$, we see that for this winding, $y_b = +5$; and $y_f = -3$. The average pitch, being half the arithmetical sum of the front and back pitches, is $y_{av} = 4$; while the resultant pitch is $y_r = +2$, being the algebraic sum of the front and back pitches. The resultant pitch is the number of inductors passed over from the beginning of one element to the beginning of the next.




| Front | Back | | Front |
|---|---|---|---|
| + a | 1 | 6 | b |
| b | 3 | 8 | c |
| − c | 5 | 10 | d |
| d | 7 | 12 | e |
| + e | 9 | 14 | f |
| f | 11 | 16 | g |
| − g | 13 | 2 | h |
| h | 15 | 4 | a |

Fig. 126. Development of Simplex Lap Winding and Winding Table

If we divide the resultant pitch by the number of inductors in series per element, which in the case just considered is 2, we obtain the commutator pitch $y_k$ which is the number of commutator bars between the beginning of one element and the beginning of the next element connected to the first. Thus

$$y_k = \frac{y_r}{2} = \frac{+2}{2} = +1$$

The product being 1 shows that the winding is connected successively to each commutator bar and that it must be singly re-entrant, as it can proceed around the commutator once only before closing upon itself. If the product had been 2, it would show that the winding was connected to alternate bars and would have to proceed twice around the core before closing and would, therefore, be doubly re-entrant. If we let $U$ be the number of times the winding must be re-entered before finally including all inductors, we have

$$\frac{y_r}{2} = \frac{y_b + y_f}{2} = U$$

when $U$ may be any whole number.

There is also the condition that no conductor shall be encountered twice. It is evident in lap windings that the front and back pitches cannot be the same, as we would come back to the con-

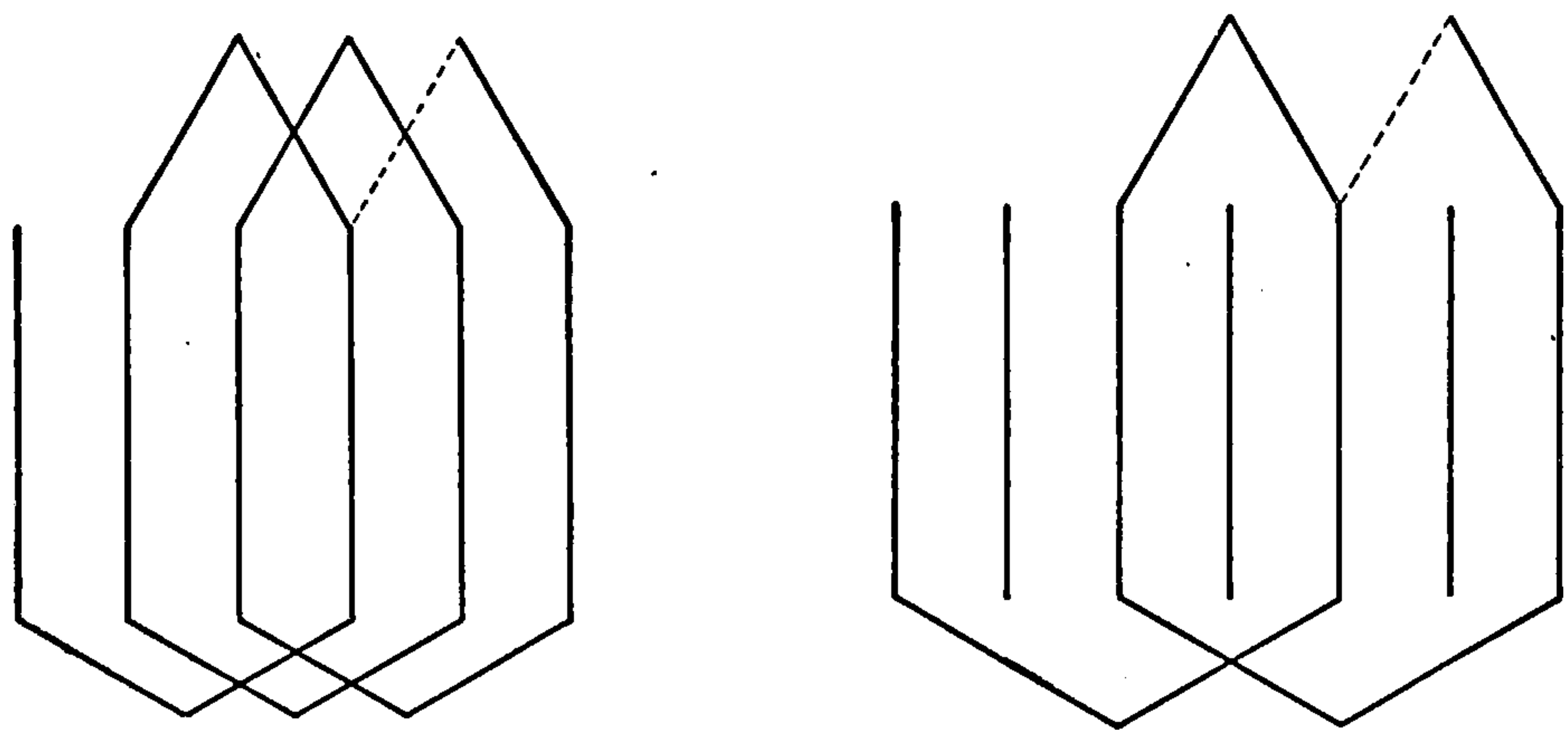


Fig. 127. Fig. 128.
Diagrams of Lap Winding

ductor from which we started. Further, it is necessary that the resultant pitch be an even number, for from the equation

$$\frac{\text{resultant pitch}}{\text{number of inductors per element}} = \text{commutator pitch}$$

it can be seen that since the number of inductors per element is even, to make the commutator pitch a whole number, the resultant pitch must be even. This is shown diagrammatically in Fig. 127. Fig. 128 shows that $y_b$ and $y_f$ must both be odd, since with even values we will encounter the same inductor twice.

We can now take up the general equations which consider the number of inductors upon the armatures. The characteristic feature of a simplex lap winding is that there are as many parallel paths through the armature as there are poles, twice as many if it is duplex, and so on. It is, therefore, often known as a *parallel-grouped* or *multiple-circuit* winding. A duplex winding is essentially nothing but two separate simplex windings, and our formulas will, therefore,

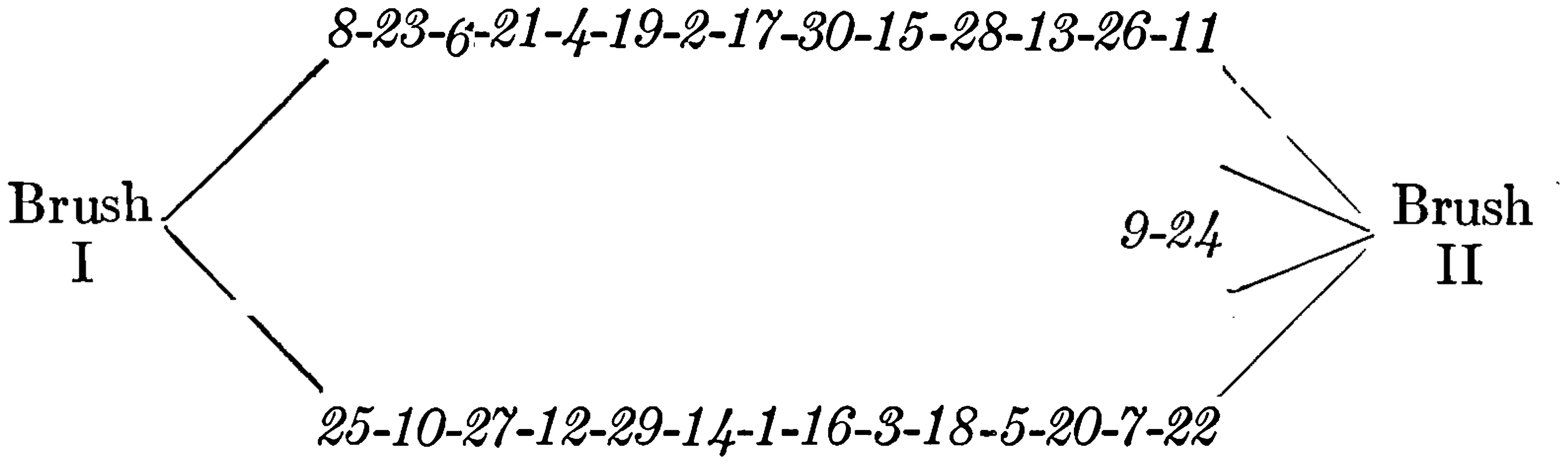
We can now consider a few applications of the formulas to lap windings. Fig. 129 shows a bipolar simple lap winding with 30 inductors. We have then $N = 30$, $2p = 2$, $y_k = 1$, hence

$$y_f = \frac{30 \pm f}{2} \pm 2 \qquad\qquad y_b = \frac{30 \pm f}{2}$$

In this particular case $f = 0$, and hence

$$y_f = 17 \text{ or } 13 \qquad\qquad y_b = -15$$

The values $y_f = 13$ and $y_b = -15$ have been chosen and it will be seen that there are two parallel connected circuits leading from brush to brush as follows:




Had the values $y_f = 17$ and $y_b = -15$ been taken, the winding would have been much the same except that it would require more wire for the front connections.

If we had taken the values $\pm 2$ for $f$ it would be seen that the values of $y_f$ and $y_b$ would be even, which is, as we have seen, impossible. The value $f = \pm 4$ is, however, possible, giving the values

$$y_f = 15 \text{ or } 19 \qquad\qquad y_b = 17$$

or

$$y_f = 11 \text{ or } 15 \qquad\qquad y_b = 13$$

depending upon whether the + or the − sign has been used.

We said before that the front and back pitches should be approximately equal to the pole pitch $\left(\frac{Z}{2p}\right)$ in order that conductors moving simultaneously under poles of opposite polarity should have their generated e. m. f.'s additive. The smallest pitch meeting this condition would stretch completely across a pole-face, while the largest would stretch from the given pole-tip to the next pole-tip of like polarity. When the pitch is considerably smaller than the pole pitch we have what is known as a *chord winding* or a winding with shortened pitch. It will be obtained if the value for $f$ is increased.

Such a winding is shown in Fig. 130 where $N = 28$, $2p = 2$, and $f = -8$. We have then $y_f = +9$ and $y_b = -11$.

It can readily be seen that whatever currents are flowing in the short-circuited turns will be in opposite directions, so that the magnetic effects produced will be opposed and the resultant zero. Thus a winding with shortened pitch tends to reduce armature reaction. The disadvantage of the winding is that the two conductors of any

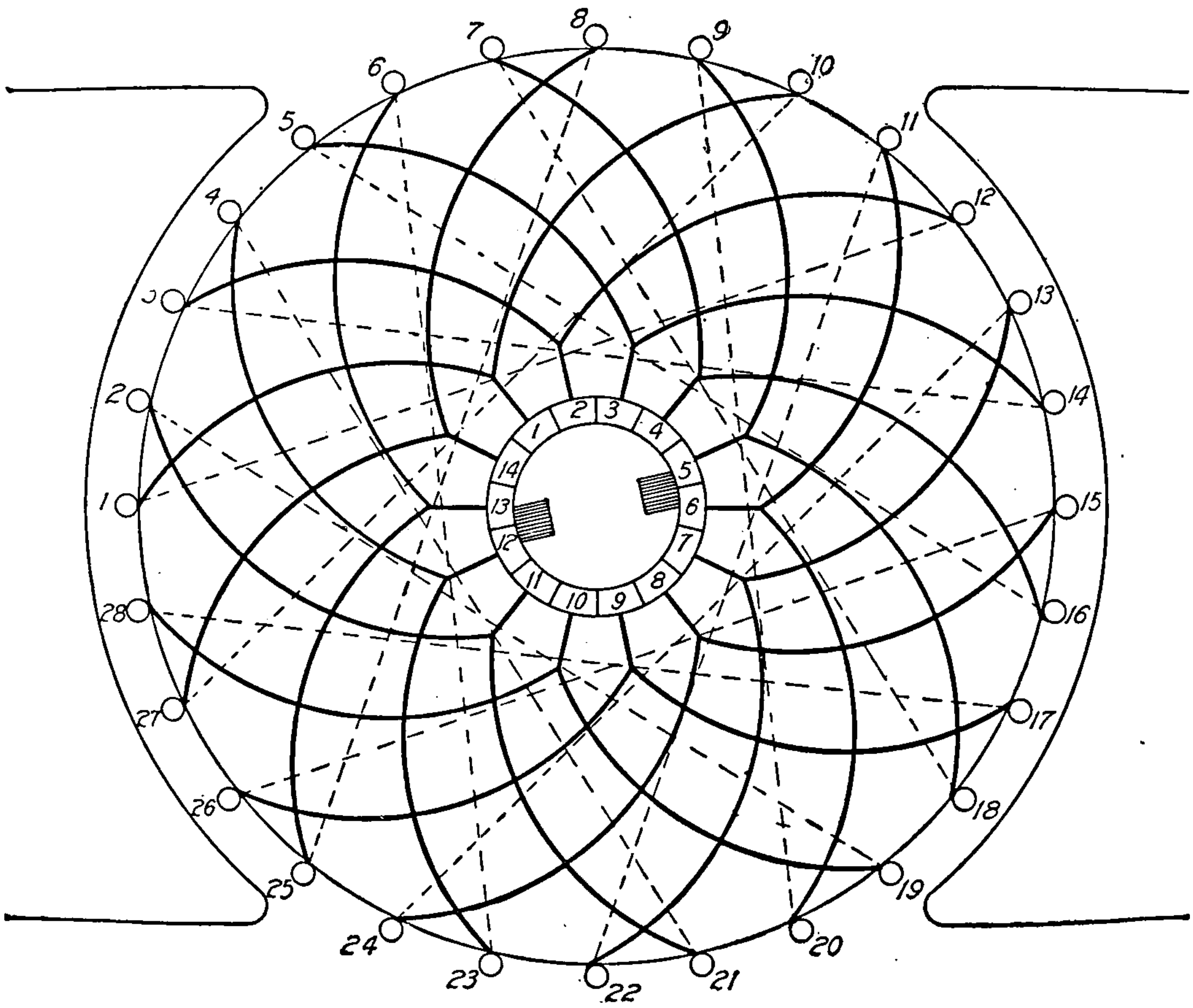


Fig. 130. Chord Winding with Thirty Inductors

section are not both passing into a commutating field at the same time, so for this reason it is not suitable for handling large outputs of current.

On the following pages will be found examples of windings in common use. In the illustrations, the short, radial, numbered lines represent the conductors; the crossed lines outside of the circle of conductors represent the connections at the back end of the armature; and the crossed lines between the circle of conductors and the commutator at the center, represent the connections at the front end of the armature. For the sake of simplicity, only a few conductors are shown in these examples; and it should be noted that in actual designs, their number $Z$ attains a much greater value.

Fig. 131 represents a six-pole drum simplex or singly re-entrant lap winding, with 60 conductors, a front pitch of $-11$, and a back pitch of $+9$. In this particular case the general progression of the

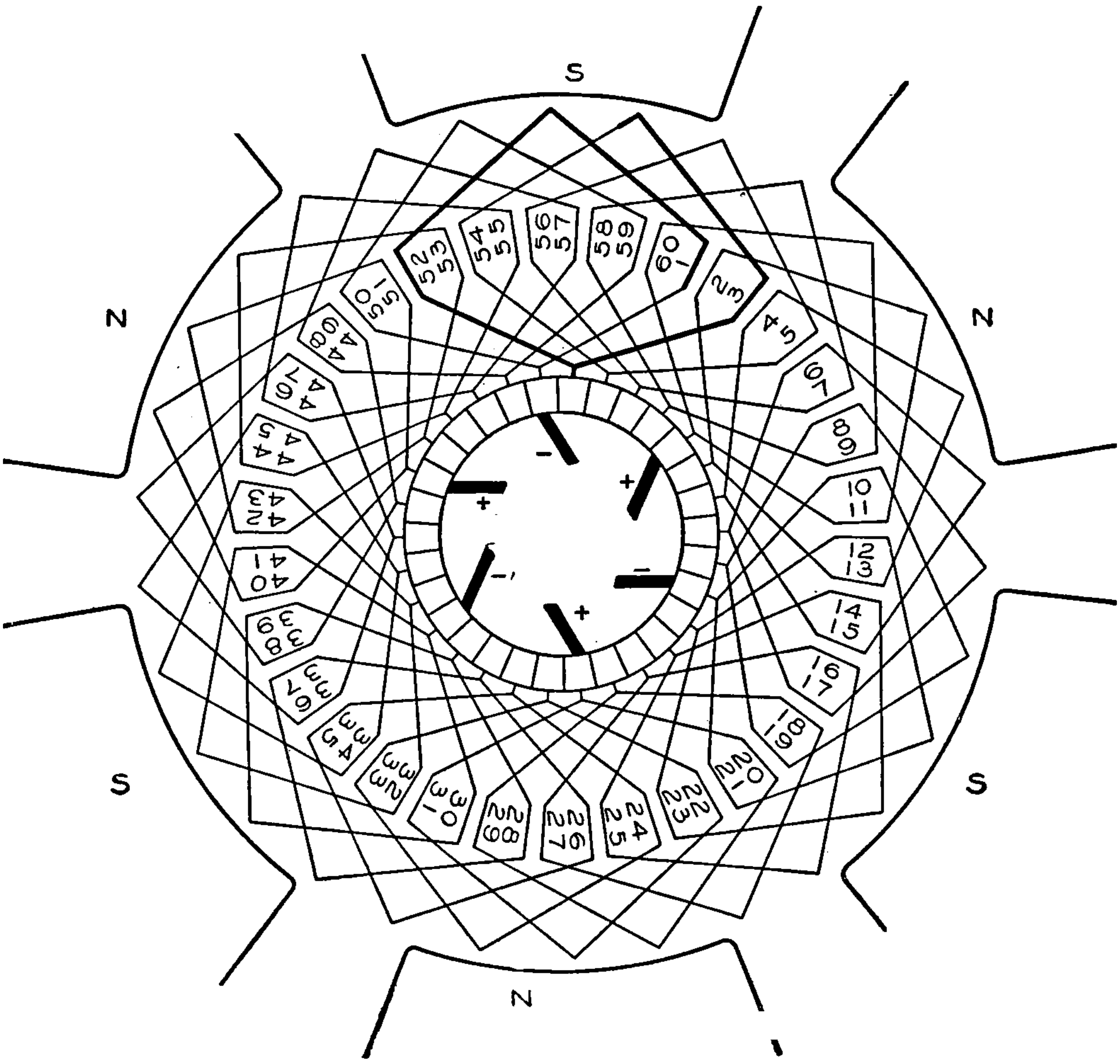



Fig. 131. Six-Pole Drum Singly Re-entrant Lap Winding

winding is around the drum in an anti-clockwise direction, and on this account it is sometimes called a *retrogressive* winding to distinguish it from a clockwise, or *progressive,* winding. The winding here shown has a commutator pitch of $-1$, and there are six paths in parallel through the armature, necessitating six brush sets unless the winding or commutator is cross-connected.

the back pitch is $-5$, and the commutator pitch is $+2$, while there are 8 paths in parallel through the armature. Four brushes only are required, and inspection shows this to be a progressive winding.

Summarizing, a lap winding must comply with the following conditions:

(*a*) All winding elements must be similar mechanically and electrically, and must be symmetrically placed upon the armature.

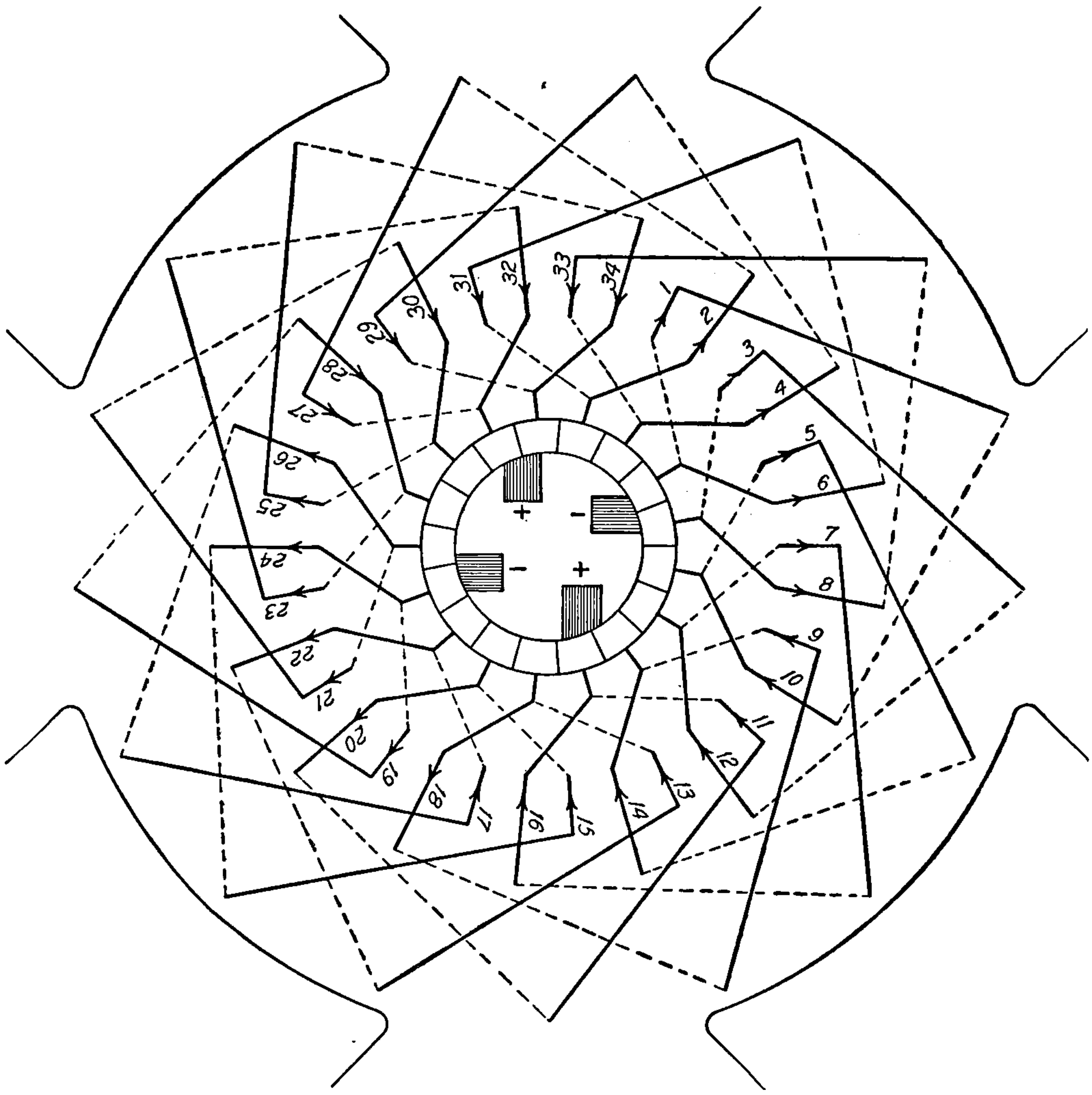



Fig. 133. Four-Pole Drum Doubly Re-entrant Lap Winding

(*b*) In a simplex winding, every inductor must be passed over once only, and the winding must close upon itself, or be re-entrant.

(*c*) If the winding is re-entrant it must finally close upon itself.

(*d*) In a multiplex winding, each simplex element must comply with condition (*c*).

(*e*) In a two-layer winding, that is, one where the conductors are placed one on top of another in a slot, it is usual to give the upper ones odd numbers, and the lower ones even numbers, or conversely.

(*f*) Front and back pitches must be opposite in sign.

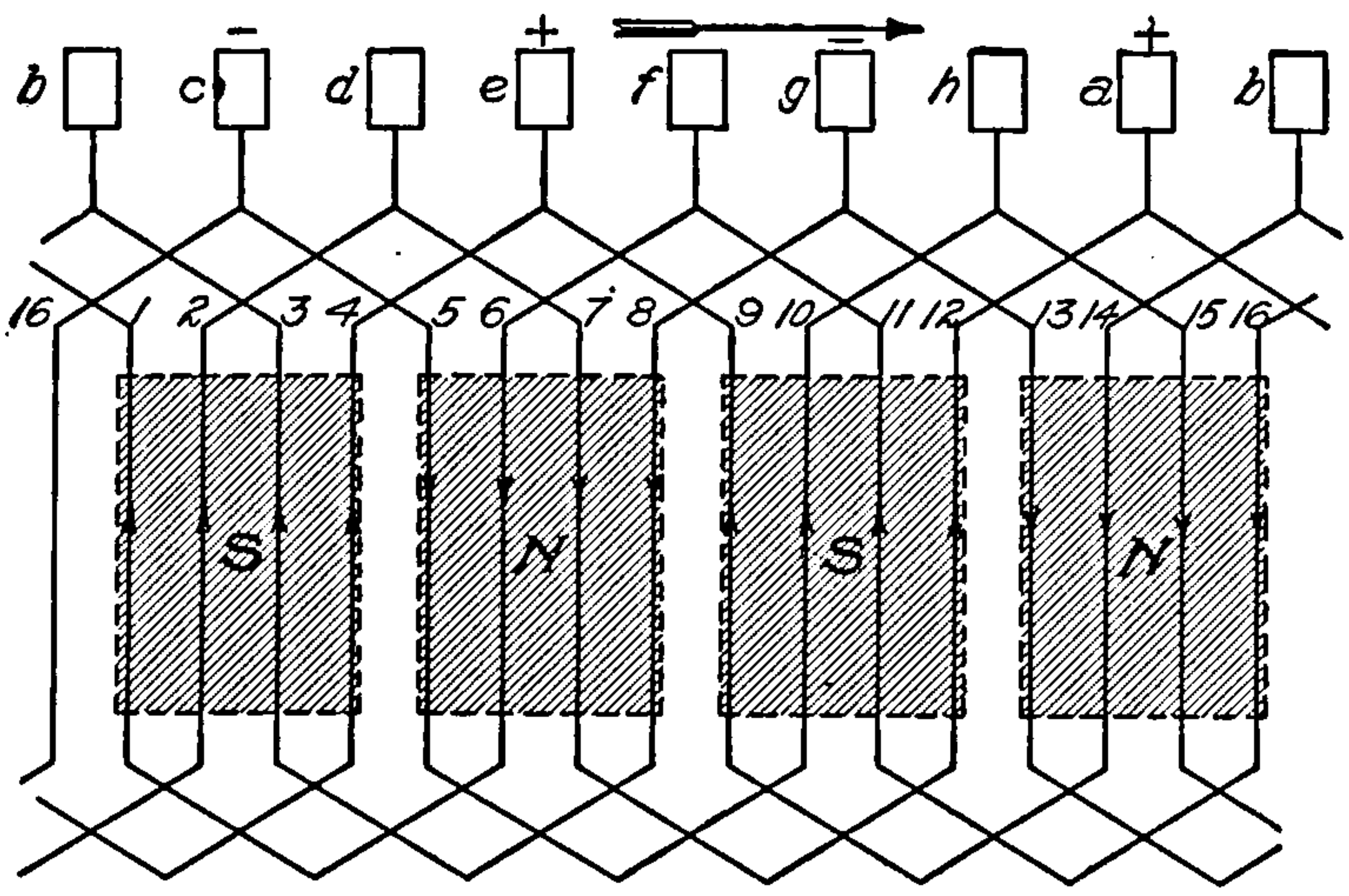
(*g*) The front and back pitches must be unequal, otherwise the coil would be short-circuited upon itself.

(*h*) In a simplex lap winding, the front and back pitches differ by 2; that is $y_f = y_b \pm 2$.

(*i*) In a multiplex lap winding, the front and back pitches differ by $2x$, where $x$ is the number of component simplex windings.

(*j*) $Z$ may be any even number; and in slotted armatures, it must also be a multiple of the number of slots; the latter may be even or odd.

Further, there must be as many circuits through the armature as there are poles and there will, therefore, be as many brush sets as there are poles, unless the winding is cross-connected as already explained.




| Front | Back | | Front |
|---|---|---|---|
| +a | 1 | 6 | f |
| f | 11 | 16 | c |
| -c | 5 | 10 | h |
| h | 15 | 4 | e |
| +e | 9 | 14 | b |
| b | 3 | 8 | g |
| -g | 13 | 2 | d |
| d | 7 | 12 | a |

Fig. 134. Development of Four-Pole Simplex Wave Winding

*Wave Windings.* The winding illustrated in Fig. 134 is called a *simplex wave winding*. Starting at bar *a*, we pass along conductor *1* to the back of the armature, thence by a connector to conductor *6*, and then ahead to bar *f*. From here we follow along conductor *11*, and then *16* to *c*, whence we are led along *3* and *8* to *g*. Following through the complete winding, we arrive at bar *a* by way of conductor *14*, after having traversed each conductor once. Thus the winding closes upon itself after passing through $Z \div 2$ winding elements.

For this winding, then, we have

$$y_f = +5; \qquad y_b = +5; \qquad y_{av} = +5; \qquad y_r = +10$$

The equations for wave and series windings are as follows:

$$y_r = y_f + y_b = \frac{Z \pm 2}{p}$$

and since $K = \frac{Z}{2}$

$$y_k = \frac{K \pm 1}{p}$$

It is evident that $y_r$ must be an even number, and as there are

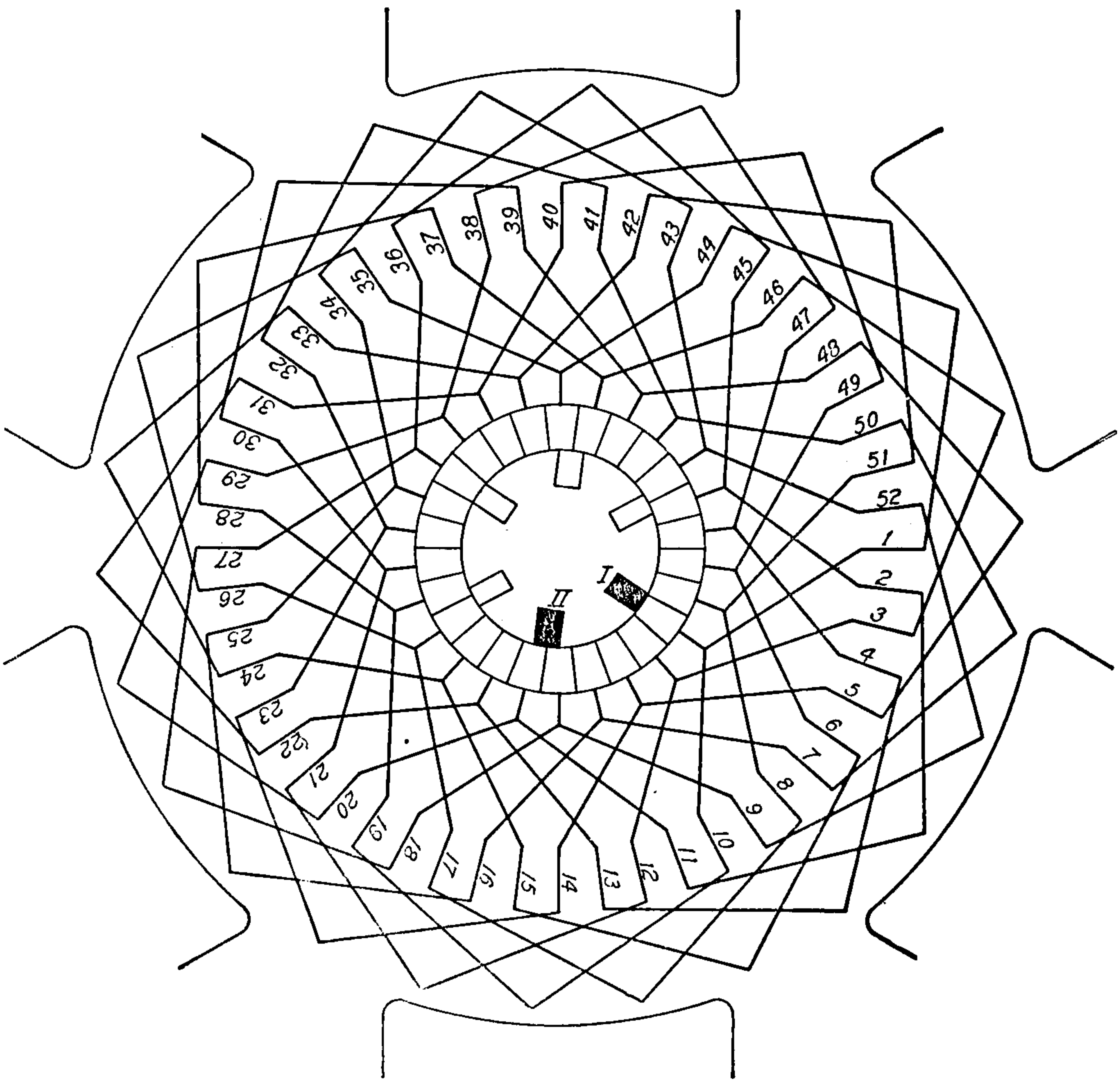



Fig. 135. Six-Pole Drum Simplex Wave Winding

two inductors per element, the odd inductors will lead from the commutator to the rear of the armature core, while the even numbered are connected in the reverse order, or the converse may be the order of connection. So that in advancing from the beginning of one element we must pass over an even number of inductors to arrive

winding always gives 2 paths through the armature, irrespective of the number of poles.

It is seen, therefore, from the fundamental formula for the e. m. f. of a dynamo, that, for a given number of armature inductors, a wave winding will give a higher voltage than a lap winding in a multipolar field. The latter, however, will give a greater number of paths in parallel through the armature, thus increasing its current capacity.

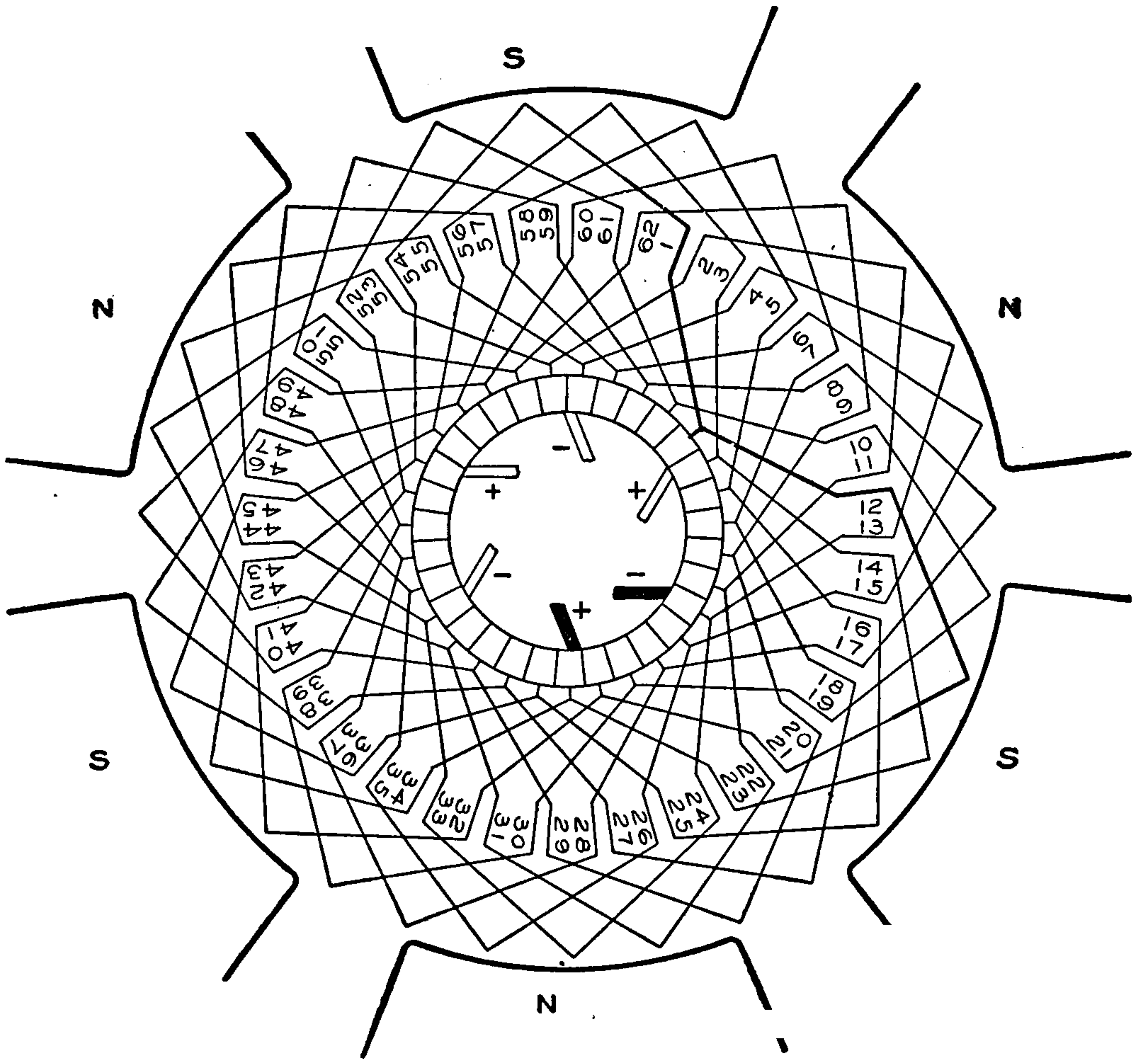
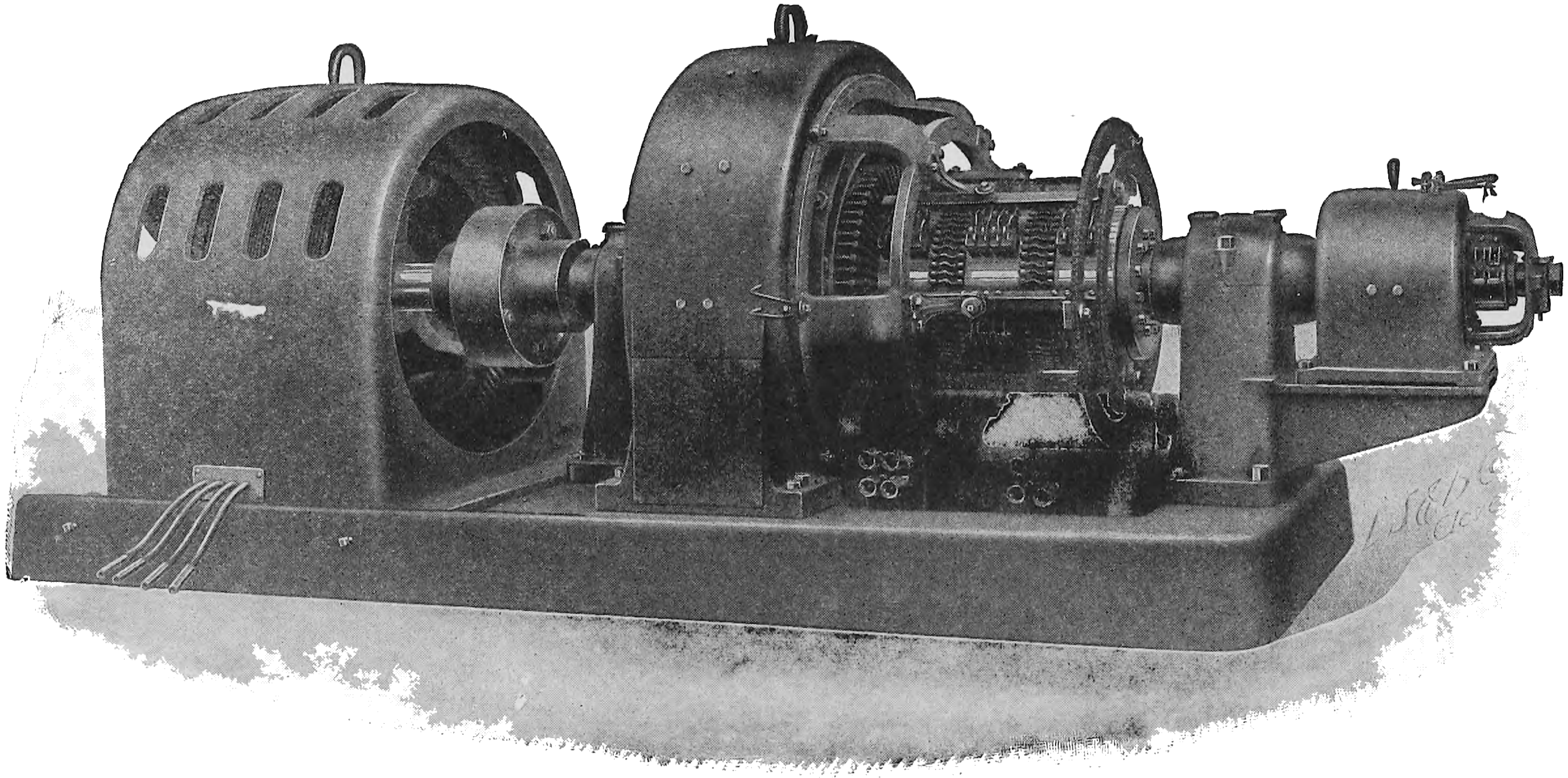



Fig. 136. Six-Pole Drum Simplex Singly Re-entrant Wave Winding

Fig. 136 illustrates a six-pole drum simplex singly re-entrant wave winding of 62 inductors. It has a front pitch of +11, and a back pitch of +9, that is, the front and back pitches are unequal. giving an average pitch of 10, and also a commutator pitch of 10. This winding has two paths in parallel through the armature, so that only two brush sets are required.



MOTOR GENERATOR SET CONSISTING OF INDUCTION MOTOR DRIVING A THIRTY-VOLT, 2000-AMPERE, DIRECT-CURRENT GENERATOR WITH EXCITER

*Courtesy of Burke Electric Company*

## TABLE X

### Formulas for Ring and Drum Windings

RING WINDINGS

| Types of Winding | No. Circuits in Parallel through Arm. = $c$ | No. Circuits in Parallel per Winding = $c_1$ | No. Separate Windings = $x$ | Field Step = $m$ | No. Conductors = $Z$ | Resultant Pitch = $y$ | Commutator Pitch = $y_k$ | Conductors in Series between Brushes | No. Brush Sets | Angle between Brush Sets | Figs. Illustrating Winding |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **A** | $2p$ | $2p$ | 1 | 0 | $= gG = gK$ | $\pm g$ | $\pm g$ | $Z \div 2p$ | $2p$ | $360° \div 2p$ | 111 |
| **B** | 2 | 2 | 1 | 1 | $= gpy \pm 1$ and $= gG = gK$ | $\frac{Z \mp 1}{p}$ and must be odd | $\frac{K \mp 1}{p}$ | $Z \div 2$ | Min. 2<br>Max. $2p$ | $360° \div 2p$ or any odd multiple | 115 |
| **C** | 4, 6, 8, or any other even number > 2 | $c$ | 1 | 1 | $\frac{py \pm c}{2}$ | $\frac{2Z \mp c}{2}$ | $\frac{2K \mp c}{p}$ | $Z \div c$ | $2p$ | $360° \div 2p$ | 118 |
| **D** | $2xp$ | $2p$ | 2, 3, 4, or any other whole number | 0 | $= xgG = xgK$ | $\pm gx$ | $\pm gx$ | $Z \div 2xp$ | $2p$ | $360° \div 2p$ | 119 |
| **E** | $2x$ | 2 | do | 1 | $gnpy \pm n$ | $\frac{Z \mp x}{xp}$ | $\frac{K \mp x}{p}$ | $Z \div 2x$ | Max. $2p$<br>Min. 2 | $360° \div 2p$ or any odd multiple | .... |
| **F** | $xc_1$ | 4, 6, 8, or any other even number > 2 | do | 1 | $gnpy \pm nc$ | $\frac{Z \mp xc}{xp}$ | $\frac{K \mp xc}{xp}$ | $Z \div xc_1$ | $2p$ | $360° \div 2p$ | .... |

LAP-WOUND DRUM WINDINGS

| Types of Winding | No. Circuits in Parallel through Arm. = $c$ | No. Conductors in Series between Brushes | No. Separate Windings = $x$ | No. Circuits in Parallel per Winding = $c_1$ | Field Step = $m$ | No. Armature Conductors = $Z$ | Resultant Pitch = $y$ | Forward Pitch = $y_f$ | Backward Pitch $y_b$ | Commutator Pitch = $y_k$ | No. Brush Sets | Angle between Brush Sets | Figs. Illustrating Winding |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **G** | $2p$ | $Z \div 2p$ | 1 | $2p$ | 0 | $Z = 2gG = 2gK$, *i. e.*, any even number | $\pm 2$ | Equal to or less than $\frac{Z}{p}$, and must be odd | $-(y_f \pm 2)$ | 1 | $2p$ | $360 \div 2p$ | 132 |
| **H** | $2px$ | $Z \div 2px$ | 2, 3, 4, or any other whole number | $2p$ | 0 | | $\pm 2x$ | | $y_f - 2x$ | $\pm x$ | $2p$ | $360° \div 2p$ | .... |
| **J** | 4, 6, 8, or any other even number > 2 | $Z \div c$ | 1 | 4, 6, 8, or any other even number > 2 | 0 | | $\pm c$ | | $y_f - c$ | $\pm \frac{1}{2} c$ | $2p$ | $360° \div 2p$ | 135 |
| **K** | $xc_1$ | $Z \div xc_1$ | 2, 3, 4, or any other whole number | do $x\,2p$ | 0 | | $\pm xc_1$ | | $y_f - xc_1$ | $\pm \frac{1}{2} xc_1$ | $2p$ | $360° \div 2p$ | 133 |

## WAVE-WOUND DRUM WINDINGS

| * Types of Winding | No. Circuits in Parallel through Arm. = $c$ | No. Conductors in Series between Brushes | No. Separate Windings $=x$ | No. Circuits in Parallel per Winding $=c_1$ | Field Step $=m$ | No. Conductors $=Z$ | $y_f=y_b$ | Commutator Pitch $=y_k$ | No. Brush Sets | Angle between Brush Sets | Figs. Illustrating Winding |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **L** | 2 | $Z \div 2$ | 1 | 2 | 1 | $2\,p\,y_{av} \pm 2$ | $\frac{Z \mp 2}{2\,p}$ must be odd and have no common factor with $Z$ | $\frac{K \mp 1}{p}$ | Min. 2 Max. $2\,p$ | $360° \div 2\,p$ or any odd multiple | 135 |
| **M** | $x\,c_1$ | $Z \div x\,c_1$ | 2, 3, 4, or any other whole number | 2 | 1 | $x\,2\,p\,y_{av} \pm 2\,x$ | $\frac{Z \mp 2x}{x\,2\,p}$ where $y_{av}$ is even $y_f$ may $= y_{av} + 1$ $y_b$ may $= y_{av} - 1$ | $\frac{K \mp x}{x\,p}$ | Min. 2 Max. $2\,p$ | | 137 |
| **N** | 4, 6, or any other even number>2 | $Z \div c$ | 1 | 4, 6, 8, or any other even number>2 | 1 | $2\,p\,y_{av} \pm c$ | $\frac{Z \mp c}{2\,p}$ | $\frac{2\,K \mp c_1}{2\,p}$ | Min. 2 Max. $2\,p$ | | .... |
| **P** | $x\,c_1$ | $Z \div x\,c_1$ | 2, 3, 4, or any other whole number | 2, 4, 6, or any other even number | 1 | $x\,2\,p\,y_{av} \pm x\,c_1$ | $\frac{Z \mp x\,c_1}{x\,2\,p}$ | $\frac{2\,K \mp x\,c_1}{x\,2\,p}$ | Min. 2 Max. $2\,p$ | | 136 |

*Key to Special Types of Ring, Lap, and Wave Windings is given below.

## KEY TO TABLE X

### RING WINDINGS

**A**—Parallel Grouping (Simplex).
**B**—Series Grouping.
**C**—Series-Parallel Grouping (Simplex Doubly or Multiply Re-entrant).
**D**—Duplex or Multiplex Parallel Grouping.
**E**—Duplex or Multiplex Series Grouping.
**F**—Duplex or Multiplex Series-Parallel Grouping.

### LAP-WOUND DRUM WINDINGS

**G**—Simplex Singly Re-entrant (Parallel) Lap Winding.
**H**—Duplex or Multiplex (Parallel) Lap Winding.
**J**—Simplex (Series-Parallel) Doubly or Multiply Re-entrant Lap Winding.
**K**—Duplex or Multiplex (Series-Parallel) Doubly or Multiply Re-entrant Lap Winding.

### WAVE-WOUND DRUM WINDINGS

**L**—Simplex Singly Re-entrant (Series) Wave Winding.
**M**—Duplex or Multiplex (Series) Wave Winding.
**N**—Simplex Doubly or Multiply Re-entrant (Series-Parallel) Wave Winding.
**P**—Duplex or Multiplex Doubly or Multiply Re-entrant (Series-Parallel) Wave Winding.

Summarizing, wave windings must comply with conditions *a, b, c, d,* and *e,* as noted under lap windings on page 108, and also with the following:

(*k*) Front and back pitches must be alike in sign.

(*l*) Front and back pitches may be equal, or differ by any multiple of two. Usually they are both equal nearly to $Z \div p$, although one may be less, and the other greater.

(*m*) Front and back pitches must both be odd.

In Table X is given a resumé of the formulas for armature windings. Some of the types included have not been taken up in the

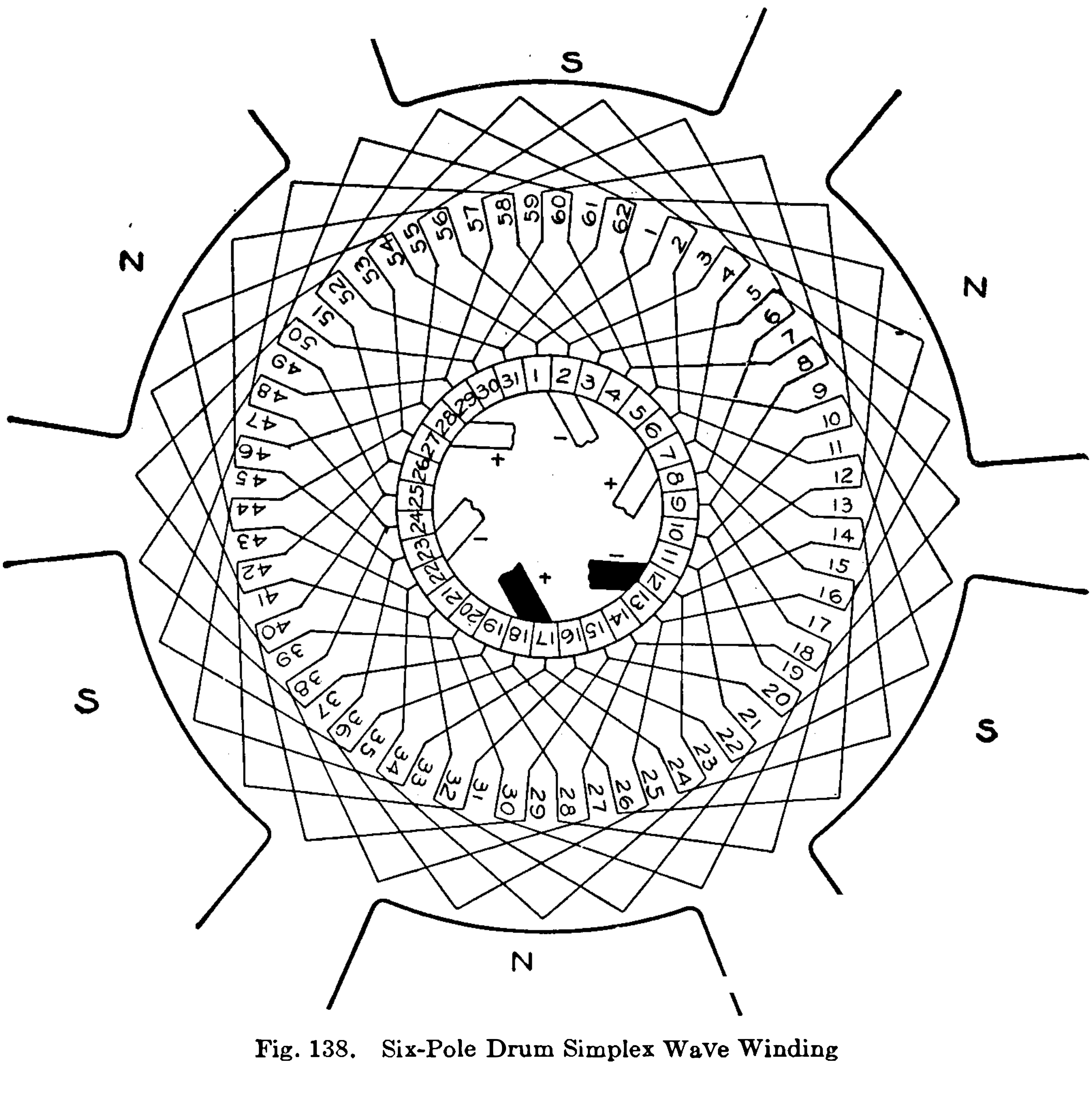



Fig. 138. Six-Pole Drum Simplex Wave Winding

text, but they have been added in case the student desires to go deeper into the subject.

**Length of Armature Winding.** The length of wire in an armature winding depends upon the particular type of winding employed. Determination of this length is necessary in the design of dynamo-

mil foot, and the resistance of a square mil foot of copper wire at 20° C. is $10.35 \times 0.7854 = 8.15$ ohms, or at 0° C. it is $9.55 \times 0.7854 = 7.5$ ohms.

The resistance of any copper conductor, the cross-section of which is given in circular mils, is at 20° C. equal to $\frac{10.35 \times l}{d^2}$, where $l$ is the length of the conductor in feet, and $d^2$ is the cross-section in circular mils, that is, the square of the diameter in mils.

EXAMPLE. 1,200 feet of copper wire 0.1 inch (100 mils) in diameter is required for a certain six-circuit armature winding. Substituting in the equation, $r_a = \frac{\rho l}{c^2 s}$, we have for the resistance of the armature

$$r_a = \frac{10.35 \times 1{,}200}{36 \times 10{,}000} = 0.0345 \text{ ohm at } 20^\circ \text{ C.}$$

**Armature Losses.** The losses in the armature may be divided into those due to the resistance of its winding, and those due to the hysteresis and eddy currents in its iron core.*

Under the preceding heading, a method of finding the resistance of the armature winding was given; hence the copper loss in the armature due to the resistance of its winding is

$$w_{cu} = I_a^2 \, r_a \qquad (27)$$

For calculating the hysteresis loss $w_h$ in the armature, we may use the formula and curves given on page 21, or may refer to a curve obtained by test upon the iron to be used. Similarly, the eddy-current loss $w_e$ may be computed from the formula given on page 22, or from the graphs of Fig. 18. The total iron loss in the armature is, therefore,

$$w_i = w_e + w_h \qquad (28)$$

It is found, however, by tests upon actual machines, that the iron losses thus computed are considerably lower than the true values. This is no doubt due to unequal distribution of flux in the various parts of the magnetic circuit subject to a varying flux-density; also to the departure from the ideal conditions in the matter of dispersion and to the presence of wasteful currents in other parts of the ma-

*Windage due to the rotation of the armature will be dealt with under a later heading.

chine. Prof. J. Epstein* gives curves, Fig. 139, showing that the calculated losses of a machine based on any of the heretofore standard data would be low; hence the actual commercial efficiency is lower than the computed.

In addition to the calculated iron and copper losses, there may be a loss in the armature conductors due to eddy currents, and another loss if for any reason the current does not distribute itself evenly through the conductor. Also, if the division of current between the parallel circuits of the armature winding is not uniform, and equalizing connections are not provided, an additional loss

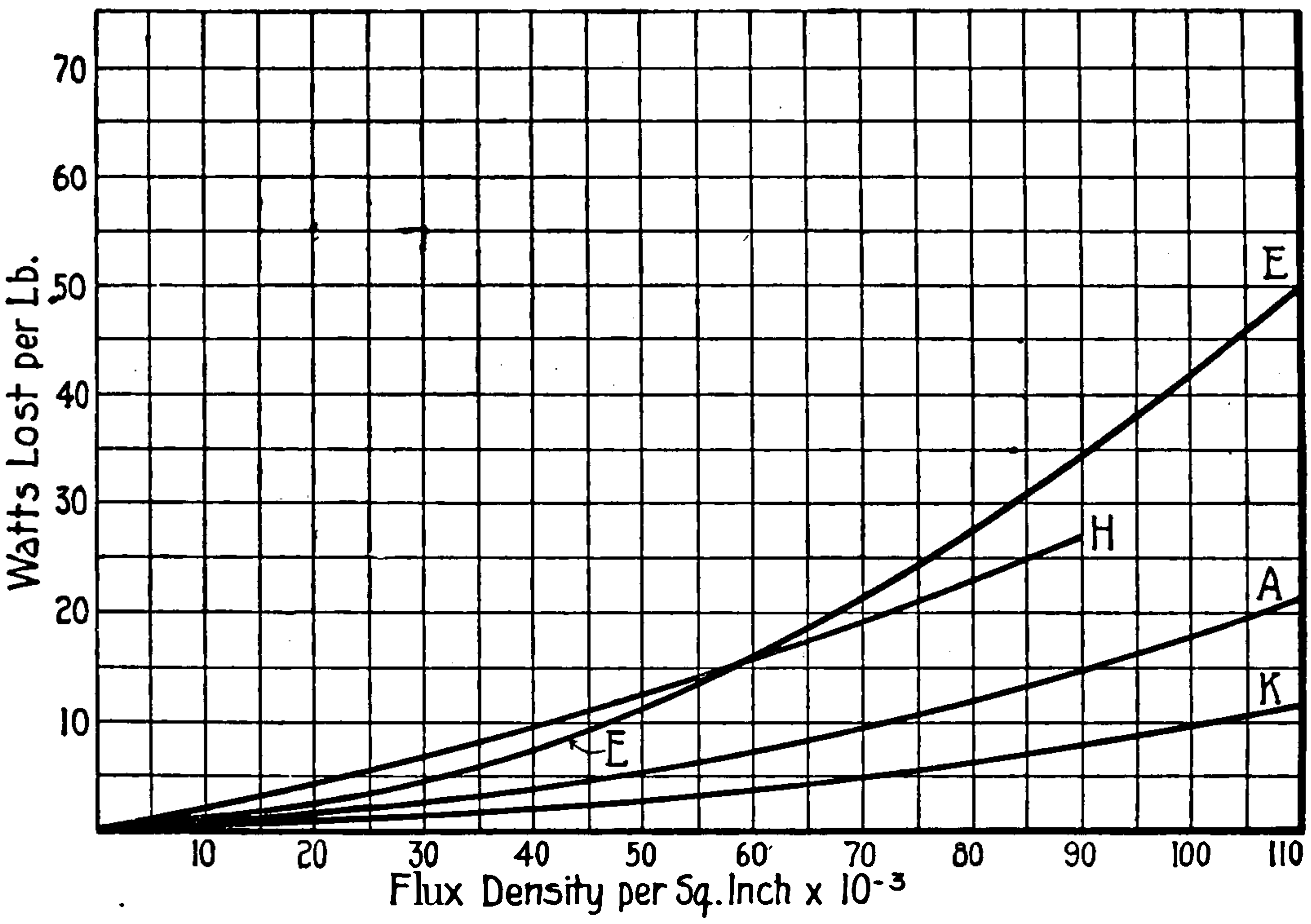



Fig. 139. Standard Iron-Loss Curves at 30 Cycles per Second. E—Prof. Epstein; H —Hobart "Electric Motors;" A—Prof. Arnold, Die Gleichstrommaschine; K—G. Kapp, Gleichstrom und Wechselstrom

results. These are so obscure as to baffle computation and, as their value is small, they may be neglected.

**Heating of Armatures.** The amount of heat which will be dissipated by a unit-surface of a moving armature depends upon:

(1) Resistance, eddy-current, and hysteresis losses in the armature.

(2) Heat-radiating surface of the armature.

(3) Peripheral speed of the armature.

(4) Proportion, within limits, of the ratio of the radiating surface to polar surface.

(5) Temperature of the radiating surface.

*Proceedings of the Institution of Electrical Engineers of Great Britain, Nov. 11, 1906.

The first of these is dependent upon the internal actions of the armature, and represents the total heat which must be dissipated.

The surface exposed to the cooling action of the air is somewhat indefinite, but in most cases the total peripheral surface of the armature is assumed as radiating surface, and to this may be added one-half the surface of the ends of the armature.

As the peripheral speed of the armature becomes greater, it is found that the radiating capability of its surface increases, though not in direct proportion.

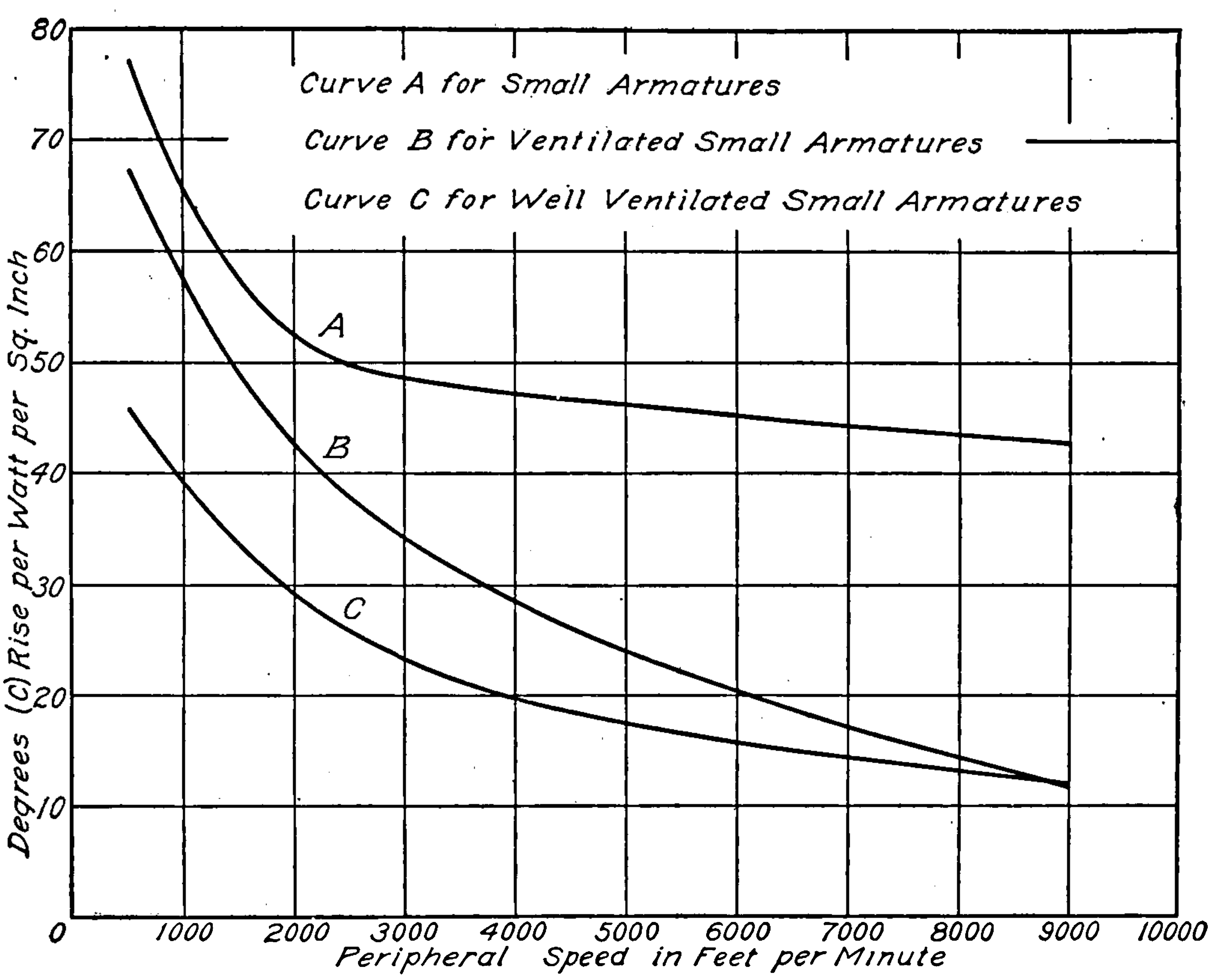



Fig. 140. Curves for Estimating Temperature-Rise

A. H. and C. E. Timmerman* found by actual test that the effect of pole-faces above a surface is to interfere with the radiation of heat. As the proportion of surface covered by the pole-faces became larger, the amount of heat radiated per degree rise in temperature became less. They also found that elevation in temperature of a surface caused an increase in the radiation of heat per degree rise in temperature, but that this rate diminished as the temperature rose.

*Transactions of the American Institute of Electrical Engineers, Vol. X, 1893.

**TABLE XI**

**Voltage and Number of Segments**

| For Machines Working at | Average Volts per Segment = $e_k$ | Average Segments per Pole or Circuit |
|---|---|---|
| 500 to 650 volts | 5 to 12 | 40 to 150 or more |
| 200 to 250 volts | 3 to 8 | 25 to 75 |
| 100 to 130 volts | 2 to 4 | 20 to 50 |

The proper number of segments is, therefore, determined by the winding of the armature, which depends upon the voltage and output of the machine. If by experience the suitable number of average volts per segment $e_k$ of the commutator be known, then $K$, the number of segments, may be readily computed from the following formula

$$K = Ec \div e_k \qquad (29)$$

Experience shows that the values of $e_k$ indicated in Table XI, may be chosen, although the matter is influenced by the current to be collected. If the latter be less than 100 amperes, then the value of $e_k$ may be increased, but in no case should it exceed 25 volts.

Arnold has given the rule that *the number of commutator segments must never be less than from 0.037 to 0.04 times the product of the number of armature inductors into the square root of the current carried by one circuit of the armature.* This rule is an empirical one based on observations with regard to sparking; nevertheless it has been found that good machines were built in which the constant was slightly less than 0.037.

EXAMPLE. A 1,000-kilowatt generator having 16 paths in parallel through its armature produced 500 volts at its terminals. The number of armature conductors was 2,304. Hence, according to Arnold's rule, $K$ must not be less than $0.037 \times 2{,}304 \sqrt{2{,}000 \div 16} = 956$. As a matter of fact, 1,152 segments were taken for this machine, making the number of segments equal to one-half the number of conductors.

**Size of Commutator.** The size of the commutator depends upon the number of segments, their thickness and that of the insulation between them, and the length of the segments parallel to the shaft. The diameter is limited by the peripheral speed allowable. The length depends upon the amount of current to be collected, a density of 40 amperes per square inch being as much as should be allowed for the contact area between a carbon brush and the bar. Bars are rarely ever thinner than 0.2 inch, or with insulation say 0.25 inch, and the peripheral speed of a commutator seldom exceeds 2,500 feet per minute; so that by keeping within these limits good results may be expected. A favorite size for commutator diameters is $\frac{3}{4}$ that of the armature diameter, which serves as another guide.

**Commutator Losses.** The losses which the commutator surface must take care of may be divided into those arising from the resistance, or more properly the voltage drop, of the brush contact, and from the friction of the brushes against the rotating commutator. The former depends mainly upon the following factors:

(1) Material of the brushes.
(2) Pressure of the brushes upon the commutator.
(3) Peripheral speed of the commutator.
(4) Current-density in the brush.
(5) Condition of commutator and brushes.

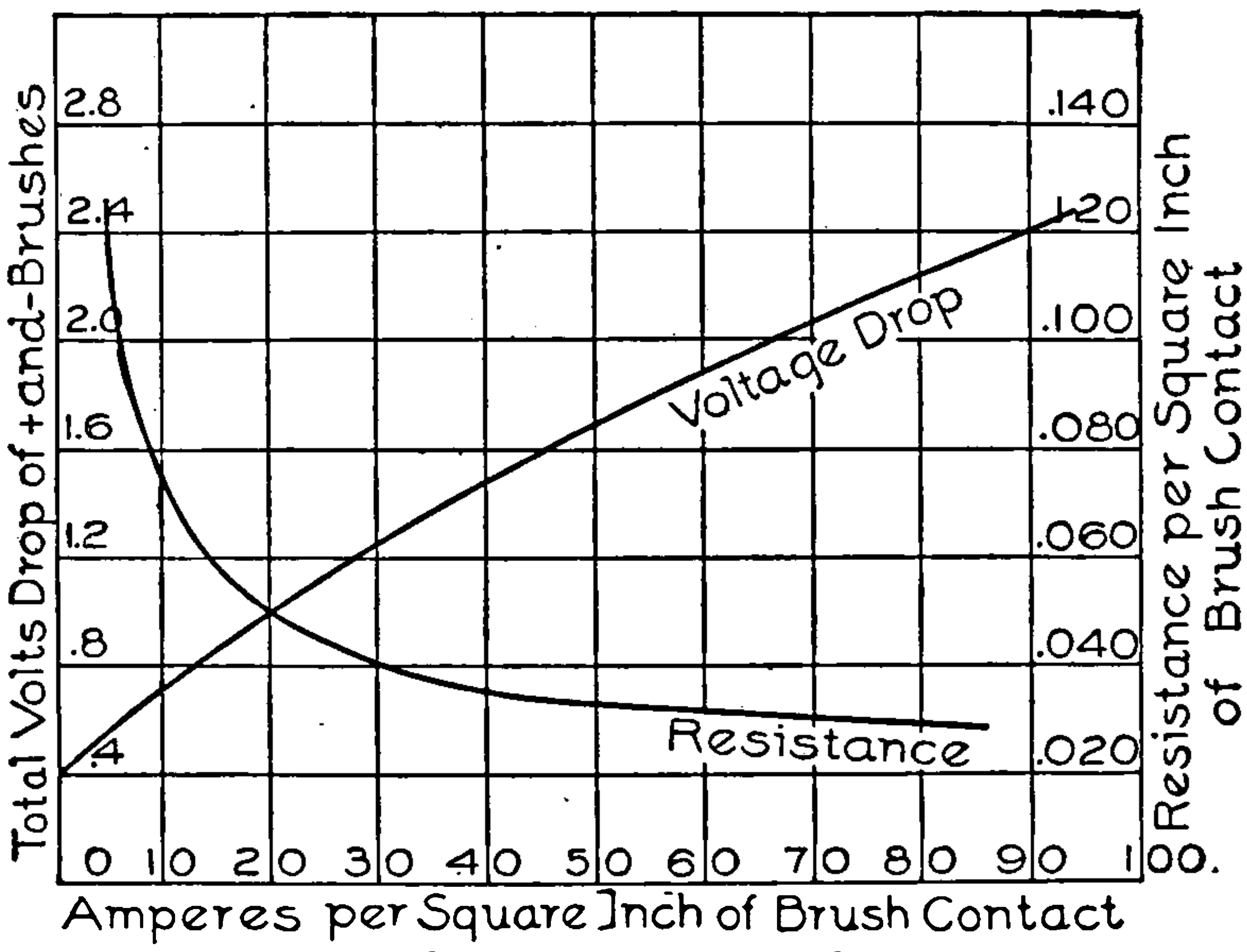



Fig. 141. Curves Showing Average Brush Drop and Contact Resistance at Various Current-Densities for Several Standard Grades of Carbon and Graphite Brushes

The loss due to friction of the brushes upon the commutator varies with:

(1) Pressure of the brushes.
(2) Peripheral speed of the commutator.
(3) Coefficient of friction between commutator and brushes.

Fig. 141 shows the effect of various current-densities. Fig. 142 shows how the pressure of the brushes affects the voltage-drop; while

Fig. 143 indicates the effect of peripheral speed of the commutator upon this drop, if we divide the watts loss by the amperes per square inch of brush contact; Fig. 141 also illustrates the relation between the current density in the brush and the voltage-drop across both positive and negative brushes. The influence of the condition of the commutator and brushes upon contact resistance cannot be stated exactly; but it is a fact that if either be in bad condition, the losses at the commutator may be increased many fold.

Multiplying the volts drop, obtained from Fig. 141, by the current per brush set, we obtain the energy loss due to brush-contact resistance. For example, if we design the brushes so that the current-density in them is 35 amperes per square inch at rated load, we have a drop over the contact surfaces of both positive and negative brushes

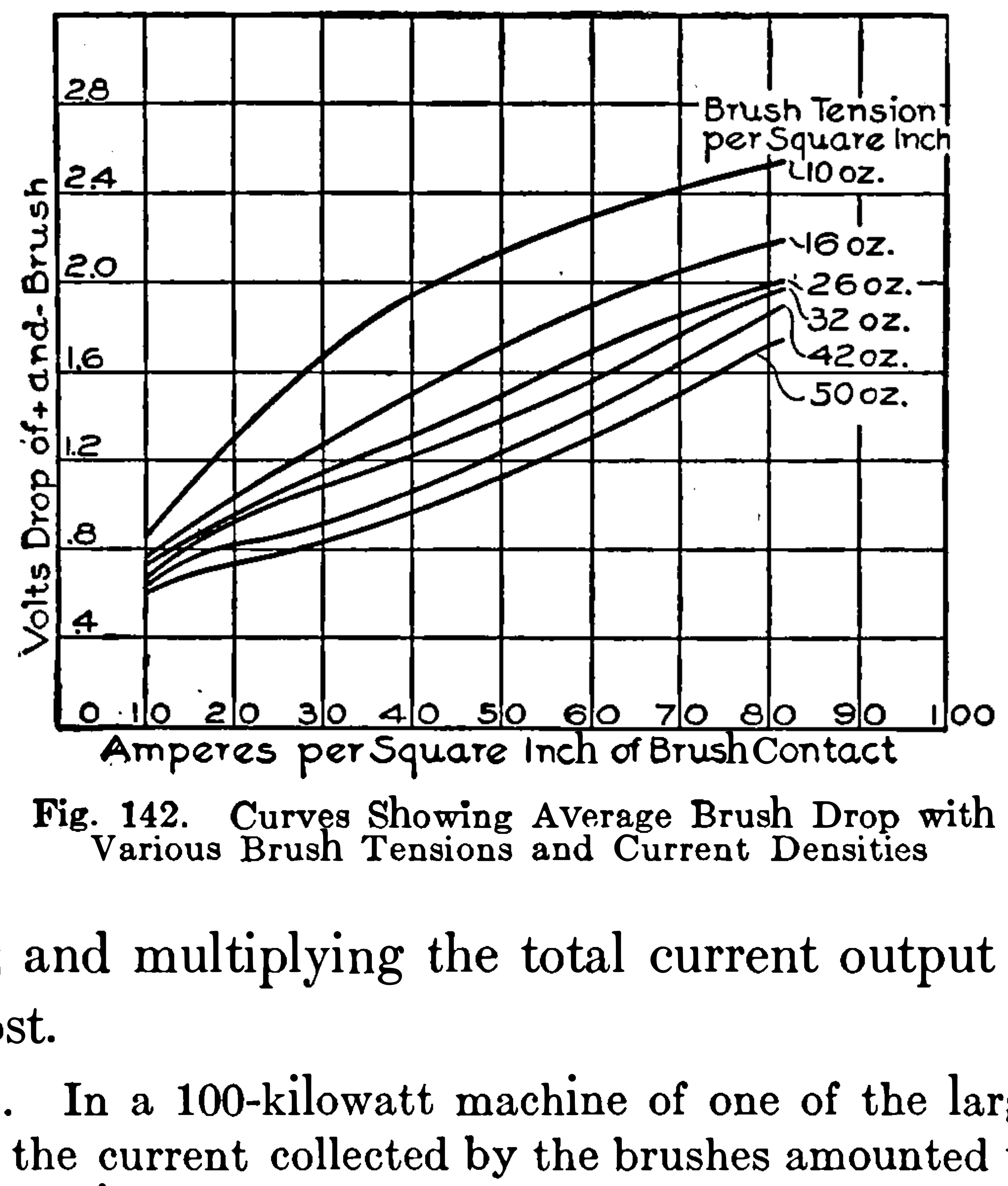



Fig. 142. Curves Showing Average Brush Drop with Various Brush Tensions and Current Densities

of 1.35 volts; and multiplying the total current output by 1.35 gives the watts lost.

Example. In a 100-kilowatt machine of one of the large manufacturing companies, the current collected by the brushes amounted to 415 amperes. If the current-density in the brushes had been 35 amperes per square inch, the loss due to contact resistance would have been

$$1.35\times415=560 \text{ watts}$$

The variation of friction losses, which the surface of the commutator must radiate as heat, with peripheral speed of the commutator at various pressures, is shown graphically in Fig. 143, while the dependence of the coefficient of friction upon the commutator peripheral speed is indicated by Fig. 144 for carbon brushes in good condition.

**Commutator Heating.** The final temperature which the commutator surface will attain depends upon the total losses to be radiated by it and the radiating surface, together with the peripheral speed. According to tests made by Prof. E. Arnold, the final rise in temperature of the commutator in degrees centigrade will be

$$\theta_k = \frac{46.5 \times w_k}{A_k(1+0.005\ v_k)} \qquad (30)$$

in which $w_k$ represents the total commutator losses, electrical and mechanical, in watts; $A_k$ represents the radiating surface of the commutator in square inches; and $v_k$ represents the peripheral speed of the commutator in feet per minute.

According to Parshall and Hobart, the rise in temperature of the commutator will seldom exceed 20° C. with one watt per square inch of peripheral radiating surface at a peripheral speed of 2,500 feet

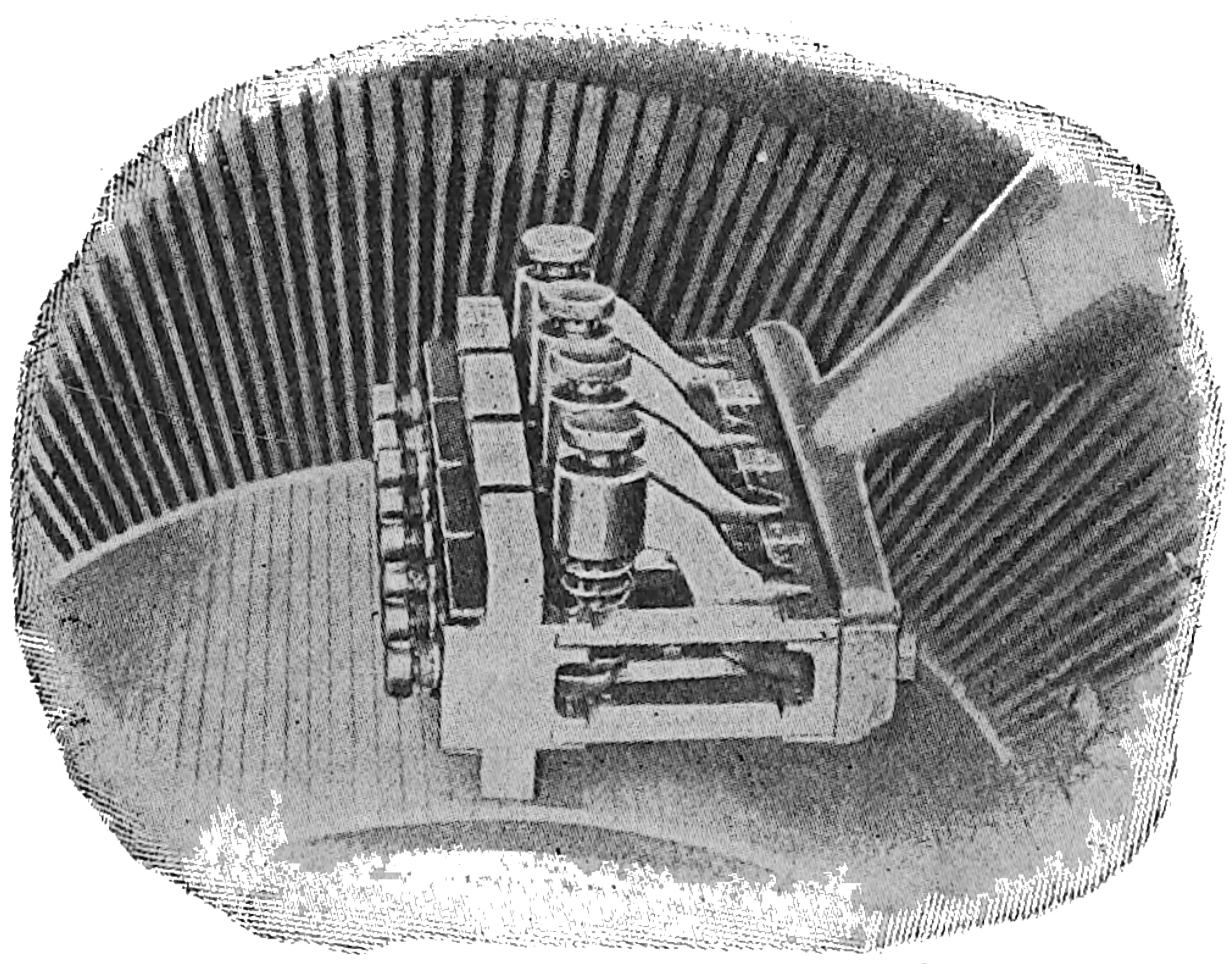


Fig. 145. Parallel Movement Brush Holder

per minute, a figure which may be much improved upon with ventilated armatures.

**Number and Size of Brushes.** The total number of brush sets is usually fixed by the type of armature winding, as previously stated; but this criterion gives us no clew to the number of brushes per set. In all but the smallest machines, it is usual to place at least two brushes exactly similar, side by side—Fig. 145 shows four—instead of one broad brush, thus allowing one brush to be removed for trimming or renewal while the machine is running. The contact between the brushes and the commutator is made much better by this subdivision,

### TABLE XII
### Standard Sizes of Carbon Brushes

| Length Width Thickness | Length Width Thickness | Length Width Thickness | Length Width Thickness | Length Width Thickness | Length Width Thickness | Length Width Thickness |
|---|---|---|---|---|---|---|
| 2½×2¼× ¼ | 3×1 × ¼ | 3½×1 × ¼ | 4×1 × ¼ | 5×1 × ¼ | 6×1½× ½ | 7×1½× ½ |
| 2½×2¼× ½ | 3×1 × ½ | 3½×1 × ½ | 4×1 × ½ | 5×1½× ¼ | 6×1½× ¾ | 7×2 × ½ |
| 2½×2¼× ¾ | 3×1 × ¾ | 3½×1 × ¾ | 4×1 × ¾ | 5×1½× ½ | 6×1½×1 | 7×2¼× ½ |
| 2½×2¼×1 | 3×1 ×1 | 3½×1 ×1 | 4×1 ×1 | 5×1½× ¼ | 6×1½×1¼ | 7×2½× ½ |
| 2½×2 × ½ | 3×1½× ¼ | 3½×2 × ¼ | 4×1½× ¼ | 5×1½×1 | 6×1½×1½ | 7×2½× ⅜ |
| 2½×2½× ¼ | 3×1½× ½ | 3½×2 × ½ | 4×1½× ½ | 5×1½×1½ | 6×2 × ½ | 7×2½× ⅝ |
| 2½×2½× ½ | 3×1½× ¾ | 3½×2 × ¾ | 4×1½× ¾ | 5×2 ×1 | 6×2½× ¾ | 7×2¼× ⅜ |
| 2½×2½× ¾ | 3×1½×1 | 3½×2 ×1 | 4×1½×1 | 5×2 ×1¼ | ........... | 7×2¼× ⅝ |
| 2½×2½×1 | 3×2 × ¼ | 3½×3 × ¼ | 4×2 × ¼ | 5×2½× ¼ | ........... | 7×2¼× ¾ |
| ........... | 3×2 × ½ | 3½×3 × ½ | 4×2 × ½ | 5×2½× ½ | ........... | 7×2¼× ⅞ |
| ........... | 3×2 × ¾ | 3½×3 × ¾ | 4×2 ×1⅜ | 5×2½×1 | ........... | 7×2¼×1 |
| ........... | 3×2 ×1 | 3½×3 ×1 | ........... | ........... | ........... | 7×2¼×1½ |
| ........... | 3×3 × ¼ | 3½×3½× ¼ | ........... | ........... | ........... | ........... |
| ........... | 3×3 × ½ | 3½×3½× ½ | ........... | ........... | ........... | ........... |
| ........... | 3×3 × ¾ | 3½×3½× ¾ | ........... | ........... | ........... | ........... |
| ........... | 3×3 ×1 | 3½×3½×1 | ........... | ........... | ........... | ........... |
| ........... | ........... | 3½×3½×1½ | ........... | ........... | ........... | ........... |

for a slight inequality at one point of the latter may slightly raise one brush of a set at each revolution, without much harm, while with one broad brush, the entire brush would be lifted, causing bad sparking. Subdivision of the brush also tends to equalize the wear upon the commutator, each brush being separately held against the commutator, and the gap between two adjacent brushes of the same set being bridged by the brushes of the other set or sets. The number of individual brushes in each group depends upon the current capacity, the size of the machine, and the judgment of the designer, and varies from two to eight or more.

The proper thickness for carbon brushes cannot be stated definitely, but they are usually made to span 2 to 2½ bars in the case of armatures having simplex windings. For armatures with duplex and triplex windings, thicker brushes must necessarily be used. It is usual to have metal brushes span about 1½ commutator bars.

Table XII gives standard sizes of carbon brushes employed by most manufacturing companies; and in designing a generator or motor, it is best to select one of these sizes that most closely approximates the requirements.

**Heating of Carbon Brushes.** Fig. 146 gives the variation of the temperature-rise of two well-known grades of carbon brushes with increase in the current-density employed. The room temperature at the time of the test was about 24° C., so that the values on the curves represent final or total temperatures. It is, therefore, necessary to deduct 24 from the values given by these curves in order to realize the actual temperature-rise.

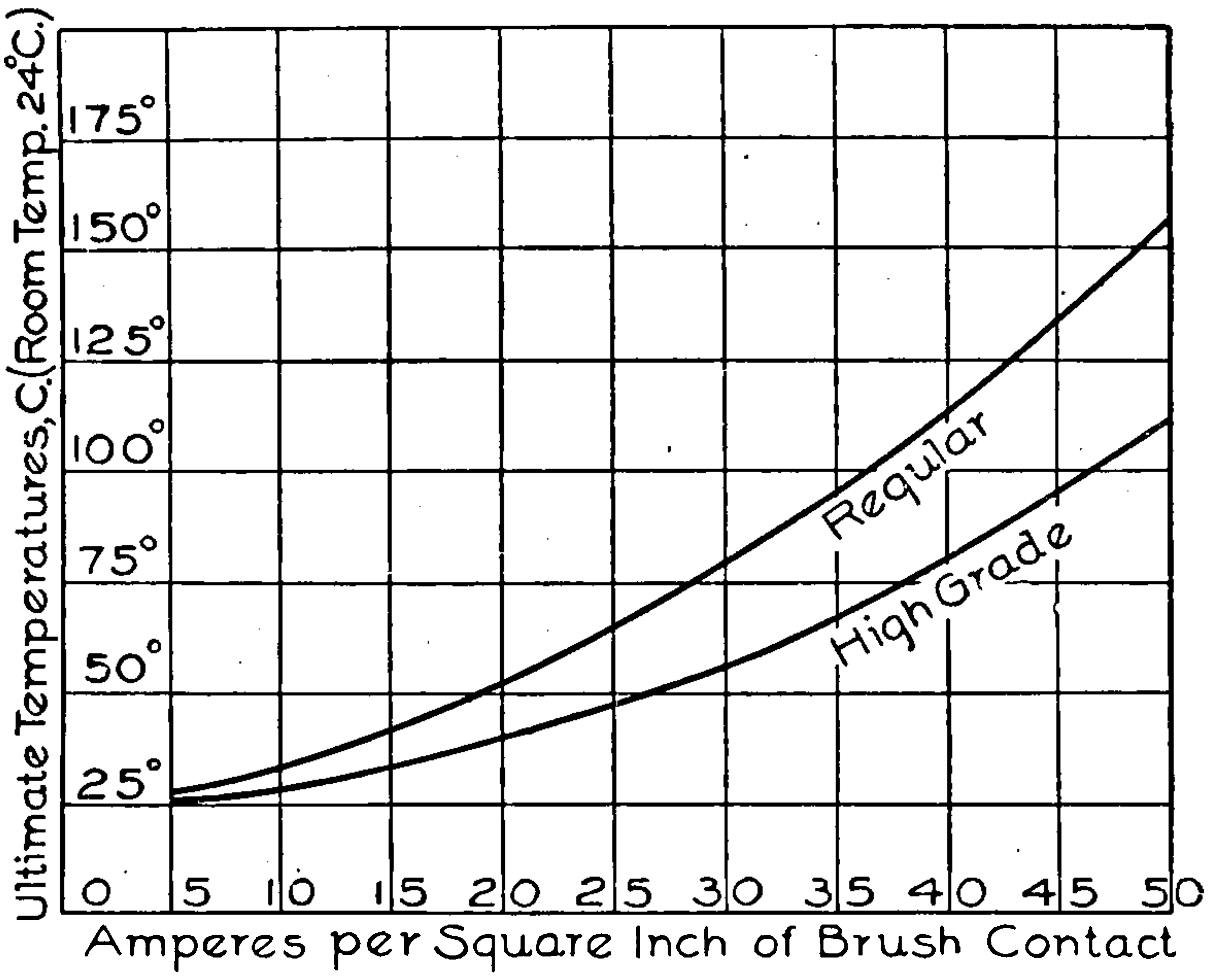
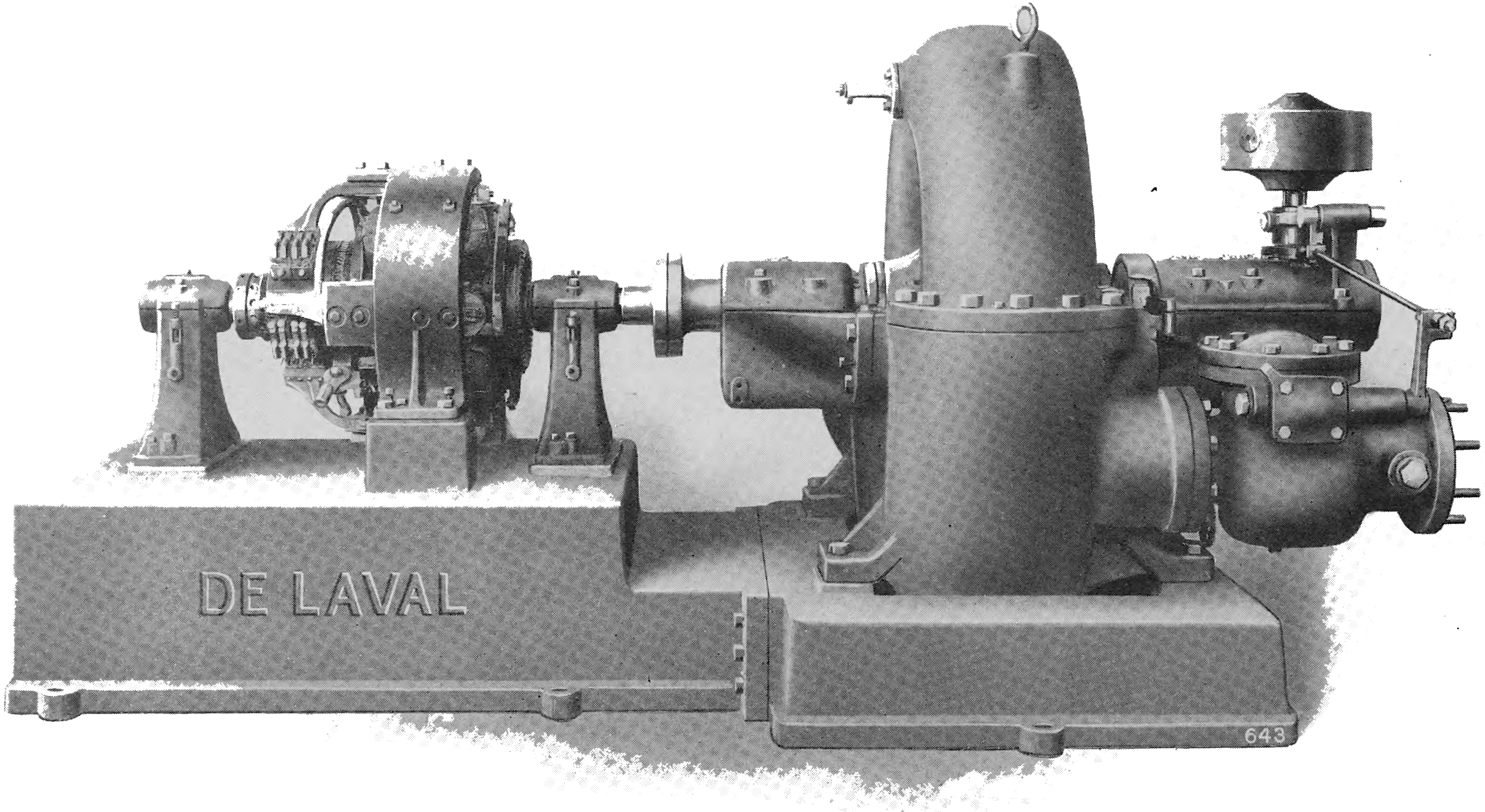



Fig. 146. Average Temperature Curves of Standard Grades of Carbon or Graphite Brushes

## CALCULATIONS OF MECHANICAL PARTS

The usual practice is to have the magnet yoke of a generator or motor serve as a frame for all the remaining parts, except in larger sizes, for which independent bearings are used. The strength of the material used in the field-ring is great, and as its bulk is large in comparison with the load sustained, it is rarely that mechanical calculations are made. However, in the case of the armature shaft, the arms or spokes for the spider, and the bearings, calculations are necessary.

**Armature Shafts.** The shafts of armatures are usually made of mild steel; and for their design, reference may be made either to standard works on machine design or to the following formulas based on the usual methods employed in that class of work, and modified to meet the requirements of electrical machinery. Shafts for the latter are generally made somewhat larger than for other




**DE LAVAL "CLASS C" TURBINE DRIVING HIGH SPEED DIRECT-CURRENT GENERATOR**

*Courtesy of DeLaval Steam Turbine Company*

machines, on account of the magnetic pull which comes upon the shaft when the armature is even slightly out of center of the poles, as already noted.

The diameter of that portion of the shaft within the armature core, Fig. 147, may be found from the expression

$$d_c = k_1 \sqrt[3]{\frac{W}{\text{r. p. m.}}} \tag{31}$$

in which

$d_c$ = Shaft diameter within the core, in inches;

$k_1$ = A constant depending upon the output of the machine as given in Table XIII;

$W$ = Output of the machine in watts.

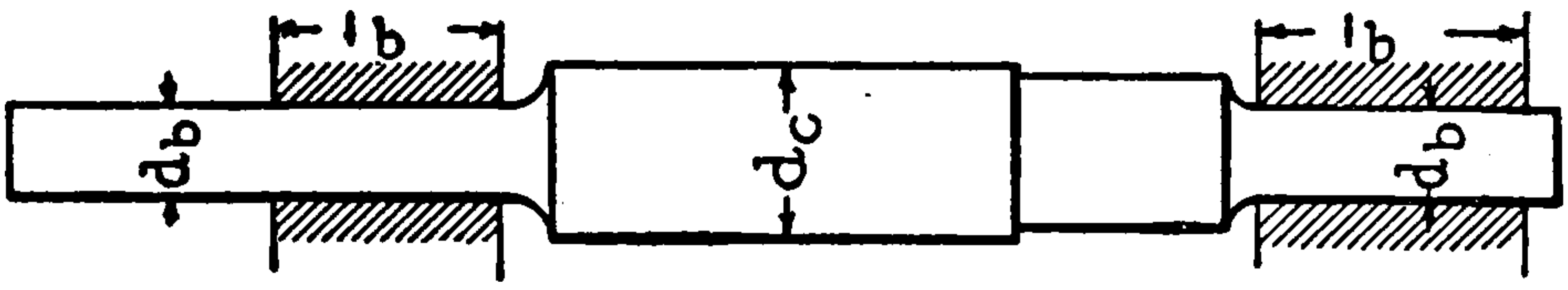



Fig. 147. Armature Shaft

**TABLE XIII**

**Value of Constant in Formula for Diameter of Core Portion of Shaft**

| Capacity of Machine (in Kilowatts) | Value of $k_1$ |
|---|---|
| Up to 1 kilowatt | 1 |
| 1– 5 " | 1.1 |
| 5– 10 " | 1.2 |
| 10– 50 " | 1.3 |
| 50– 100 " | 1.4 |
| 100– 200 " | 1.5 |
| 200– 500 " | 1.6 |
| 500–1,000 " | 1.7 |
| 1,000–2,000 " | 1.8 |

The shaft diameter in the bearing or journal may be computed from the formula

$$d_b = k_2 \sqrt{W} \sqrt[3]{\text{r. p. m.}} \tag{32}$$

TABLE XIV

**Value of Constant in Formula for Diameter of Shaft in Bearing**

| Type of Armature | Value of $k_2$ |
|---|---|
| High-speed drum armature | 0.0025 |
| High-speed ring armature | 0.003 |
| Low-speed drum armature | 0.004 |
| Low-speed ring armature | 0.005 |

in which $d_b$ = diameter of the shaft in the bearing; and $k_2$ = a constant depending upon the speed (see Table XIV). The length of the shaft in bearings $l_b$ varies from 2 to 4 times the diameter, depending upon the speed, the lower value being for a speed of 200 r. p. m. and the higher for about 1,200 r. p. m.

**Armature Spider Spokes.** Drum armatures in which the core consists of a ring of iron supported by means of a skeleton pulley or

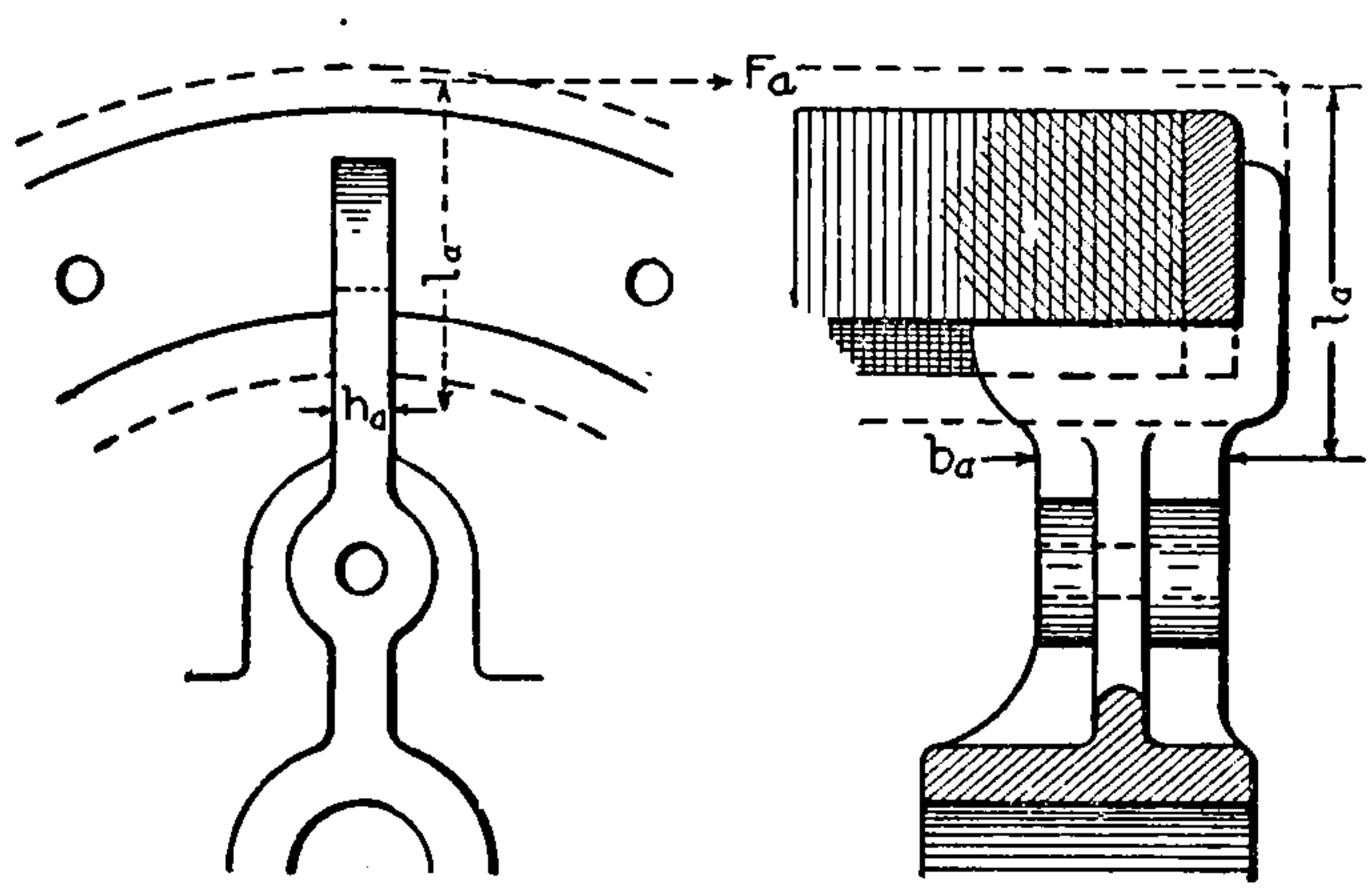



Fig. 148. Ring-Core Drum-Wound Armature in Process of Construction

spider attached to the shaft, the winding being placed in slots in the circumference of the core, are called *ring-core* armatures to distinguish them from *ring-wound* armatures such as shown in Fig. 45. Fig. 148 represents a ring-core, drum-wound armature in process of construction. In both cases the driving of the armature is effected by a number of spokes which, respectively, form part of the spider itself (Fig. 149) or of a separate frame keyed to the skeleton pulley (Fig. 150). The spokes are usually elliptical in cross-section, and are generally made of cast iron or steel. They should be designed adequately to support and drive the armature.

**Armature Binding Wires.** In the case of toothed armatures, the conductors must be held in the slots. For this purpose it is customary to use wedges driven in under the tops of the teeth, or, in the case of straight teeth, to use a number of external bands known as *binding wires*. These must be strong enough to resist the centrifugal forces, and yet at the same time occupy very little radial depth, that they may not interfere with the clearance between the armature and the pole-faces. The almost invariable practice is to use a tinned wire of hard-drawn brass, phosphor-bronze, or steel, which, after winding, can be sweated together into a solid band. The ultimate tensile strength of phosphor-bronze is from 65,000 to 120,000 pounds per square inch, while that of steel wire varies from 120,000 to 250,000 pounds per square inch, the larger figures relating to the smaller sizes of wire.

To estimate the proper size and number of binding wires required, we have that if $d$ be the diameter (in inches) of the circular path described by a mass of weight $W_1$ pounds, the centrifugal force will be $= 0.0000143 \times d \times w \times \overline{\text{r. p. m.}}^2$ pounds weight. So that if we assume a value of 100,000 pounds per square inch as the maximum allowable tensile stress in steel or phosphor-bronze wire, and allow a safety factor of, say 10, the total section of binding wire required will be equal to

$$\frac{0.0000143 \times 10 \times w \times Z \times d \times \overline{\text{r. p. m.}}^2}{\pi \times 100{,}000}$$

or

$$4.55 \times 10^{-10} \times w \times Z \times d \times \overline{\text{r. p. m.}}^2 \text{ square inches}$$

wherein $w$ is the weight of one inductor and $Z$ the number of inductors, consequently $W_1$ will be equal to $wZ$. From this total necessary section and an appropriate wire table, the number of wires is then calculated, and they are then arranged in suitable belts.

Example. Let $w = 0.39$ lb.; $Z = 1{,}536$; $d = 62$ in.; r. p. m. $= 150$. The total necessary section computed by the above formula is 0.379 square inch. Referring to the wire gauge tables, we find that 148 wires of No. 15 B. & S. gauge will fulfil the conditions. These may be arranged as follows: 5 belts of 16 wires each over the core body, and 4 belts of 17 wires each over the extended ends of the winding (*i. e.*, 2 belts of 17 wires each over each end).

Under each belt of binding wires, it is usual to lay a band of insulation. These bands generally consist of two layers, first a thin

TABLE XV

**Value for Constant in Formula for Length of Armature Bearing**

| Capacity of Machine (in Kilowatts) | High-Speed Armatures | Low-Speed Armatures |
|---|---|---|
| Up to 5 kilowatts | 0.1 | 0.15 |
| " 10 " | 0.1 | 0.175 |
| " 50 " | 0.125 | 0.200 |
| " 100 " | 0.150 | 0.225 |
| " 500 " | 0.175 | 0.250 |
| " 1,000 " | 0.200 | 0.275 |
| " 2,000 " | 0.225 | 0.300 |

strip of vulcanized fiber or of hard red varnished paper slightly wider than the belt of wires, and then a strip of mica (in short pieces) of about equal width. Sometimes small straps of thin brass are laid under each belt of binding wires, having tags which can be turned over and soldered down to prevent the two ends of the binding wire from flying out.

**Armature Bearings.** Bearings for generators and motors should be very strong and rigid, with ample wearing surface, in order that the armature may not become materially displaced with respect to the poles as a result of magnetic attraction as well as weight, and also to prevent overheating of the journals. The following formula takes into account the increased generation of heat at higher peripheral velocities, and also provides sufficient wearing material:

$$l_b = k_3 \times d_b \sqrt{\text{r. p. m.}} \qquad (33)$$

wherein

$l_b$ = Length of the bearing, in inches;

$d_b$ = Diameter of the shaft in the bearing (from page 129);

$k_3$ = A constant dependent upon the speed of the armature (given in Table XV).

**Losses Due to Friction in Bearings and to Windage.** These are very difficult to predetermine with even reasonable accuracy. Designers usually estimate them from previous experience. For belt-driven machines ranging in speeds from 1,800 r. p. m. to 300 r. p. m. and of capacity from 30 to 500 kw., these losses should range from 3 per cent of the output in the smaller machines to 1 per cent in the larger sizes. For direct-connected generators, this figure ranges from 1 per cent to 0.4 per cent of the output, depending upon the size and speed, being lower for machines of this type on account of the lowered r. p. m. and the better alignment.

**Calculation of Efficiency.** On page 63, efficiency was defined as the ratio between output and input of the machine. It may also be defined as the ratio between the output and the output plus the losses. These latter come under the following heads, the computation of each having been previously considered:

(1) *Copper Losses.* These consist of the sum of the $I^2R$ losses in the armature field-coils, and increase as the square of the current—being, however, independent of the speed.

(2) *Iron Losses.* These are made up of the eddy-current and hysteresis losses produced in the armature core-plates owing to the changes in flux-polarity and density to which they are periodically subjected. They vary slightly with load, on account of the strained distribution produced, and are always variable with the speed, eddy currents varying as the square of the speed, and hysteresis losses directly as the speed.

(3) *Excitation Losses.* These consist of the watts expended as heat and utilized to drive the magnetizing current around the magnetizing coils, and are included in machine $I^2R$ losses.

(4) *Commutator Losses.* These losses may be subdivided into:

(*a*) $I^2R$ loss due to brush-contact resistance;

(*b*) Brush friction loss;

(*c*) Losses through sparking and through eddy currents in the commutator bars.

Of these, *a* and *b* are the only ones usually considered, the other (*c*) being practically negligible except in generators furnishing large currents at very low voltages.

(5) *Bearing Friction and Windage Losses.* The former are the losses due to the friction of the shaft in the bearings, and depend only upon the load and speed. The latter are occasioned by the armature churning the air, and are independent of the load, but vary with the speed.

(6) *Secondary Copper and Iron Losses.* These have already been considered as eddy-current loss in the armature conductors, eddy-current loss in the pole-faces, etc.

Calculating each of these losses by the method given in detail above, we have

$$\eta = \frac{w_0}{w_0 + w_1 + w_2 + w_3 + w_4 + w_5 + w_6} \qquad (34)$$

wherein $w_0$ is the output of the machine in watts, and $w_1$, $w_2$, $w_3$, etc., represent the losses in watts just enumerated. Representative curves of these losses are shown on pages 22 and 155, while Table XVI gives the average efficiencies and apportionment of losses of direct-driven machines of various sizes.

To illustrate the method of constructing the magnetization curve of a continuous-current generator, let us consider the case of a standard Crocker-Wheeler generator, the dimensions and particulars of which are as follows:

| | |
|---|---|
| **General:** | |
| Rated load output in kilowatts | 150 |
| Terminal voltage at rated load | 250 |
| External current, in amperes, at rated load | 600 |
| Armature speed, in r. p. m. | 225 |
| Number of poles | 8 |
| **Armature Dimensions:** | |
| External diameter of core, in inches | 45 |
| Internal diameter of core, in inches | 34.5 |
| Number of slots | 116 |
| Depth of each slot, in inches | 1.00 |
| Width of each slot, in inches | 0.66 |
| Pitch of slot at armature face, in inches | 1.22 |
| Radial depth of iron in core under teeth, in inches | 4.25 |
| Total length of core, in inches | 13 |
| Iron or effective length of core, in inches | 10.57 |
| Number of conductors | 928 |
| Style of winding | simplex parallel |
| Bare dimensions of each conductor, in inches | 0.08 by 0.35 |
| Insulated dimensions of each conductor, in inches | 0.14 by 0.41 |
| Mean length of one armature turn, in inches | 87.5 |
| **Field Magnet Data:** | |
| Number of poles | 8 |
| Diameter of bore, in inches | 45.62 |
| Turns per pair of poles | 1600 |
| Shunt exciting current at rated load, in amperes | 6.96 |
| Angle covered by each pole-face, in degrees | 32 |
| **Commutator Dimensions:** | |
| Diameter, in inches | 29.5 |
| Number of segments | 248 |
| Length, in inches | 8.25 |

The magnet-cores are of steel, circular in cross-section, and bolted to the yoke, the pole-shoes being in one piece with the magnet-cores. The field frame is cast in two pieces and bolted together. All the field-exciting coils are connected in series. The armature slots are parallel-sided, of the dimensions stated above. There are three ventilating apertures in the core, each $\frac{3}{8}$ inch wide. The armature winding has eight circuits in parallel, with eight sets of brushes set 45° apart.

In order to construct the magnetization curve, we have

$$E = \frac{Z \times p \times \text{r. p. m.} \times \Phi_a}{60 \times 10^8 \times c}$$

$$= \frac{928 \times 8 \times 225}{60 \times 10^8 \times 8} \Phi_a$$

$$= 0.0000348\ \Phi_a$$

As the leakage coefficient of this machine is $\nu = 1.09$, we may construct the following, since $\Phi_m = \nu \Phi_a$.

| $E$ | $\Phi_a$ | $\Phi_m$ |
|---|---|---|
| 200 | 5,750,000 | 6,260,000 |
| 220 | 6,320,000 | 6,890,000 |
| 240 | 6,900,000 | 7,520,000 |
| 260 | 7,470,000 | 8,150,000 |
| 280 | 8,050,000 | 8,780,000 |
| 300 | 8,620,000 | 9,400,000 |

From the drawings we find:

| | |
|---|---|
| Mean length of magnetic path in magnet-yoke, in inches | 29 |
| " " " " " " two magnet-cores, in inches | 15.75 |
| " " " " " " armature core, in inches | 10 |
| " " " " " " two teeth, in inches | 2 |
| " " " " " " two air gaps, in inches | 0.625 |
| Magnetic area of yoke, in square inches | 100 |
| " " " magnet-cores, in square inches | 86.5 |
| " " " armature body, in square inches | 45.6 |

The polar angle being 32°, we have, for the number of teeth under one pole

$$\frac{32° \times 116}{360°} = 10.3$$

Allowing for spreading of flux in the air gap owing to high flux-density in the teeth, we may take 11 teeth as receiving flux from each pole.

As the pitch of slots at the bottom of the slots is $\frac{135.09}{116} = 1.165$ in., and as the slots are 0.66 inch wide, we have, as the width of a tooth at its root, $1.165 - 0.66 = 0.505$ inch. The area of the teeth receiving flux from each pole will, therefore, be

$$11 \times 0.505 \times 10.72 = 59.5 \text{ square inches}$$

## TABLE XVII

### Applications of Magnetization Current Calculations

| Portion of Magnetic Circuit | Material | Mean Length of Magnetic Path (Inches) | Magnetic Area (Square Inches) | E = 200 $\Phi a = 5,750,000$ $\Phi m = 6,260,000$ | | | E = 220 $\Phi a = 6,320,000$ $\Phi m = 6,890,000$ | | | E = 240 $\Phi a = 6,900,000$ $\Phi m = 7,520,000$ | | | E = 260 $\Phi a = 7,470,000$ $\Phi m = 8,150,000$ | | | E = 280 $\Phi a = 8,050,000$ $\Phi m = 8,780,000$ | | | E = 300 $\Phi a = 8,620,000$ $\Phi m = 9,400,000$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Flux-Density | Ampere-Turns per Inch Length | Ampere-Turns | Flux-Density | Ampere-Turns per Inch Length | Ampere-Turns | Flux-Density | Ampere-Turns per Inch Length | Ampere-Turns | Flux-Density | Ampere-Turns per Inch Length | Ampere-Turns | Flux-Density | Ampere-Turns per Inch Length | Ampere-Turns | Flux-Density | Ampere-Turns per Inch Length | Ampere-Turns |
| Magnet-Yoke | Cast Iron | 29 | 2x100 | 31,300 | 28 | 812 | 34,450 | 38 | 1,100 | 37,600 | 46 | 1,332 | 40,750 | 58.5 | 1,698 | 43,900 | 72.5 | 2,102 | 47,050 | 81.5 | 2,362 |
| Two Magnet-Cores | Cast Steel | 15.75 | 86.5 | 72,500 | 15 | 236 | 79,500 | 19 | 300 | 86,900 | 25.4 | 400 | 94,200 | 39.5 | 622 | 101,500 | 56 | 882 | 108,900 | 85 | 1,339 |
| Two Air Gaps | Air | 0.625 | 163 | 35,300 | 11,020 | 6,900 | 38,800 | 12,120 | 7,590 | 42,400 | 13,250 | 8,280 | 45,900 | 14,360 | 8,960 | 49,400 | 15,450 | 9,650 | 53,000 | 16,600 | 10,380 |
| Two Teeth | Sheet Steel | 2 | 59.5 | 96,600 | 52.5 | 105 | 106,200 | 99 | 198 | 11,600 | 287 | 574 | 127,800 | 524 | 1,048 | 135,300 | 762 | 1,524 | 145,000 | 1,003 | 2,006 |
| Armature Core | Sheet Steel | 10 | 2x45.6 | 63,000 | 3.8 | 38 | 69,300 | 6.4 | 64 | 75,600 | 10 8 | 108 | 81,900 | 16.5 | 165 | 88,200 | 25.4 | 254 | 94,500 | 43 | 430 |
| Ampere-Turns per pair of Poles | | | | ...... | ..... | 8091 | ...... | ..... | 9,252 | .... | ...... | 10,694 | ....... | ..... | 12,493 | ....... | ..... | 14,412 | ........ | ..... | 16,517 |

It is usual to operate shunt-wound generators upon that portion of the magnetization curve just above the so-called bend, while compound-wound machines are usually designed to operate at no load just below the bend of the magnetization curve.

*Computation of Voltage Drop from Magnetization Curve.* At any generator load, there are four causes tending to lower the voltage at the terminals of the machine, namely, ohmic resistance of the armature and series coils (if any); drop due to brush contact; demagnetizing action of the armature; and distortion of the armature flux.

The voltage-drop due to resistance of the armature winding, series field-coils, and brush contacts, is

$$e = I_a r_a + I_a r_{se} + I_a r_b \tag{35}$$

the second term being omitted if the series winding is absent. Then, in the assumed case, Fig. 151, the no-load e. m. f. being 240, represented by $R$ on the magnetization curve, the rated-load current being 607 amperes, and the resistance of the main circuit, including brushes, armature winding, and series field-winding, being 0.02224 ohm, we have

$$e = 0.02224 \times 607 = 13.5 \text{ volts}$$

which, added to 250, the full load e. m. f., shows that the generated e. m. f. at rated load would have to be 263.5 volts, without considering armature reaction. This is represented by the point $O$ on the saturation curve; hence 12,830 ampere-turns are required to generate this e. m. f. In other words, at rated load and speed, assuming the terminal voltage to remain the same as at no load, we require 12,830 ampere-turns upon the field, assuming armature reaction absent.

As it is often convenient to check the dimensions of an armature conductor in a preliminary design by means of this voltage-drop, Table XVIII is given.

With regard to the demagnetizing ampere-turns of the armature, we know that in general these are the ampere-turns lying within twice the angle of brush lead. Assuming the brushes to be set just under the pole-tips at rated load, the demagnetizing ampere-turns will be the number of armature conductors lying between adjacent pole-corners, multiplied by the current in them.

**TABLE XVIII**

**Voltage-Drop as Related to Output in Shunt and Compound Machines**

| Output of Machine (in kilowatts) | Value of $e$ as a Percentage of Rated-Load Terminal e. m. f. | |
|---|---|---|
| | Shunt Machines | Compound Machines |
| 5 | 7 | 10 |
| 10 | 6 | 8 |
| 25 | 5 | 7 |
| 50 | 4 | 6 |
| 100 | 3.5 | 5 |
| 200 | 3 | 4 |
| 500 | 2.5 | 3 |
| 1,000 | 2 | 2.5 |
| 2,000 | 1.5 | 2 |

These ampere-turns are multiplied by the leakage coefficient, because they have to be neutralized by the field-winding; the result is added to $X_2$, and set off on the diagram as $X_3$, Fig. 151. By projecting this up to the curve, the point $F$ is obtained, which corresponds to the necessary e. m. f.

Example. In the machine being considered, the number of slots lying between pole-tips is

$$\frac{45-32}{360} \times 116 = 4.2$$

and in each slot there are eight conductors, each carrying 76 amperes at rated load. Hence, the demagnetizing ampere-turns of the armature at rated load per pair of poles (assuming that the brushes are advanced 4°.0 from the neutral position, and that the leakage coefficient is 1.09), are

$$\frac{8 \times 8 \times 116 \times 76 \times 1.09}{360} = 1,660$$

Adding these ampere-turns to $X_2$, we get $X_3$ = 14,490 as the total ampere-turns required at rated load, assuming that there is no drop in voltage caused by diminished permeability in the teeth at the forward pole-horn due to distortion of the flux.

With a smooth-core armature, the flux distortion in the air gap does not produce a diminution in the terminal voltage of the machine but with toothed armatures, allowance must be made. In Fig. 152 let $AB$ represent the width of the pole-face to scale, and $EF$ the flux-density in the air gap $B_g$. Then the area $ABCD$ is proportional to the useful flux $\Phi_a$, and at no load we may regard this flux as being uniformly distributed along the air gap as indicated by said rectangle. Assuming the permeability of the teeth to be constant, and laying off $AH$ as the flux-density at the hindward pole-horn, and $BG$ as the flux-density at the forward pole-horn, the flux density being heaped up in the latter at rated load, and withdrawn from the former, the line $HFG$ would represent the flux-density variation from point to point in the air gap, and the area $AHGB$ would be equal to the area $ABCD$, since the permeability of the air gap is constant. But the increased flux-density at the forward pole-horn causes the permeability of the teeth at this point to have a much lower value than it has with the flux-density $B_g$, while, on the other hand, the permeability of the teeth under the hindward pole-horn has increased on account of the diminished flux-density in them. As a result, the line $HFG$ takes the bent form shown by the curve $KFL$, and *the shape of this curve is the same as that of the magnetization curve over this range.* As can readily be seen from the figure, the area $AKLB$ is considerably less than the area $AHGB$, that is, there is a diminution of the useful flux $\Phi_a$, and consequently a corresponding voltage drop, which will as a rule be greater, the higher the flux-density in the teeth.

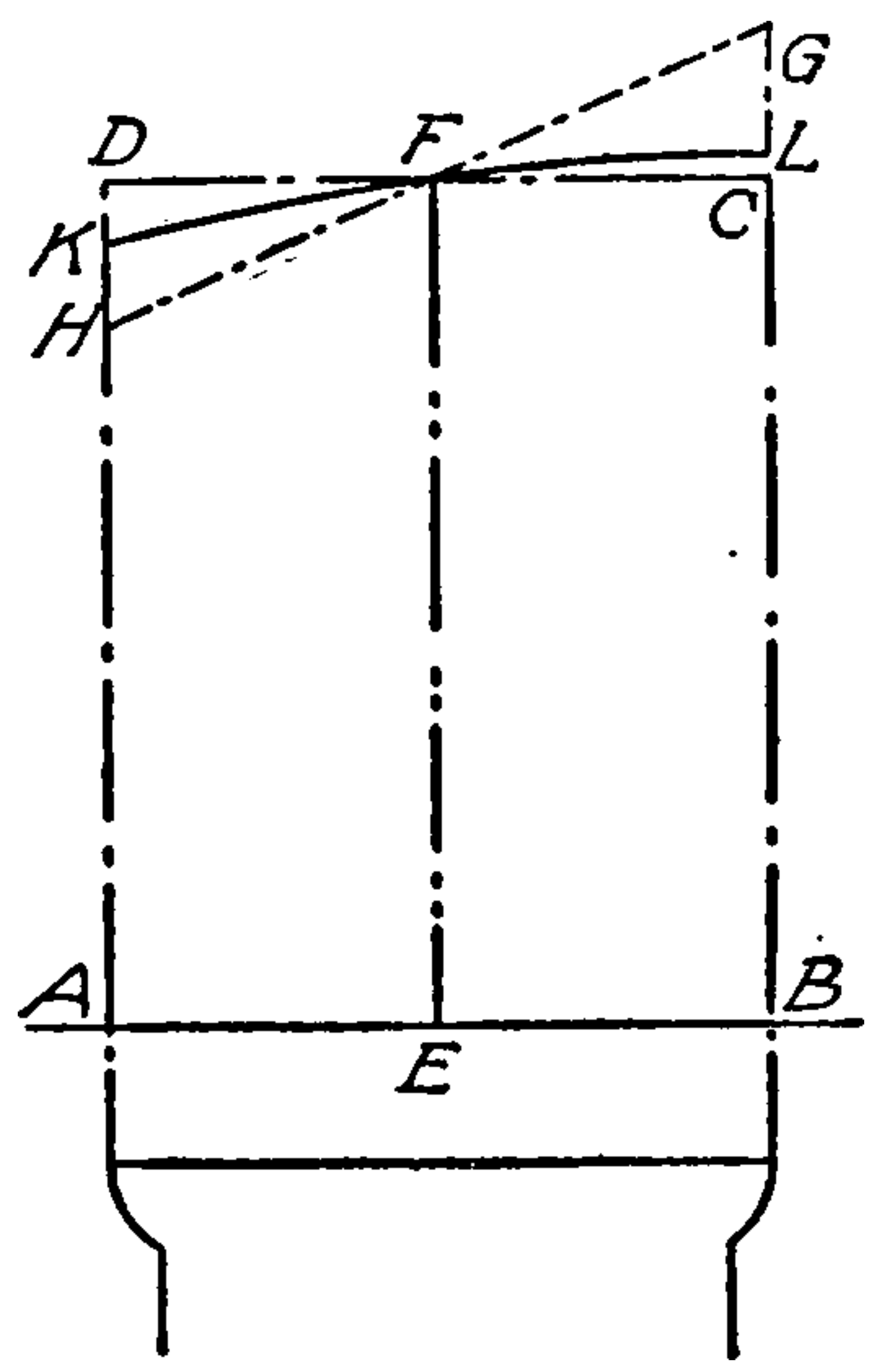


Fig. 152. Curve Showing Relation between Pressure Drop and Flux-Distortion in Air Gap

One way to estimate the number of ampere-turns needed to compensate the effect produced by the distortion of the useful flux, is as follows:

In Fig. 153, let $KL$ be the magnetization curve of the machine, the ampere-turns required for no-load, and those for rated-load induced e. m. f. at no load—and, therefore, without the extra allowance for distortion—being set off upon its scale of abscissæ $OX$, as $X_1$ and $X_3$, respectively, these having been estimated as shown in Fig 151. Now, upon $OX$, mark off $OA$ and $OB$ as shown in the figure. The point $A$ then represents the hindward pole-horn, and the point $B$ the forward pole-horn. Had the distortion been absent, the ampere-turns required to produce $E_1$ volts would have produced a flux across the gap proportional to the area of the piece $ABCD$. But, as the distortion is present, the flux is proportional to the smaller area $ABLK$. Hence, we shift the point $F$ higher up the curve to a point such as $F'$, so that the area $A'B'L'K'$ equals the area $ABCD$. This gives a new point $X_4$ along $OX$, rep-

designing the shunt regulator liberally, and by placing a shunt across the series field-coils, the desired result may be reached by trial. This is, in fact, the practice of almost all dynamo builders.

The possible discrepancies between calculations thus made and results of actual test, are shown by the following values of the ampere-turns required at no-load and at rated load, as determined by the manufacturers of the machine we have been discussing:

| Output | Calculated Values | Actual Values |
|---|---|---|
| No-load | 10,700 | 10,400 |
| Rated load | 15,800 | 15,400 |

The difference was caused, no doubt, by the fact that better quality of iron was used in the machine than that for which the ampere-turns were computed.

## CHARACTERISTIC CURVES OF CONTINUOUS-CURRENT GENERATORS

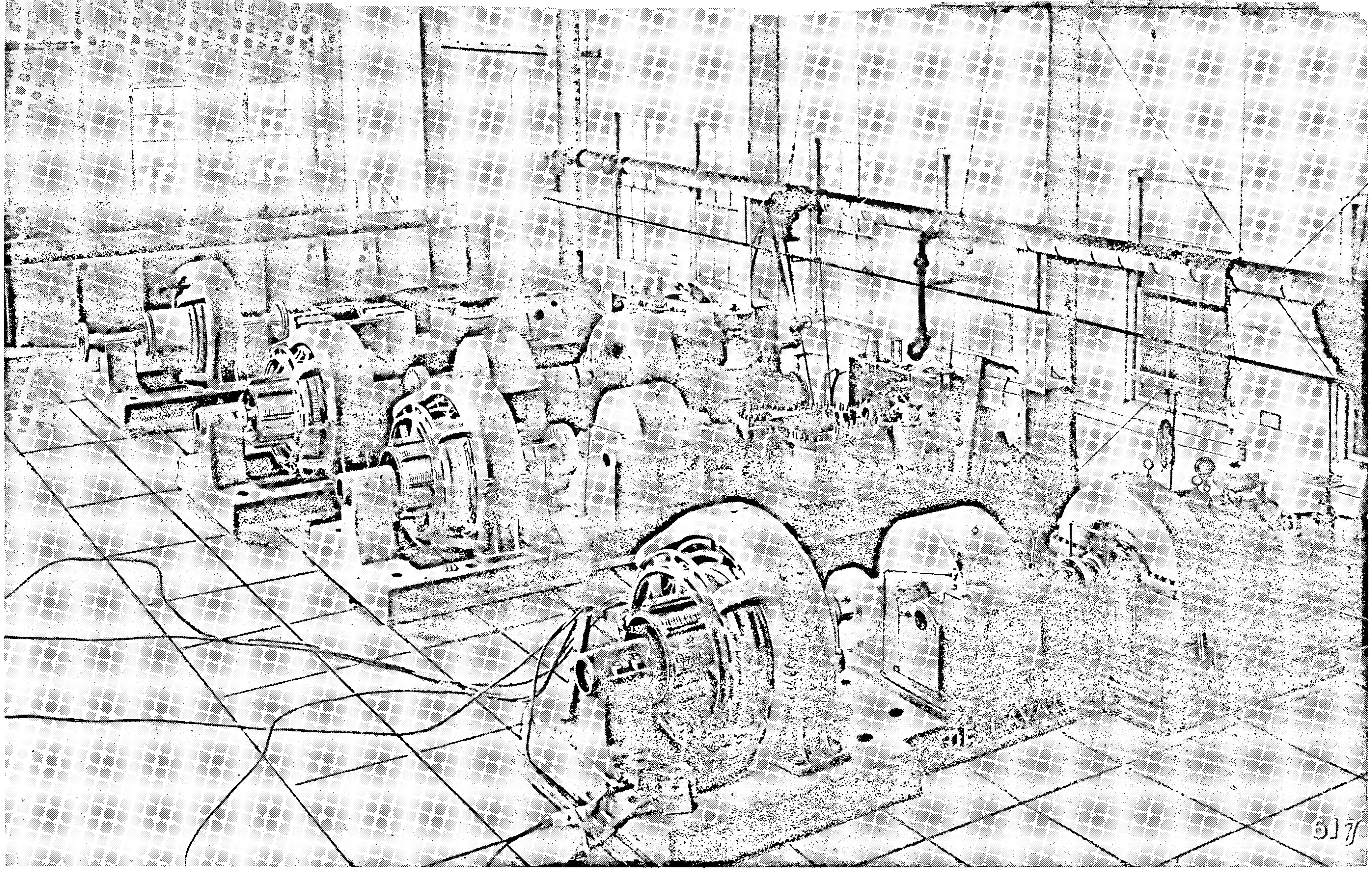
Dr. John Hopkinson, in 1879, first suggested that the behavior of a generator could best be studied from a curve representing the relation between the e. m. f. and current of the machine at different loads. In 1881, M. Marcel Deprez elaborated Hopkinson's method, determining additional curves, and gave them the name of characteristics.

At present the characteristics most commonly developed are:

(1) Magnetization curve.
(2) External characteristic.
(3) Curve of flux distortion (explained on page 41 *et seq.*)

**Experimental Magnetization Curve.** The method of predetermining the magnetization curve of any continuous-current generator was explained on page 137.

The magnetization curve of a dynamo can be determined experimentally by separately exciting its field, as shown in Fig. 154. The field current is taken from the source of constant potential, a variable resistance *VR* of great value (or a potentiometer) and an ammeter *AM* are placed in series with the fields *F*. The ammeter will measure the current which is varied from zero to a maximum value by means of the variable resistance *VR*. The armature *AA'* is rotated at rated speed and for each value of the field current the difference in potential at the brushes is read by means of voltmeter *V*.




**VIEW OF DE LAVAL MULTI-STAGE GEARED TURBINES DRIVING DIRECT-CURRENT GENERATORS ON TESTING FLOOR**

Machine in foreground is running under full load

*Courtesy of DeLaval Steam Turbine Company*

extremely small value taken by the voltmeter. This is, however, so small as to be negligible and, therefore, we may assume that no armature reaction or drop in potential occurs.

Figs. 155 and 156 are typical magnetization curves of a 30-kw. generator; Fig. 155 shows the magnetization curve of the machine when its field is wound with many turns of fine wire, *i. e.*, a shunt

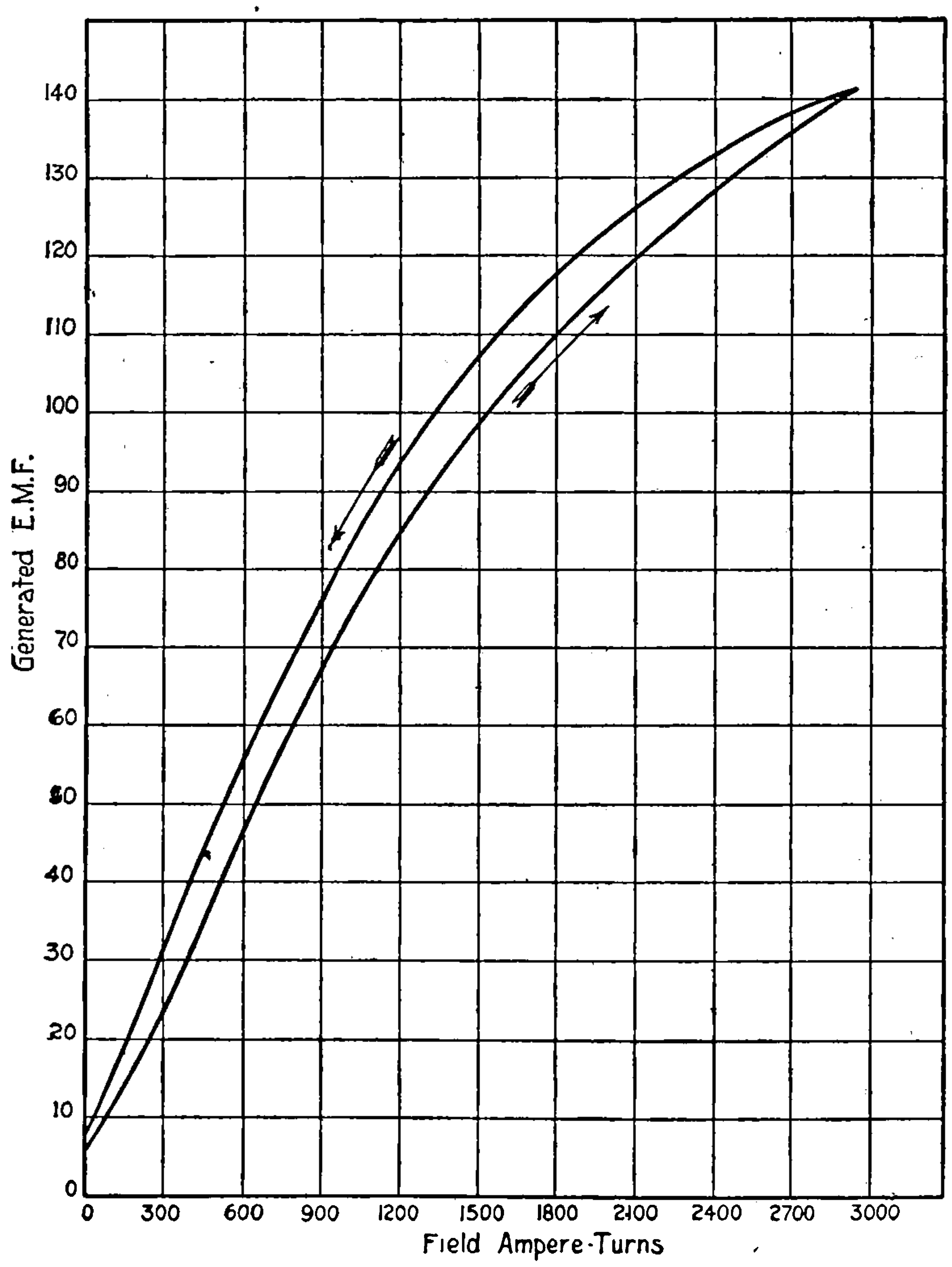



Fig. 157. Magnetization Curves of a 30-k.w.Generator with Increasing and Decreasing Field-Current

dynamo; and Fig. 156 shows the magnetization curve of the same machine when its field is wound with a few turns of coarse wire, *i. e.* a series-wound generator.

*Dependence of the Magnetization Curve upon Speed.* When the magnetization curve of a dynamo has been determined for a given speed $n$, the curve for any other speed $n'$ can be found by multiplying the ordinates of the given curve by $n' \div n$. This is evident when we consider that the flux $\Phi_a$ has a definite value for each value of field-current, so that the generated e. m. f. is proportional to the speed.

*Effect of Residual Magnetism.* When the field-exciting current of a generator is zero, the flux in the armature is in general *not* zero, on account of residual magnetism. This effect is indicated in Figs. 155 to 157, for it is seen here that when the field-exciting current is zero, the generated e. m. f. has a definite value, for the armature cutting this residual flux generates a small e. m. f.

*Effect of Hysteresis.* If, in determining the magnetization curve we start with zero field current and then gradually increase it to the rated value, taking simultaneous readings of e. m. f. and field current, we will obtain a curve which we call the *ascending curve.* If, after this, we gradually decrease the field current to zero and again take a series of readings we will obtain what is termed the *descending curve,* Fig. 157. It will be found in all cases that the descending curve gives higher values of e. m. f. for the same field current than the ascending one. This phenomenon is due to the fact that hysteresis in the iron portions of the magnetic circuit causes the flux and hence the no-load terminal voltage, corresponding to a given value of the field-exciting current, to be smaller when the latter is increasing than when it is decreasing. This effect of hysteresis upon the magnetization curve of a generator is usually ignored in discussing the relation to other characteristic curves. In fact, the effect of hysteresis is greatly diminished in practical operation, inasmuch as the mechanical vibrations of the machine and the slight pulsations of armature and field currents cause the flux to settle to a normal value.

**External and Other Characteristic Curves.** The external characteristic curve of any dynamo-electric machine is a curve representing the relation between the terminal voltage of the machine and the external load in amperes. Besides the external characteristic curve, the *total characteristic curve* is sometimes considered. This curve represents graphically the relation between the generated e. m. f. of the machine and the armature current.

Inasmuch as the characteristic curves of the series, shunt, and compound generators differ markedly from one another, those pertaining to each type will be considered separately.

There are, however, two reactions which occur whenever current flows through the armature of any type of generator. One of these, namely, armature reaction, we have already studied and it was found that the current flowing through the armature caused the main field flux to become distorted with the result that it was somewhat decreased (Part I, page 43). The other reaction occurring is the drop in potential due to the flow of current. It must be remembered that the armature from brush to brush consists simply of a number of copper wires in parallel. It is a physical fact when current flows over a conductor that there is a drop in potential equal to $IR$, wherein $I$ is the current and $R$ the resistance. For any value of the flux there will be some value of the generated e. m. f. and accordingly if some of it is used up internally in the armature the remainder or terminal e. m. f. becomes less. The general formula for a generator is as follows:

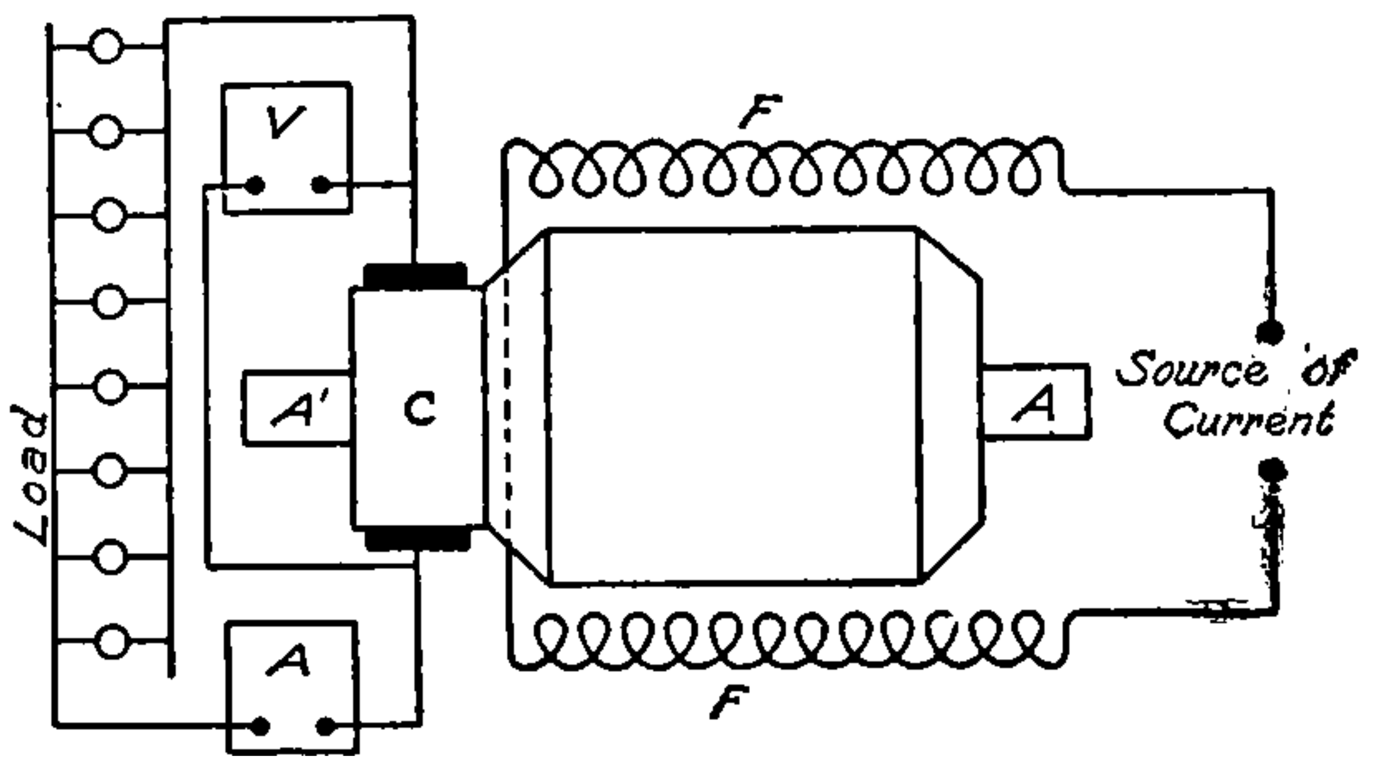



Fig. 158. Diagram of Connections for Separately-Excited Machines

$$E \text{ generated} = E \text{ at terminals} + IR \qquad (36)$$

wherein $I$ is the armature current and $R$ the resistance of the armature circuit including brush contacts and series field winding if there is one.

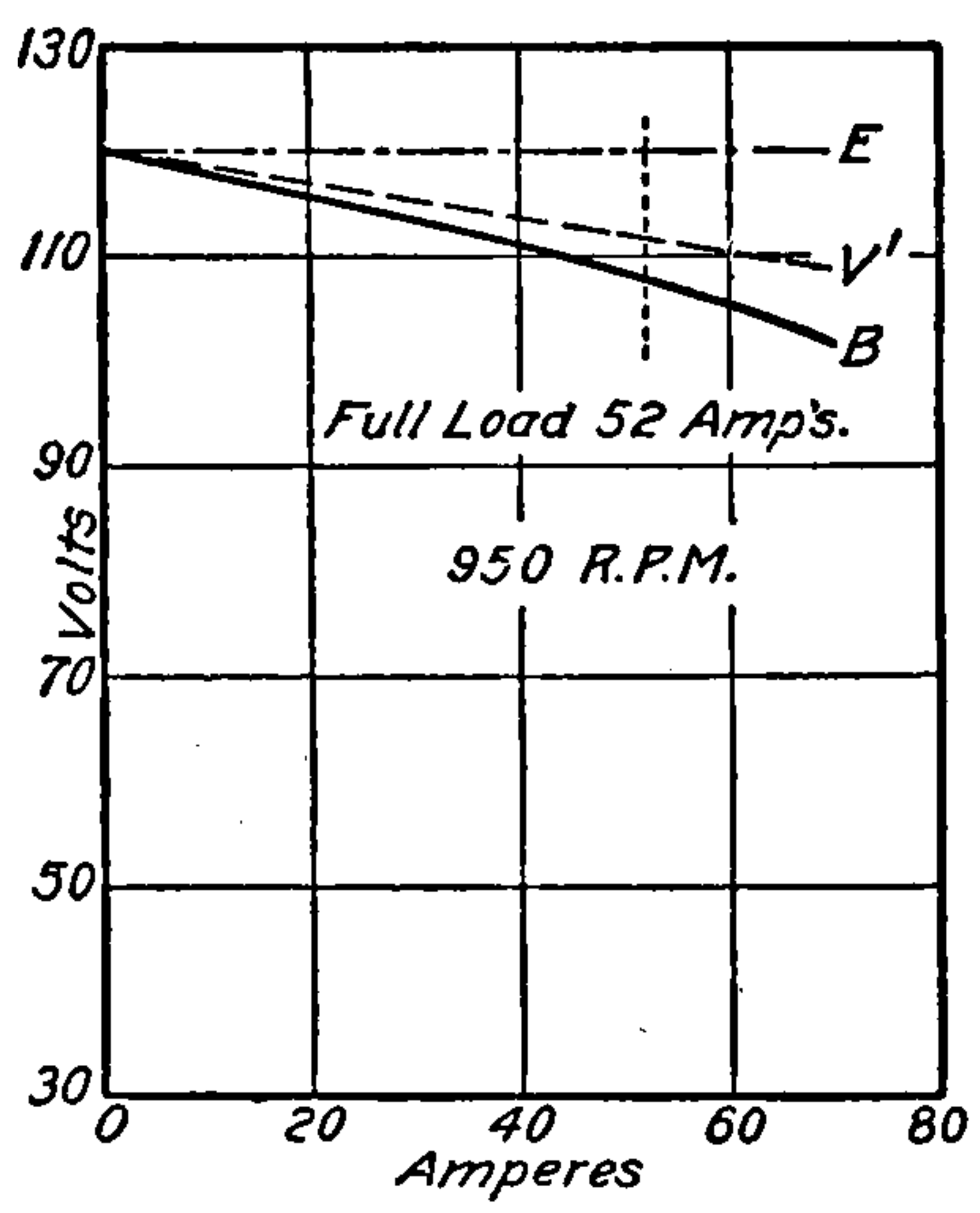



Fig. 159. Characteristic Curve of Separately-Excited Generator

**Characteristic Curves of Magneto and Separately-Excited Machines.** In the magneto machine, the permanent magnetism of the steel may be considered approximately constant, and the same condition would obtain in a separately-excited machine, Fig. 158, if the field-current were kept constant. Owing, however, to the reactions of the armature when the current flows therein, the useful flux and terminal voltage are decreased. In Fig. 159 are given the results of tests upon a separately-excited dynamo. The line $E$ represents the generated e. m. f. of the machine when operated

The external characteristic is plotted between current and terminal e. m. f. Since the same current passes through the external circuit as passes through the armature and field windings, the external and armature currents are equal. Further we have $E$ gen. = $E$ term. + $IR$; where $R$ is the resistance of armature, field, brush contacts, etc., combined. If we add the value of the $IR$ drop to the terminal e. m. f. we obtain the generated e. m. f. Fig. 162 shows both external and total characteristics and the value of the $IR$ drop for a series generator.

The effect of residual magnetism upon the external and total characteristic curves of a series-wound generator causes the curve to intersect the axis of volts above the origin, as indicated in Fig. 162; that is, at zero external current,

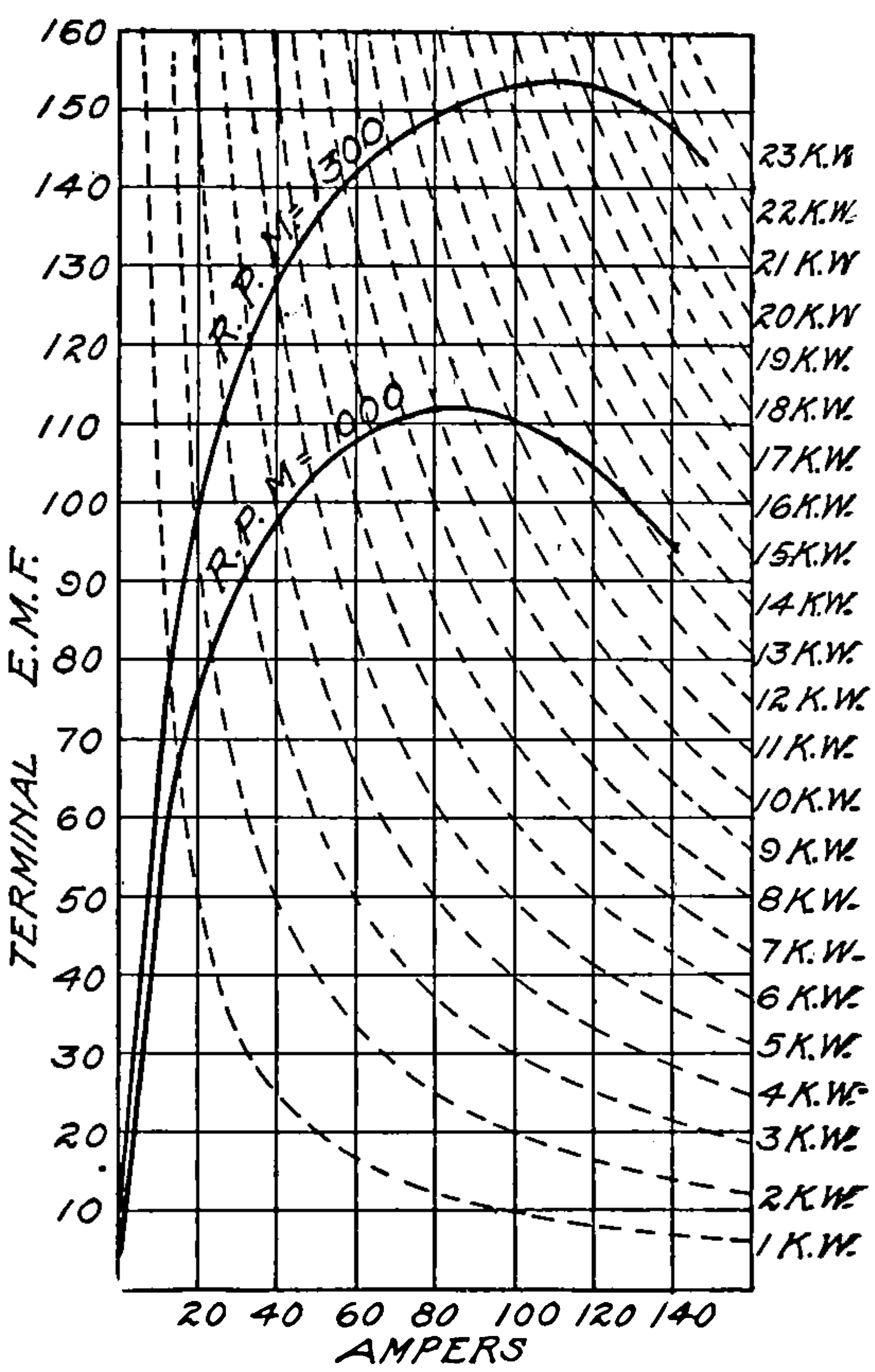



Fig. 161. Characteristic Curves of a Series-Wound Generator at Different Speeds

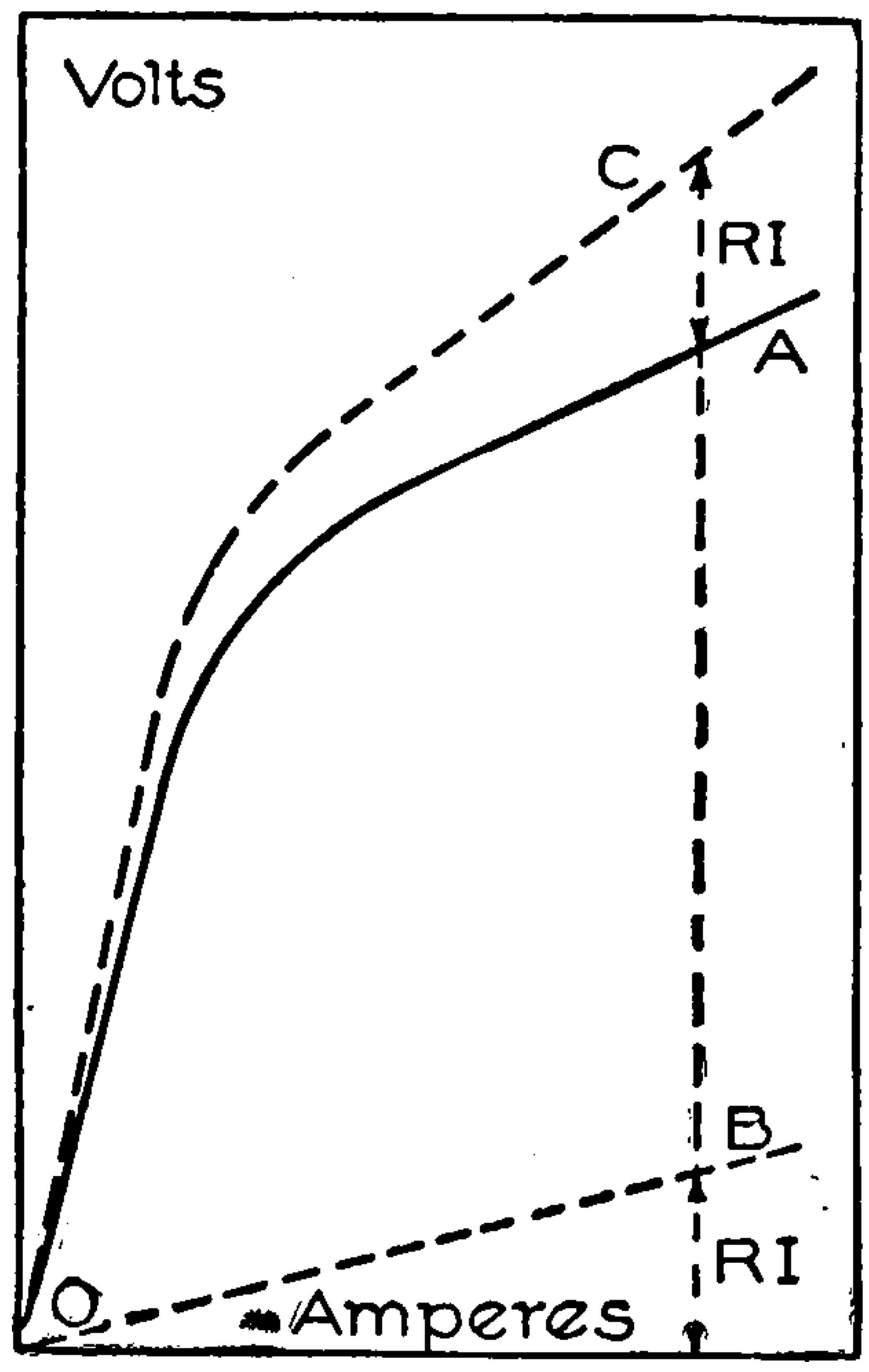



Fig. 162. Effect of Residual Magnetism on Characteristic Curve of a Series-Wound Generator

and hence zero field-exciting current, an e. m. f. is generated in the armature of small value, as already explained. Thus a series generator is self-starting as regards generation of voltage.

*Relation between Magnetization Curve and Total Characteristic Curve of a Series-Wound Generator.* If it were not for the demagnetizing action of the armature current on the field, the total characteristic curve of a series-wound generator would be almost identical with the magnetization curve. The effect of the armature current is, however, either to reduce inducing flux and therefore the generated voltage which corresponds to a given field-exciting current, or to necessitate an increased field-exciting current to give the requisite terminal voltage.

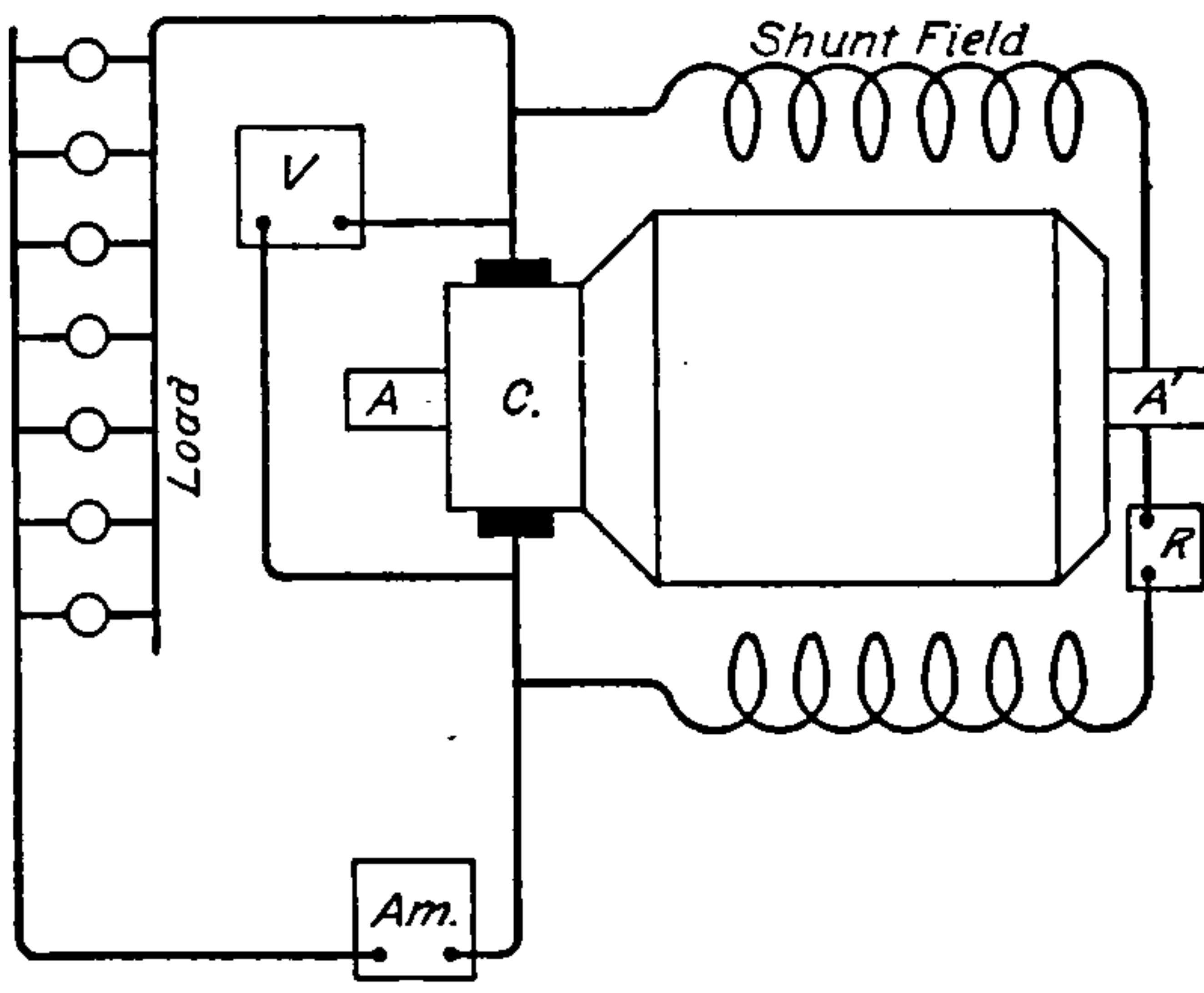



Fig. 163. Diagram of Connections for a Shunt-Wound Generator

*Dependence of the Characteristic Curve on Speed.* Since the flux has a definite value for a given value of current output of a series-wound generator, and therefore is independent of the speed, the generated voltage is proportional to the speed for a given value of the output current. The external characteristic curve corresponding to the speed $n'$ may in consequence be derived from the external characteristic curve corresponding to the speed $n$, as follows: Add $IR$ to each ordinate of the given characteristic, thus finding the total characteristic for the same speed $n$.* Then multiply the ordinates of this characteristic curve by $n' \div n$, thus finding the total characteristic curve for the speed $n'$. Subtract $IR$ from each ordinate of this curve, thus obtaining the external characteristic curve for the speed $n'$.

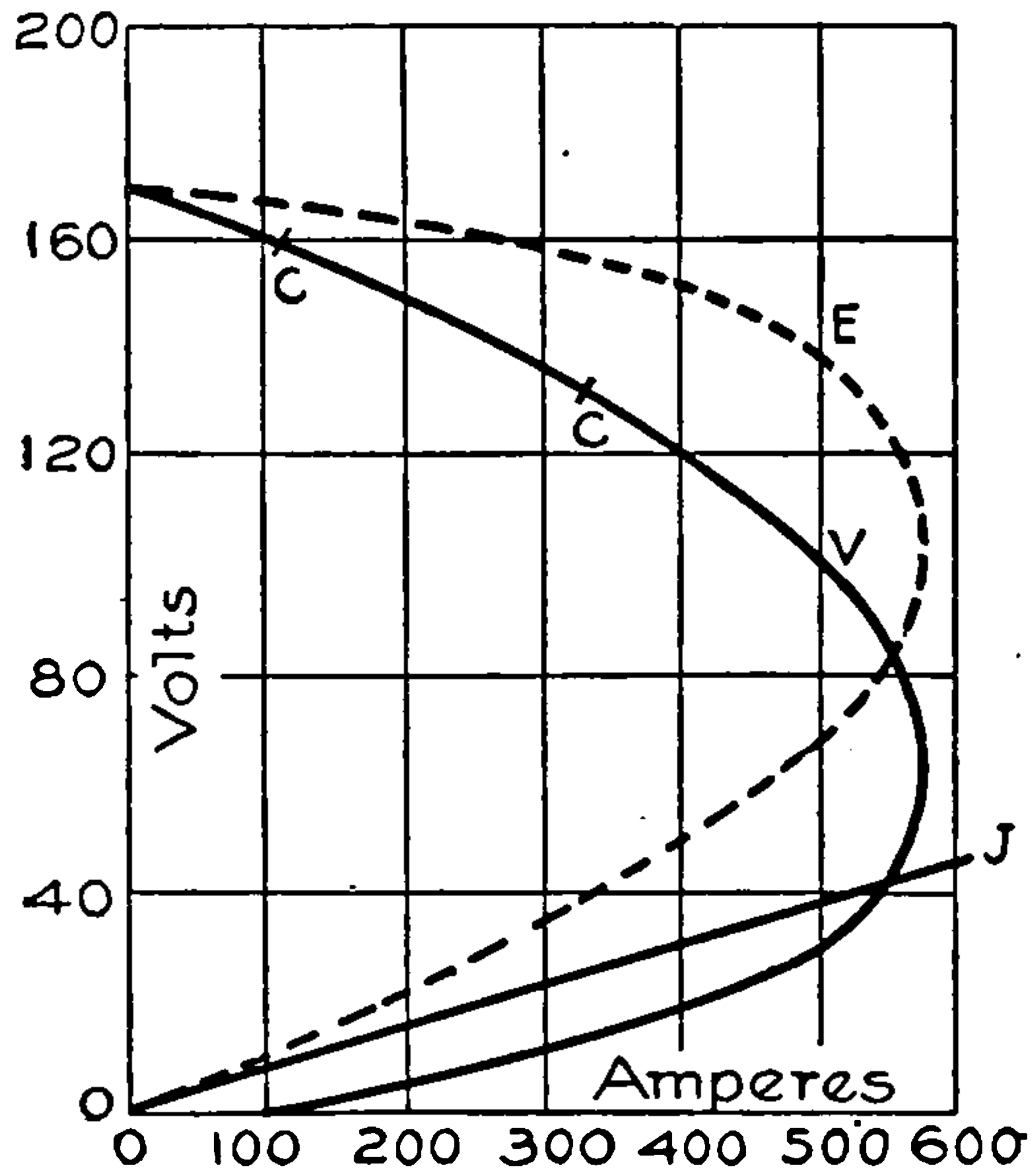



Fig. 164. Characteristic Curves of a Shunt Generator

**Characteristic Curves of Shunt-Wound Generators.** The external characteristic curve of the shunt-wound generator is determined experimentally by running the machine at rated speed and noting the terminal voltage for various values of the external current with connections as shown in Fig. 163.

*External and Total Characteristic Curves.* The full line in Fig. 164 represents the external characteristic curve of a typical shunt-

*$n$ = Initial speed; $n'$ = Final speed.

wound generator, the portion *cc* being that part upon which machines of this type are usually operated.

This curve is seen to differ radically from the corresponding curve of a series-wound machine. It is to be seen from Fig. 163 that the shunt field is connected directly to the armature terminals with a rheostat ($R$) in series so that the exciting current also passes through the armature. When a shunt generator is brought up to speed, the residual magnetism causes a small amount of flux which the armature inductors cut, producing a small e. m. f. This acting across the field causes a small exciting current to flow which in turn produces more flux. This action goes on until a balance is reached which will be the rated no-load value of the terminal e. m. f. As soon as load is added to the generator, armature reaction comes into play and aided by the $IR$ drop in the armature circuit causes the terminal voltage to fall. Besides this, as soon as the terminal voltage falls, there will be less field current which causes a decrease in the field strength and also in the generated e. m. f. This continues and finally the curve bends over sharply and both terminal e. m. f. and armature current decrease toward zero.

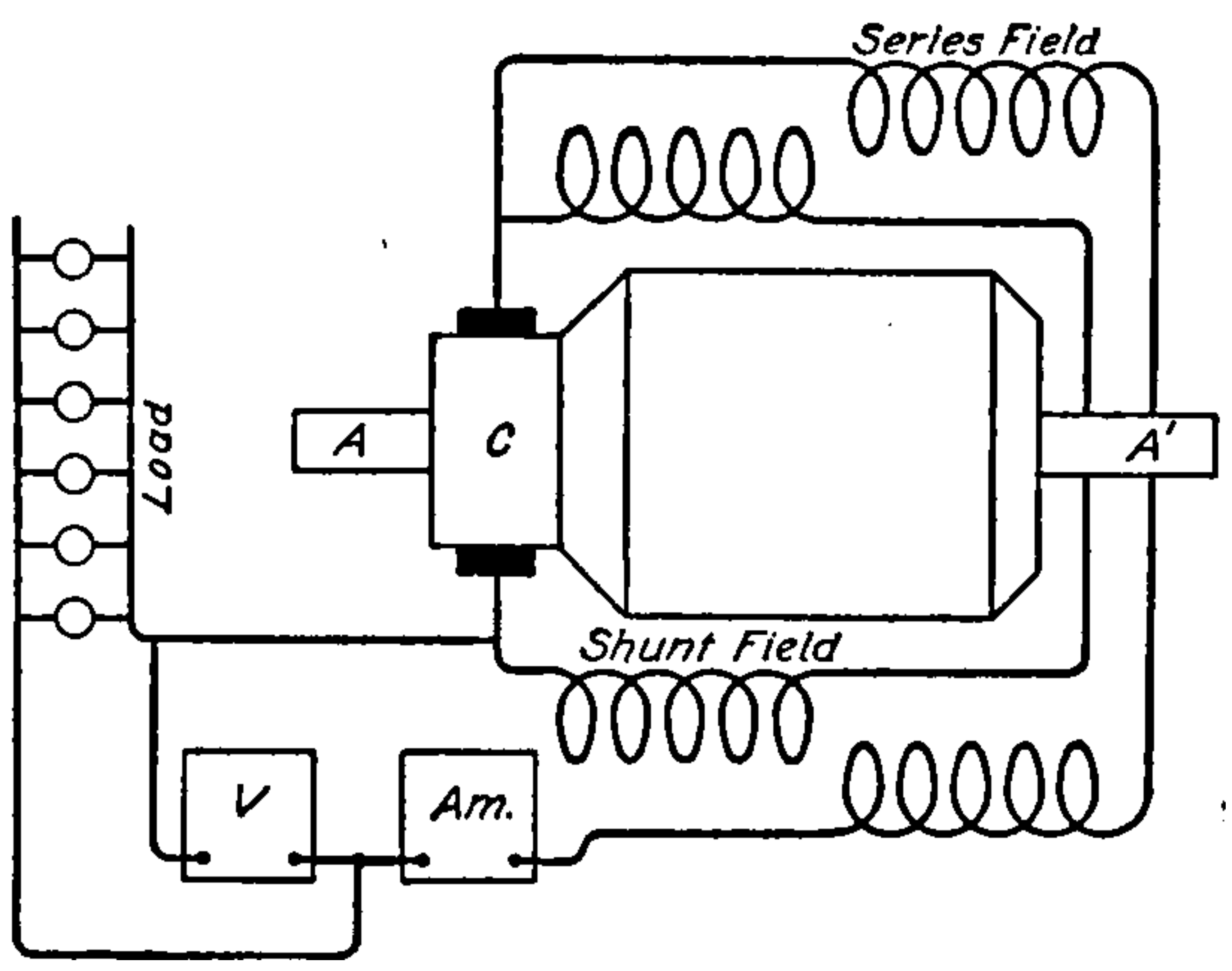



Fig. 165. Diagram of Connections for Compound-Wound Generator

When we put load on the generator we are simply decreasing the external resistance. At the start the external resistance is decreasing more rapidly than the terminal e. m. f. and thus the current rises, but the latter, however, soon overtakes the former and finally decreases faster than the external resistance. This causes the curve to bend back. At dead short circuit the terminal e. m. f. becomes practically zero but the residual magnetism generates just sufficient voltage to cause some current to flow through the armature and the short circuit.

The total characteristic shown as a broken line in Fig. 164 is obtained from the external characteristic by adding the value of the $IR$ drop to the terminal e. m. f. and adding the field current to external current. for the field current also passes through the armature.

*Efficiency and Loss Curves.* From a commercial standpoint there is still another curve which is of extreme importance. As in all machines which transform energy from one form to another, some energy is wasted in an electric generator. Commercial efficiency is defined as *the ratio of output to input* and evidently this ratio can never be unity. The losses in a generator are divided into two classes as follows:

1. ELECTRICAL OR COPPER LOSSES.
   - (*a*) $I^2R$ in armature conductors.
   - (*b*) $I^2R$ in brushes and brush contacts.
   - (*c*) $I^2R$ in armature leads.
   - (*d*) $I^2R$ in field windings, shunt and series.

In the case of a self-excited dynamo, or a motor having a field rheostat, the losses in the field rheostat must be combined with the others to give total loss.

2. STRAY POWER LOSSES.
   - (*e*) Bearing friction and air friction or windage.
   - (*f*) Friction of brushes on commutator.
   - (*g*) Hysteresis in the armature iron.
   - (*h*) Eddy-current loss in iron of armature and pole tips and copper of armature.

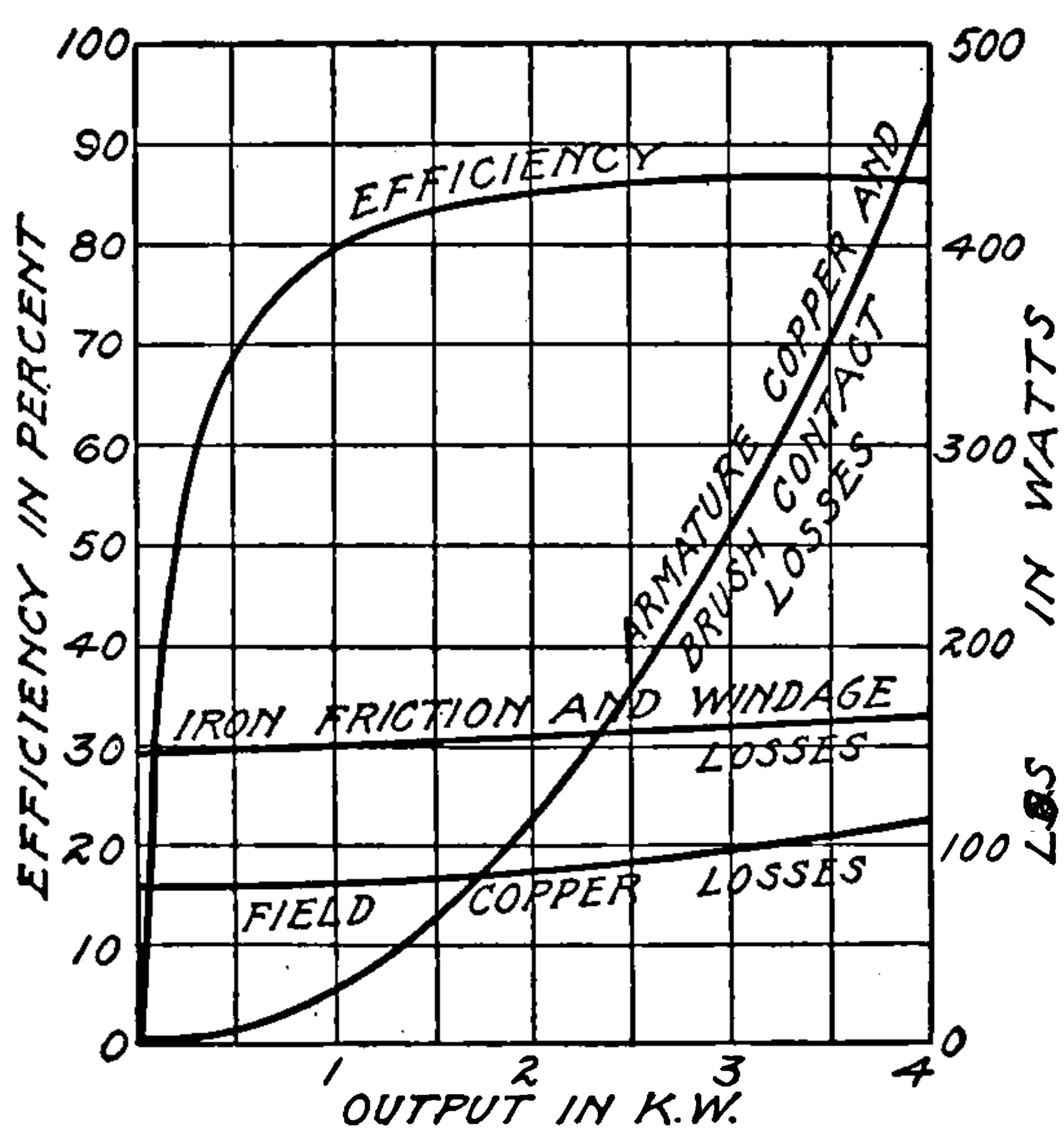



Fig. 167. Sets of Curves for 4-kw. Generator

It is a simple matter to determine what the copper losses will be if we know the current flowing in a circuit and also the resistance of the circuit. The stray power losses are, however, difficult to measure separately, so they are measured collectively.

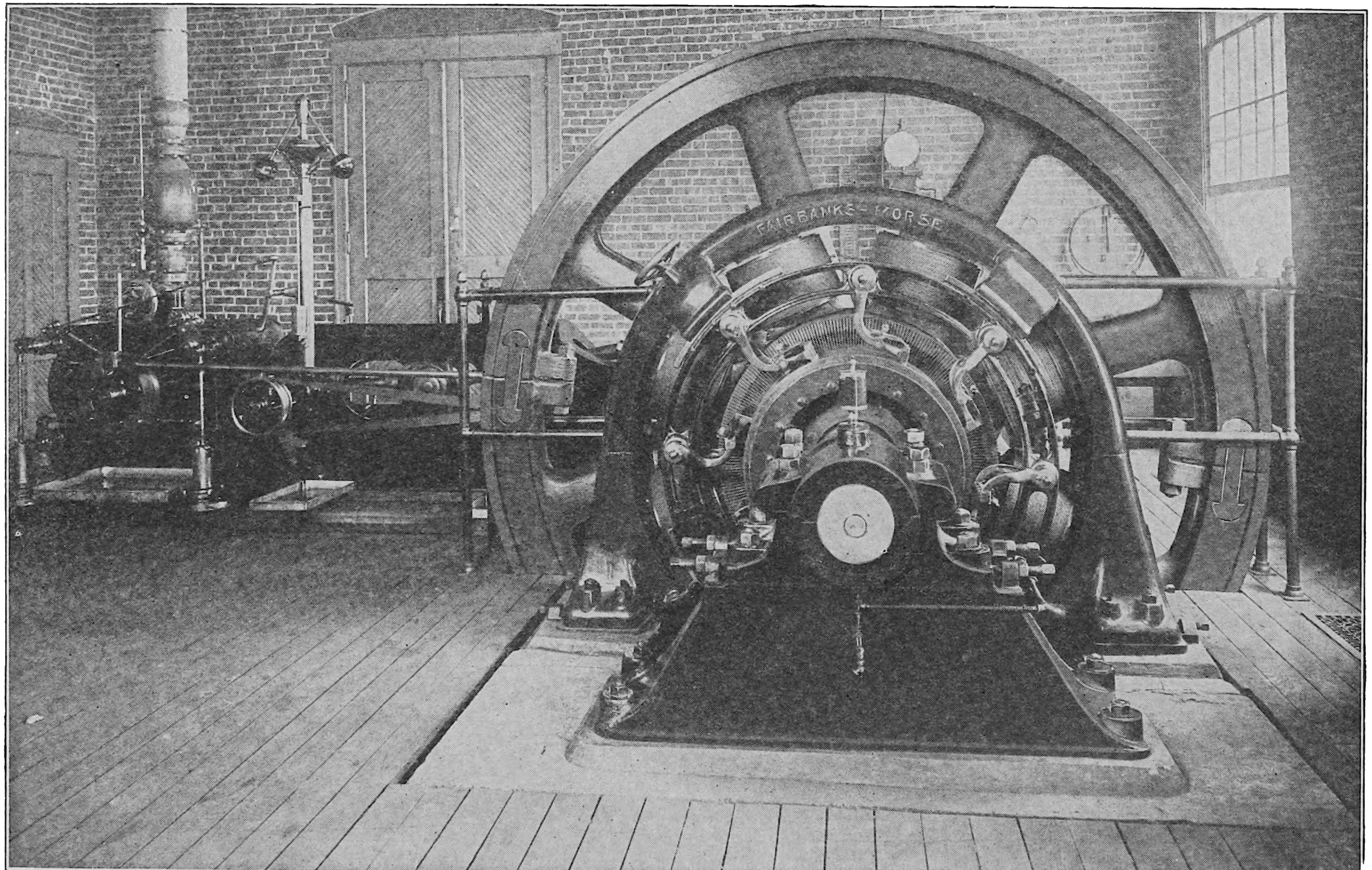
The method used for measuring these losses, depends upon the assumption that the stray power losses will be the same for any load provided the field current and speed are identical. Accordingly the machine is operated at no load and the power required to operate it noted. Since there is no output all of the input is lost and if we subtract the no-load copper losses from the no-load input, we can immediately determine the stray power losses.

In Fig. 167 are shown a set of curves for 4 kw. generator. The curve of field copper loss increases slightly since a little more field current is required to keep the terminal voltage constant as the load is augmented. The stray-power losses also increase slightly due to the change in field current. The curve for $I^2R$ in armature and brush losses increases very rapidly, as they change as the square of the armature current, which later varies from zero to full load value.

At any load it is evident that: *Input = Output + Losses,* and in a generator it is an easy matter to determine the output. Hence knowing output and losses we can determine the input and from this the efficiency from the relation.

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}}$$

The per cent efficiency curve in the figure is seen to increase quite rapidly at first but gradually tends to become horizontal and on overload it would begin to fall. This change in the efficiency is due to the fact that field copper and stray power losses increase only a little, while the armature copper losses change very slowly at first, but as full load is approached the rate of increase is enormous.


FAIRBANKS-MORSE

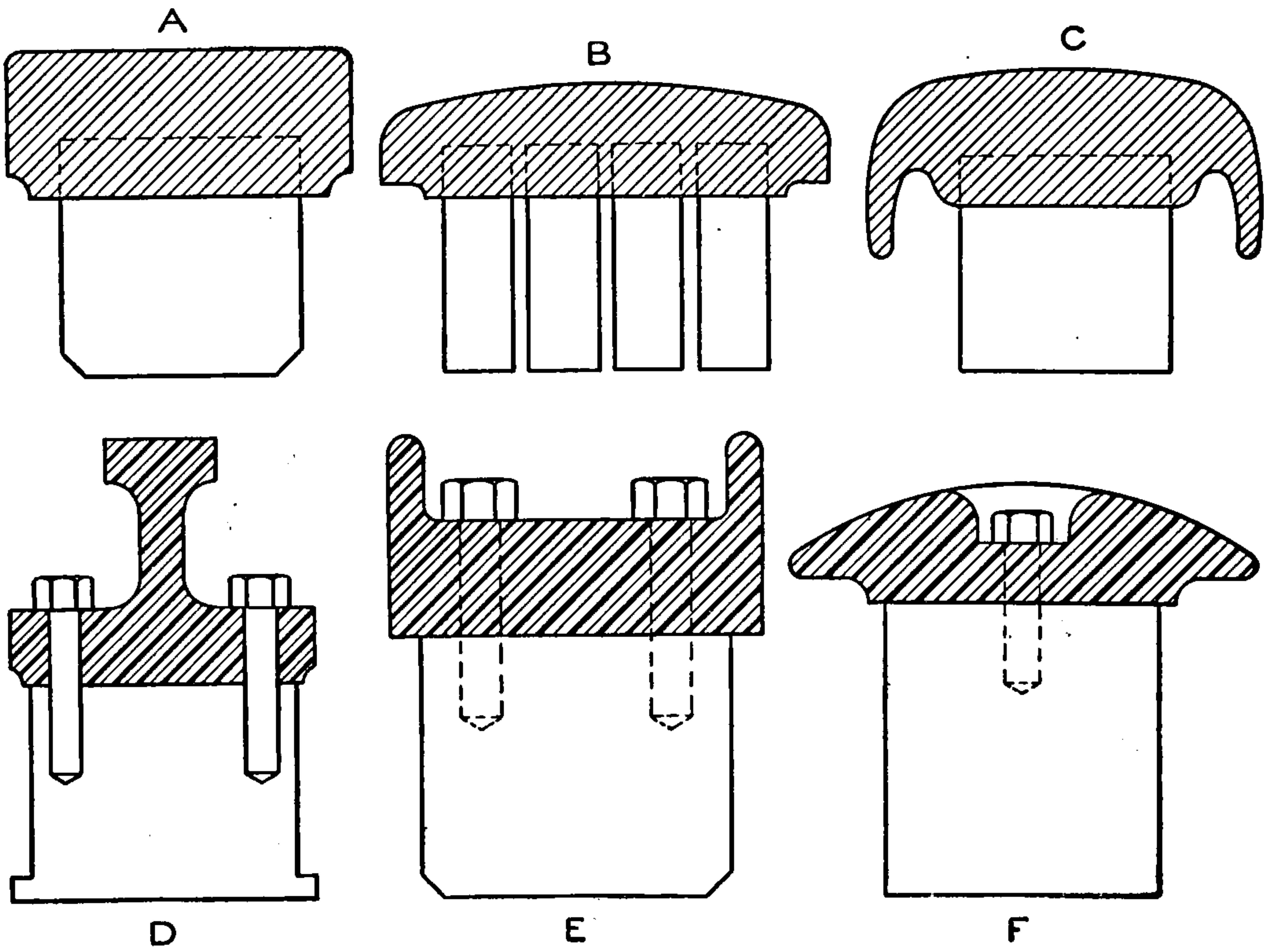



Fig. 168. Various Sections of Magnet-Yokes

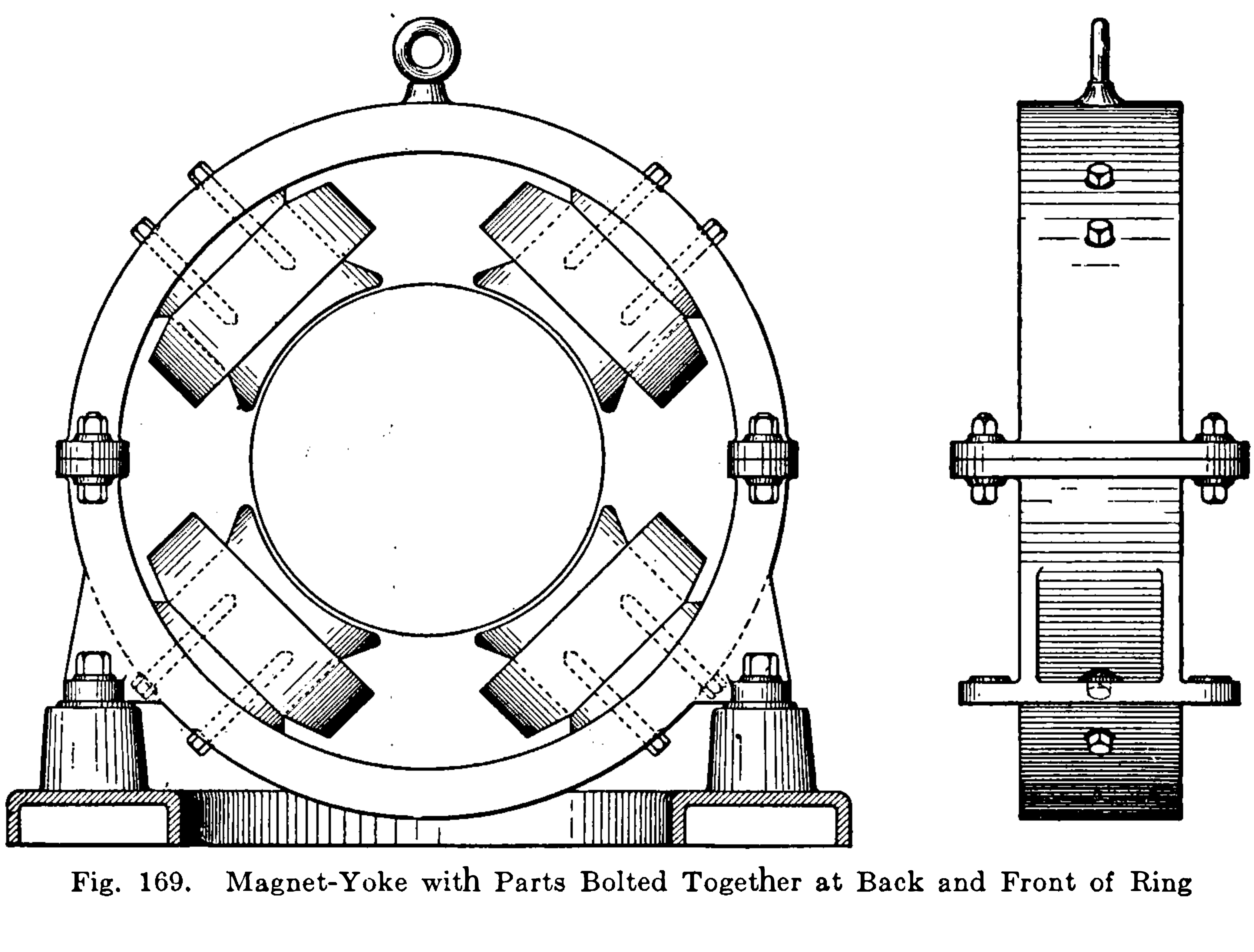


Fig. 169. Magnet-Yoke with Parts Bolted Together at Back and Front of Ring

The magnet-ring in all but the smallest machines is split in two along its horizontal diameter, or sometimes along its vertical diameter, to facilitate erection, inspection, and repair with respect to the armature. The two parts are usually held together by bolts at the side, back, or interior of the ring, as indicated in Figs. 169, 170, and 171. One or more ring-bolts are also placed at the top or on each side of the upper half in order to make handling easy.

**Field-Poles and Projections.** The field-poles are generally made of wrought iron, sheet steel, or cast steel. The magnetic properties of these materials are given in Fig. 100. Wrought iron and cast steel have approximately equal permeabilities at about 95,000 lines per square inch, below which the former is a little superior.

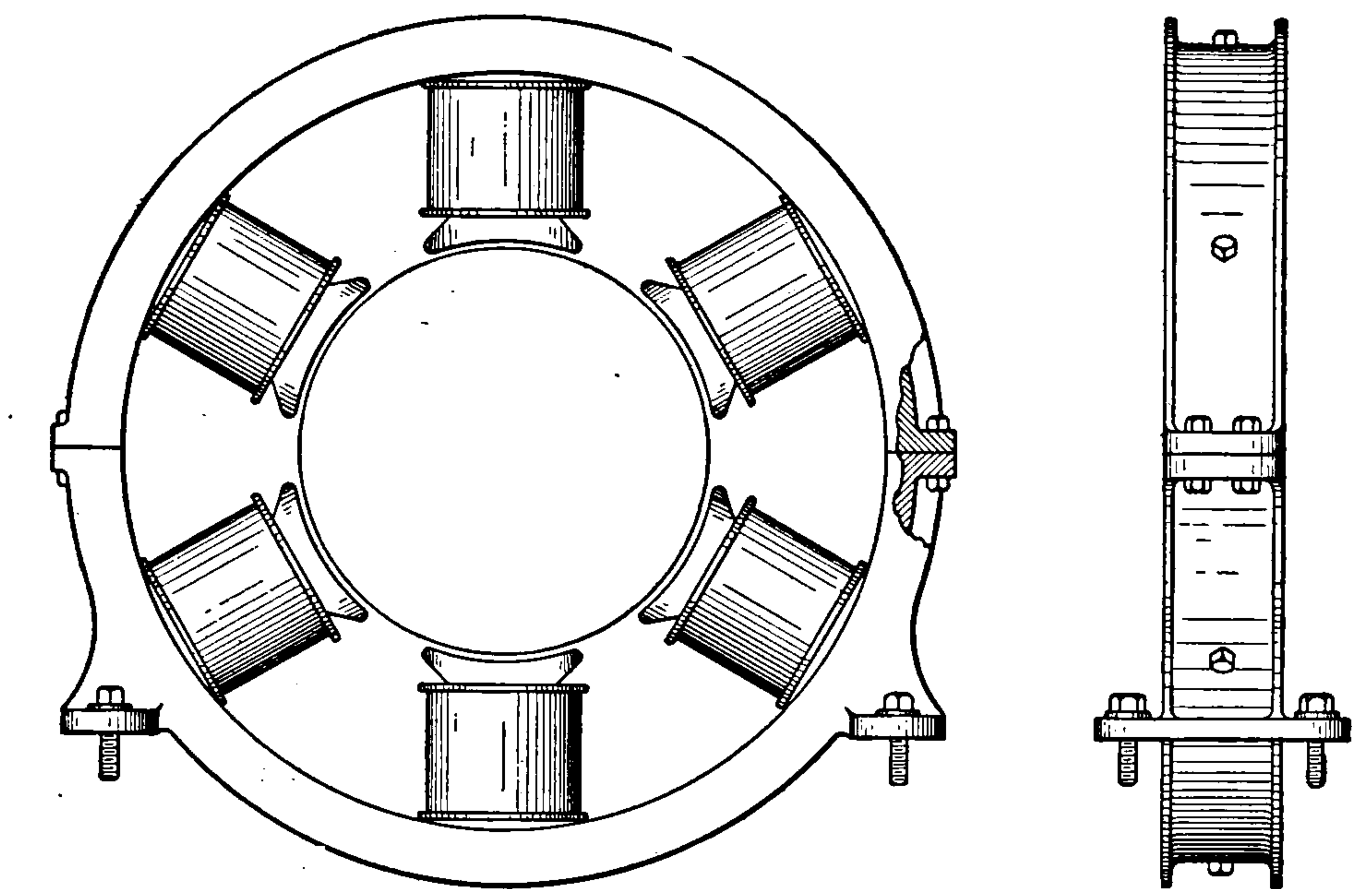


Fig. 170. Magnet-Yoke with Parts Bolted Together at Sides of Rings

The objection to the use of wrought iron, however, is the difficulty of making it in the forms required. This may be partly avoided by using simple forms such as a plain cylinder, which can easily be made by forging or by cutting off lengths from round bars.

The cheapening and developing of the process of casting "mild" steel (soft steel), with a very small amount of carbon, have resulted in the general adoption of this material for field-magnets. It combines high permeability, cheapness, strength, and the ability to be cast in any reasonable form. It is certainly not economical to use cast iron for the cores of the field-magnets since it requires from 2 to 2.5 times the cross-section of wrought iron or steel for the same reluctance. With a circular cross-section, this demands about 1.5 times the length of wire for a given number of ampere-turns; and the necessary weight of cast iron being 2 or 2.5 times greater, makes it not only clumsy but more expensive. For yokes, field-rings, bases, or other parts not wound with wire, the extra circumference is not so objectionable. Often the increased weight is positively advantageous in giving greater stability, so that cast iron is still used to some extent in these parts.

In joining cast iron to wrought iron or steel, it is hardly sufficient to butt the two together, as indicated in Fig. 92, because the

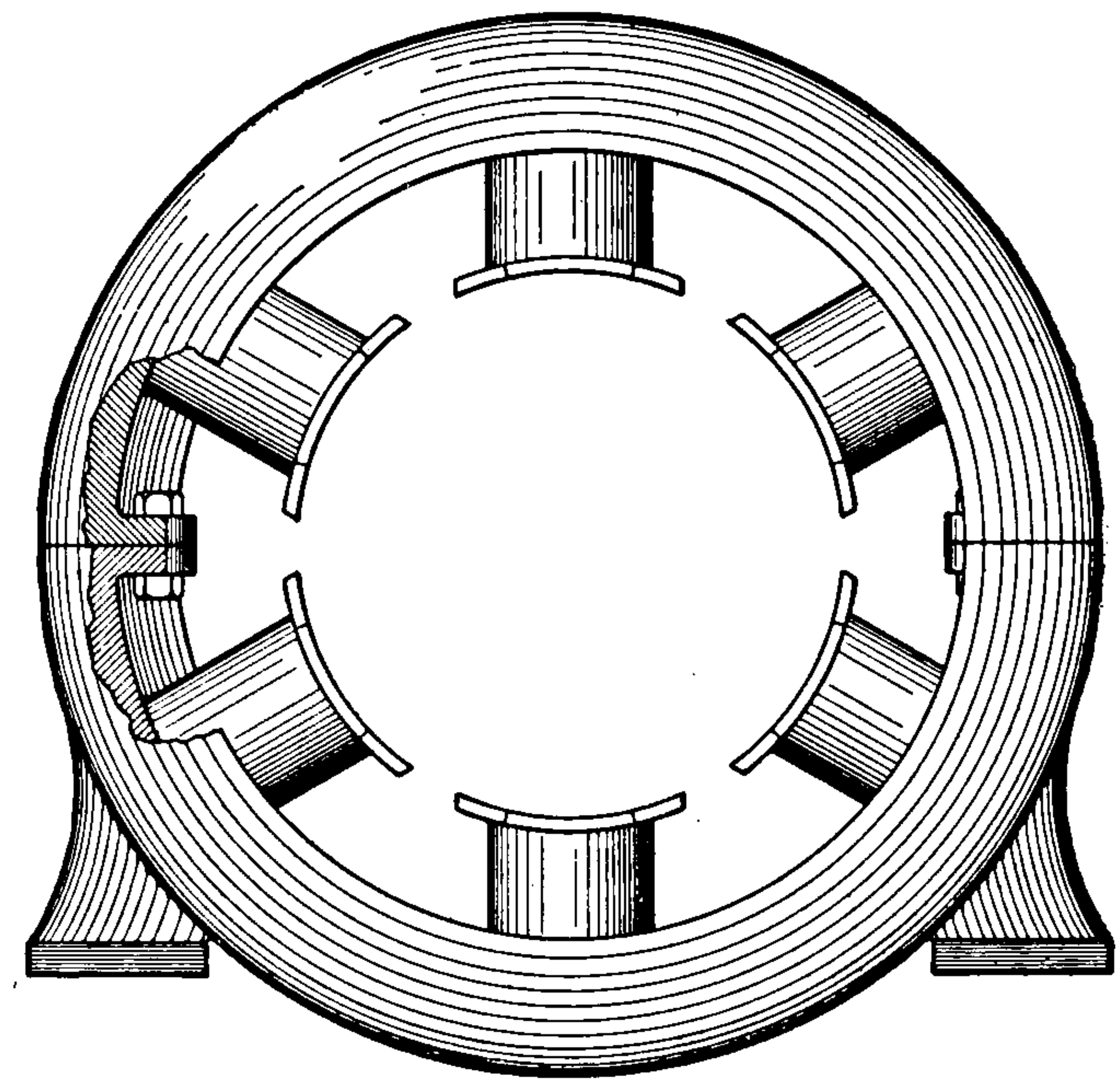
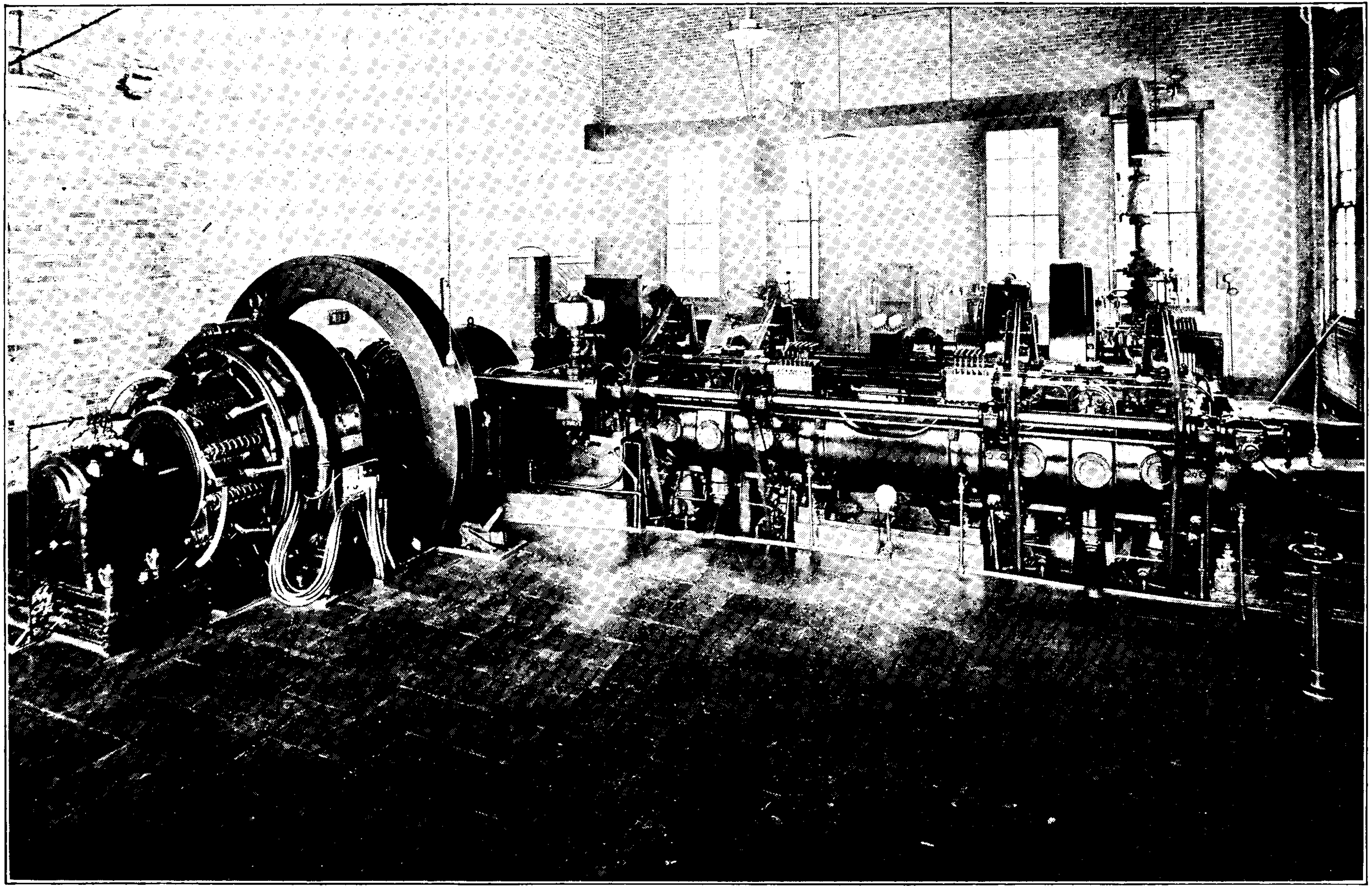


Fig. 171. Magnet-Yoke with Parts Bolted Together on Inside Ring

permeability of a given area of cast iron is only about one-half as great as that of an equal area of either of these other materials. Hence, in order to secure the proper surface of contact, the pieces of steel or wrought iron should be imbedded in the cast iron by placing the former in the mould when the casting is made, or the cast iron may be bored out to receive the ends of the cores. Joints in the magnetic circuit are not desirable, because they involve work in fitting, and may cause looseness or weakness—usually avoidable, however, with good workmanship. On the other hand, the common idea that they



**ALLIS-CHALMERS TANDEM GAS ENGINE DRIVING 225 KILOWATT D. C. GENERATOR. INSTALLATION FOR ARMSTRONG CORK COMPANY**

*Courtesy of Allis-Chalmers Manufacturing Company*

introduce great reluctance is not true, for we have seen on page 19, that an ordinary joint is equivalent to an air gap of about 0.002 inch, which is practically insignificant, and does not warrant the making of complicated castings or forgings to avoid one or two joints in the magnetic circuit, except to simplify mechanical construction.

The length of the cores required for a given field-magnet depends simply upon the amount of field-winding. The turns needed are computed as described on pages 72-81, and the size of wire from pages 80-83. It is sufficient to make the core long enough to receive these turns properly, and to expose sufficient surface to dissipate

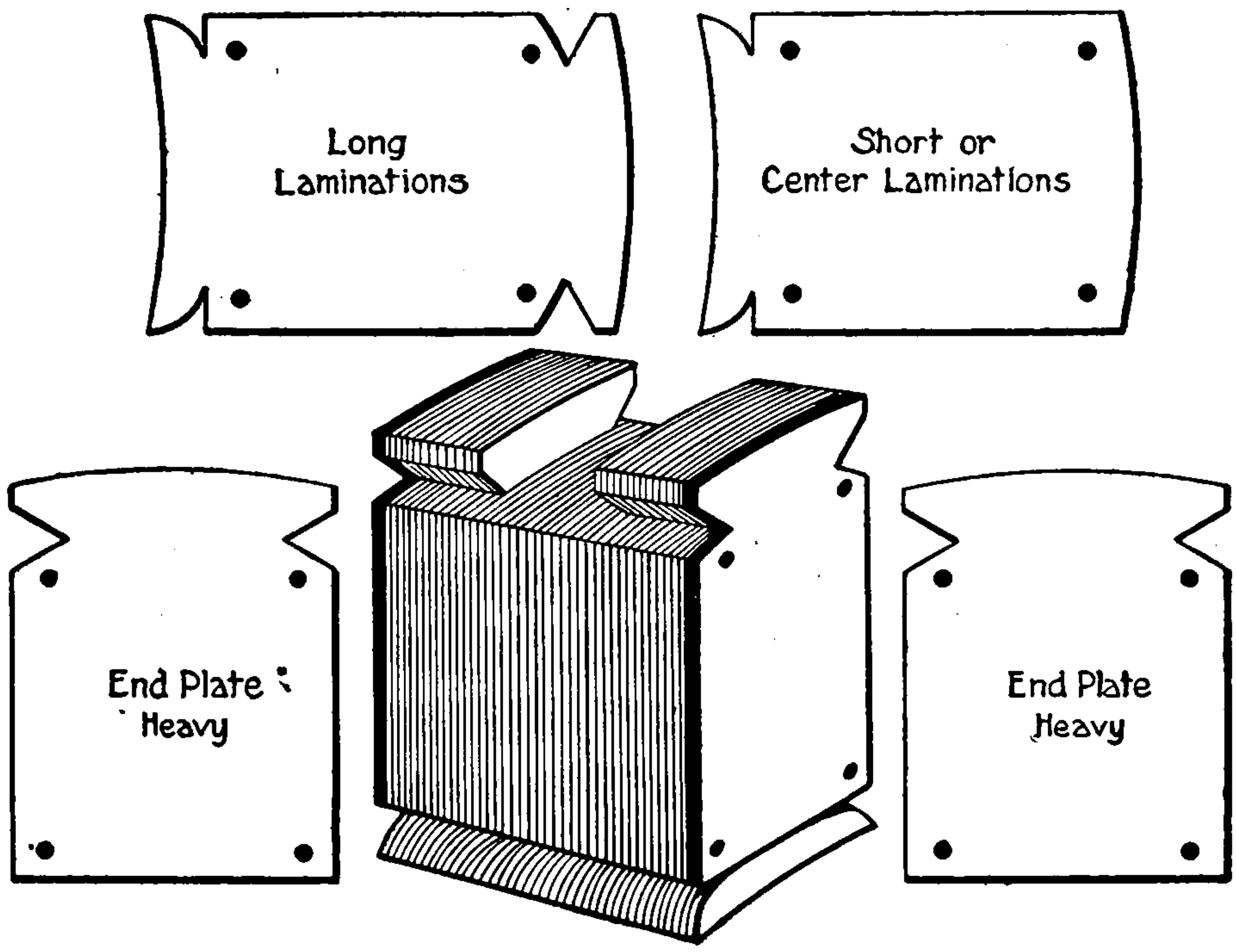



Fig. 172.—Pole-Core Stampings and Assembled Pole-Piece

the heat generated by the field-current in order to prevent excessive temperature-rise, as indicated on pages 84-86, 91.

The area of cross-section of the field-cores is determined by the total flux to be carried. A density of 13,000 to 16,000 lines per square centimeter—80,000 to 100,000 lines per square inch—is about the value for cast steel or wrought iron. The section is either circular or rectangular, the former being preferable on account of ease of winding coils for this shape, and because a circle has the least circumference for a given area, thus requiring less wire. The rectangular shape is used where the pole-core is laminated; and with the same area as one of circular cross-section, it has more radiating surface, although more wire is required for each turn.

The field-cores are attached to the yoke in several ways. The simplest method is to cast them as one piece, or to bolt them together as indicated in *D*, *E*, and *F* of Fig. 168. Another method is to place the cores of cast steel in the mould when casting the ring of cast iron. Sometimes, for large machines, only a portion of the cores is cast with the yoke, the rest being attached to the pole-pieces or shoes after mounting the field-coils. The two portions are then held together by bolts passing through the pole-shoe.

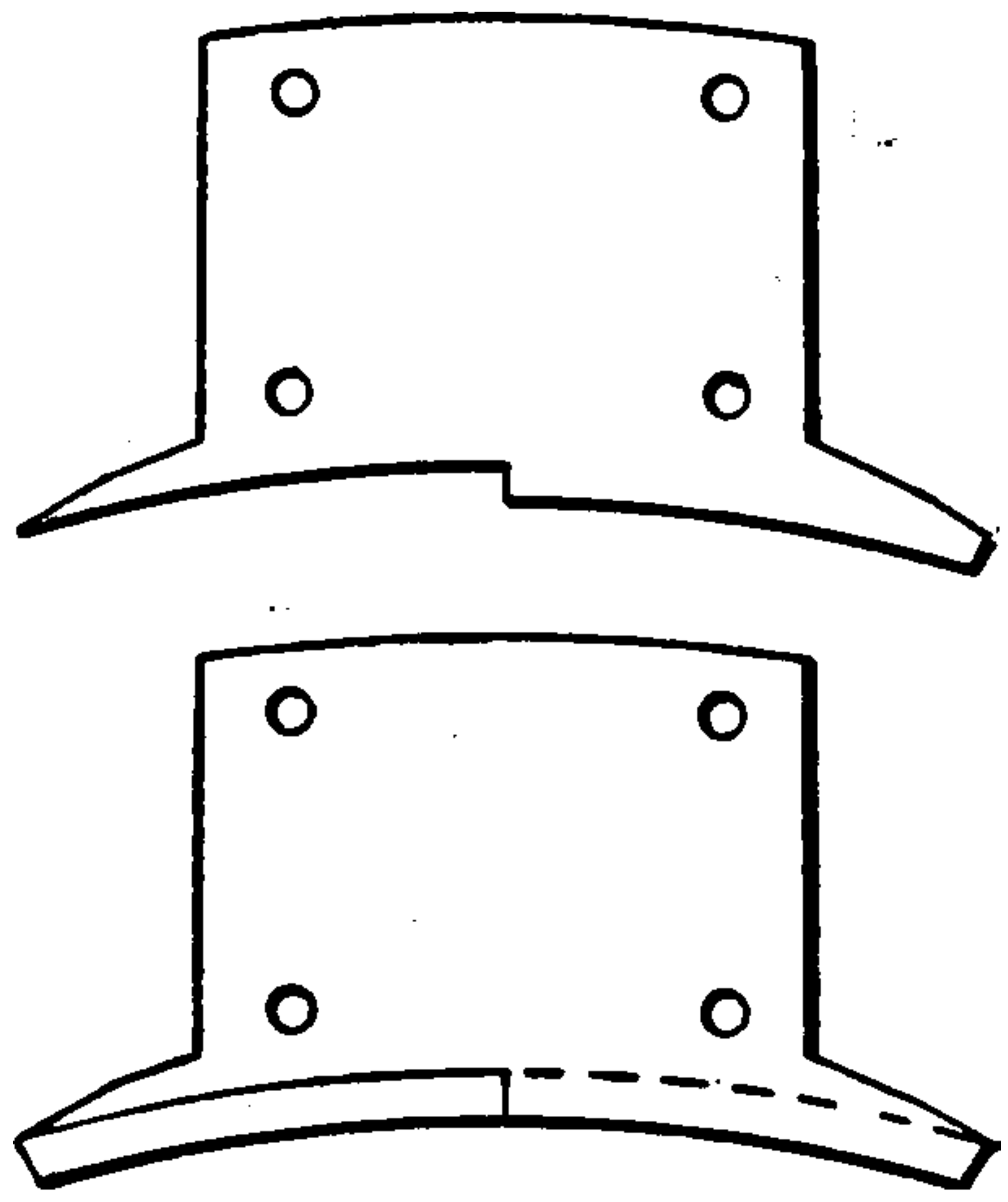


Fig. 173. Shapes Pole-Stampings

Most continuous-current machines are designed with an extended pole-piece or shoe which covers a greater surface than would the mere end of the field-core. Great attention has been paid to the special shaping of these polar extensions, as noted on pages 55-57 and in most cases they are constructed separately and attached to the cores while assembling the machine. If the core is laminated, the pole-piece forms a part of the laminæ, as shown in Fig. 172; while, if the core is partly cast with the ring, and the remainder bolted to it, as stated above, the shoe forms a portion of this addition.

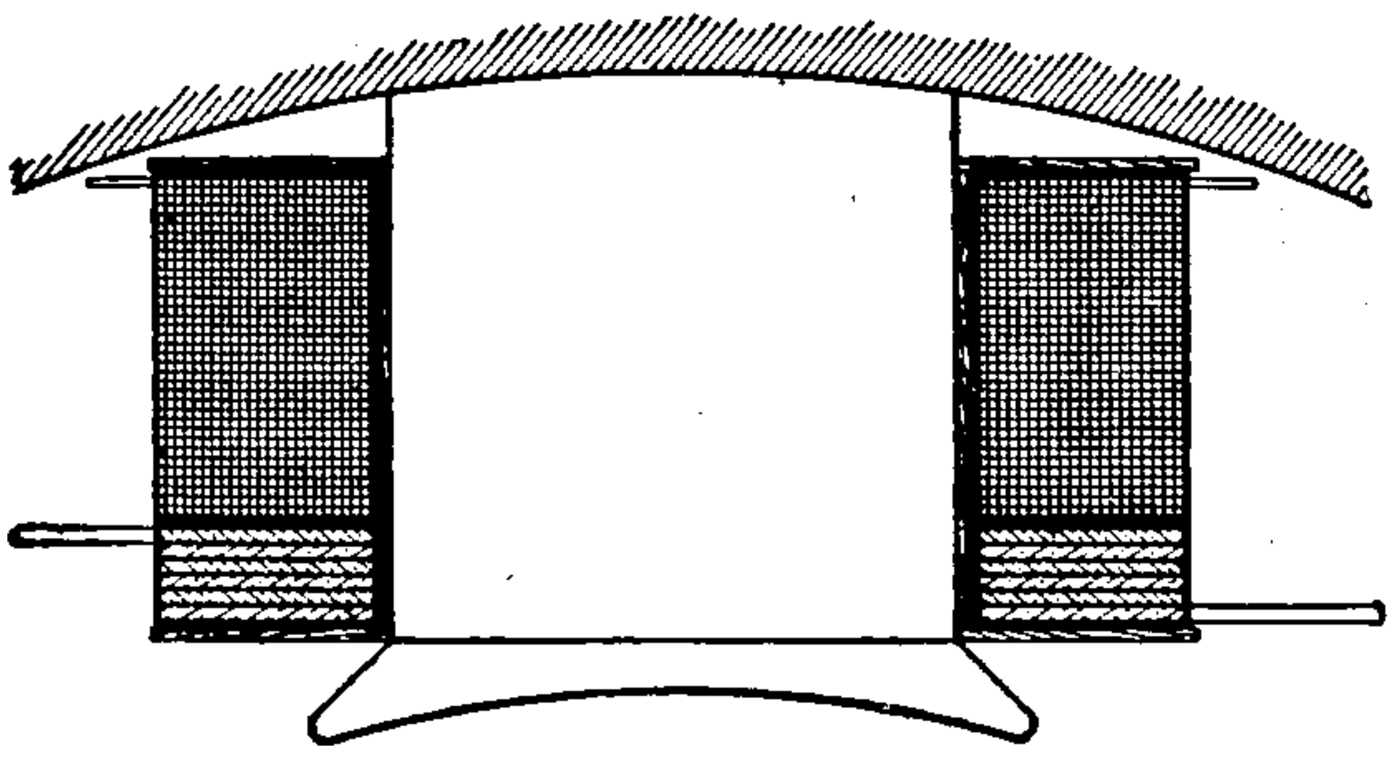


Fig. 174. Field-Magnet Bobbins with Hardwood Flanges

An extended pole-piece reduces the reluctance of the air gap, and thus the ampere-turns needed in the field-winding. On the other hand it is well to have the pole-shoe itself well saturated. Hence, to fulfil both conditions, either it ought to be made of a less permeable material than the pole-core—if the latter is cast steel or wrought iron the pole-shoe may be of cast iron—or, if made of stampings of wrought iron or mild steel, it should be so designed that its edges at least will be well saturated. This can be accomplished as indicated in Fig. 173, that is, by omitting every other lamina in the pole-piece, producing a grid-iron effect at the edges.

brought out in such a way that it cannot possibly make a short-circuit with any of the upper layers, as it crosses them. A method of winding which obviates this difficulty is to wind the coil in two separate halves, the inner ends of which are united, so that both terminals of the coil come to the outside. Fig. 178 shows such a bobbin, this method having also been used in the manufacture of induction-coil secondaries, for which it is desirable to keep the ends away from the iron core and from the primary coil.

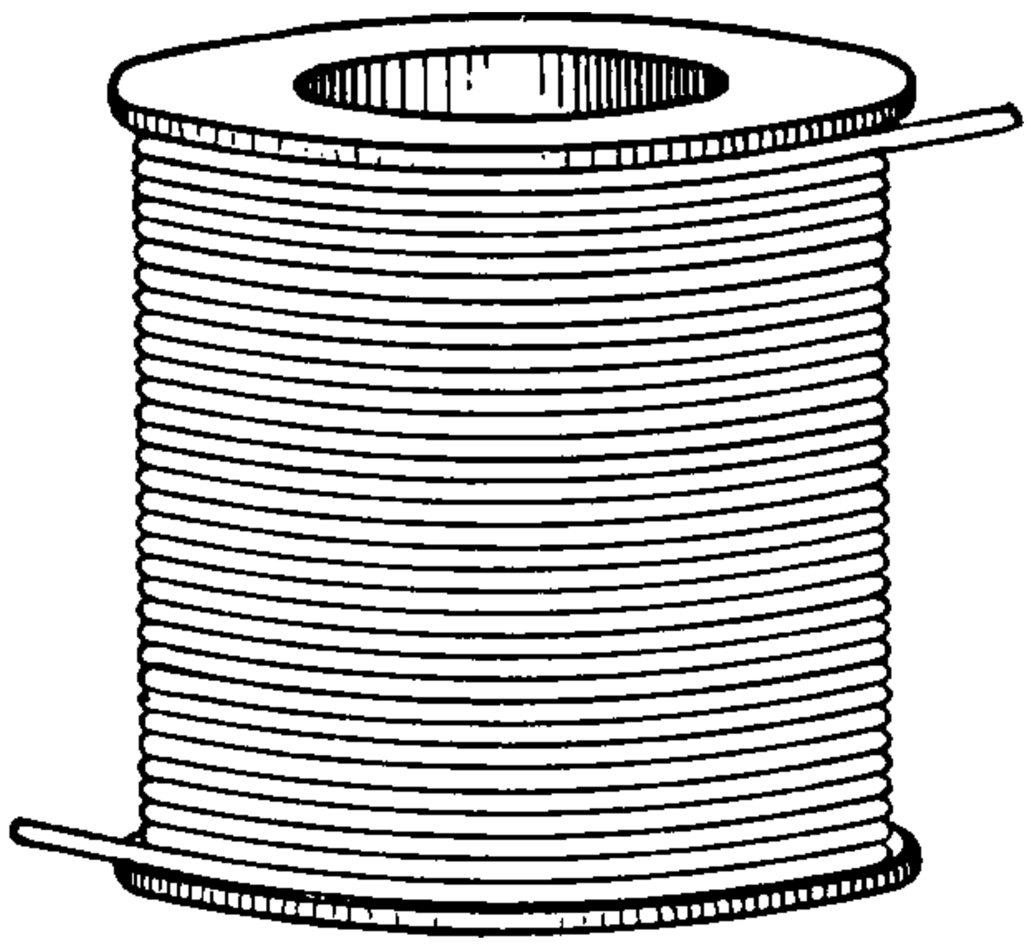


Fig. 178. Bobbin with Both Ends at Outside

Again, the winding may be piled up conically, as in Fig. 179, without any end-flanges, thus avoiding some of the risks of break-down, and bringing both free ends to the outside. In winding copper strip for some continuous-current machines, a similar plan has been adopted, the union of the two strips being effected at the interior of the coil, as indicated in Fig. 180. In still another type of continuous-current generator, the field-cores which are removable are themselves shaped to serve as bobbins and after being covered with a protecting layer of insulating material are wound in a lathe as illustrated in Fig. 181.

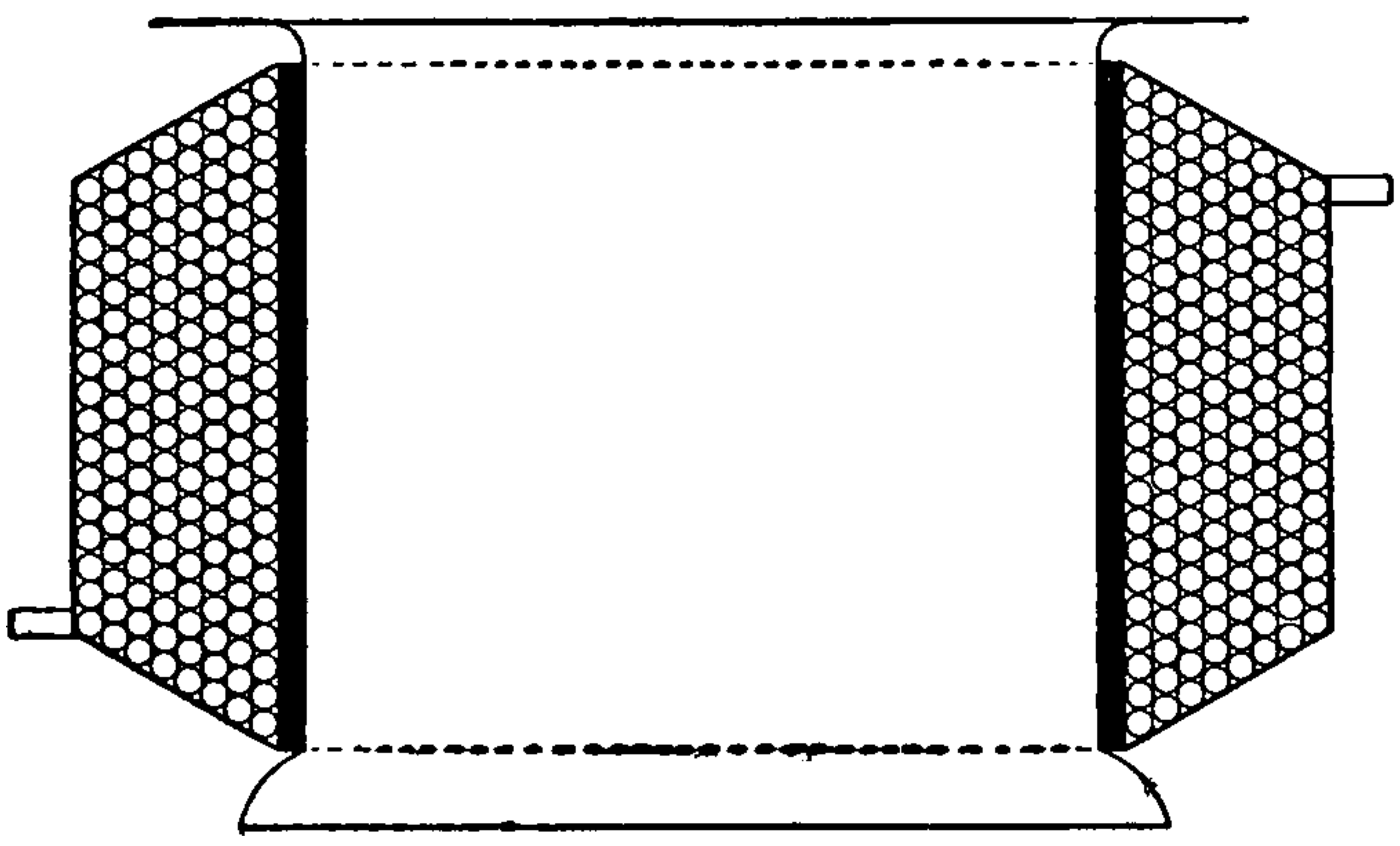


Fig. 179. Piled High-Voltage Coil

*Form-Wound Coils.* Form-wound coils are made upon a block of wood or a brass frame, to which temporary flanges are secured to hold the wires together during winding. Such coils have pieces of strong tape wound in between the layers and lapped at intervals so as to bind them together. The completed coil is then served with two or more layers of tape, each separately soaked in insulating varnish.

The whole coil is soaked in an insulating varnish and then baked in an oven, current being simultaneously sent through the wire to insure interior drying. Figs. 182, 183, and 184 illustrate form-wound coils; while Figs. 176, 177, and 185 represent bobbin-wound types.

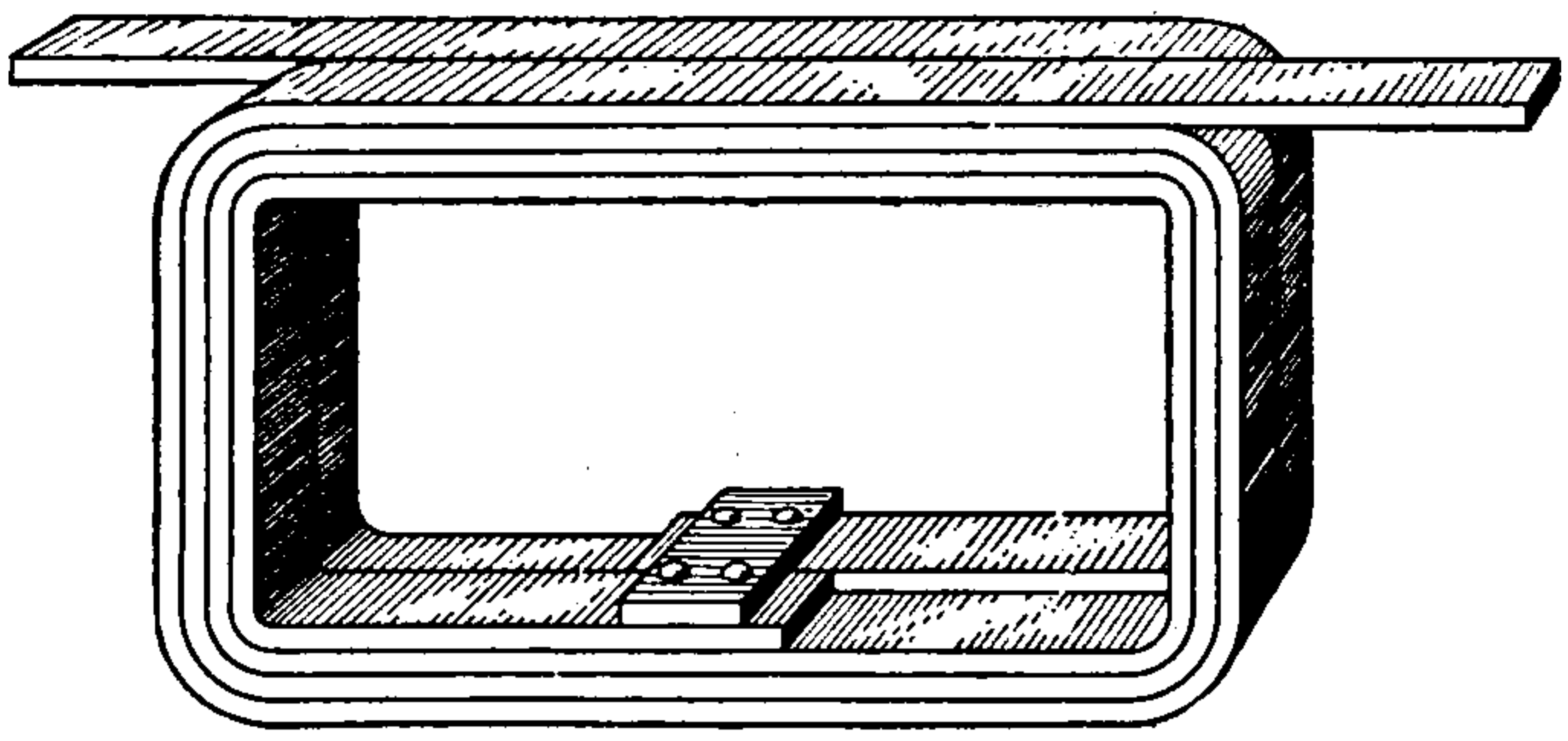


Fig. 180. Strip-Wound Coil

*Bringing Out and Fixing Ends.* A common means for bringing out the ends of coils is shown in Fig. 186. Copper strip, laid behind an end-sheet of insulating material, makes connection to the inner end, as shown in the lower part of the figure; while another strip, similarly inlaid in the upper part, serves as a mechanical as well as an electrical attachment for the outer end of the winding. Fig. 187 illustrates a simple device for securing the outer end by means of a terminal piece laid upon the coil, the last three or four turns of which are bared and wound over it, a permanent joint being obtained by soldering.

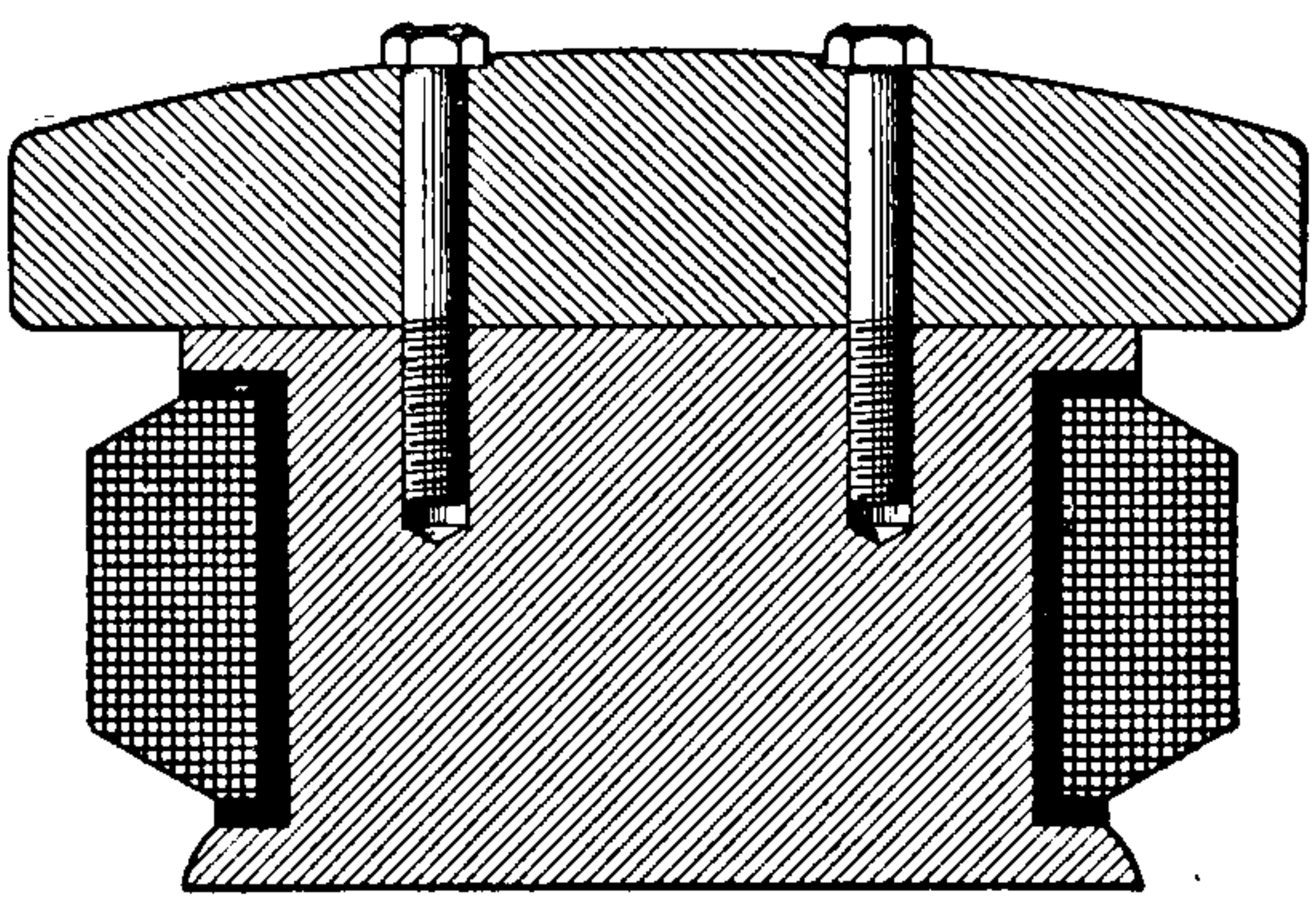


Fig. 181. Pole-Core Used as Bobbin

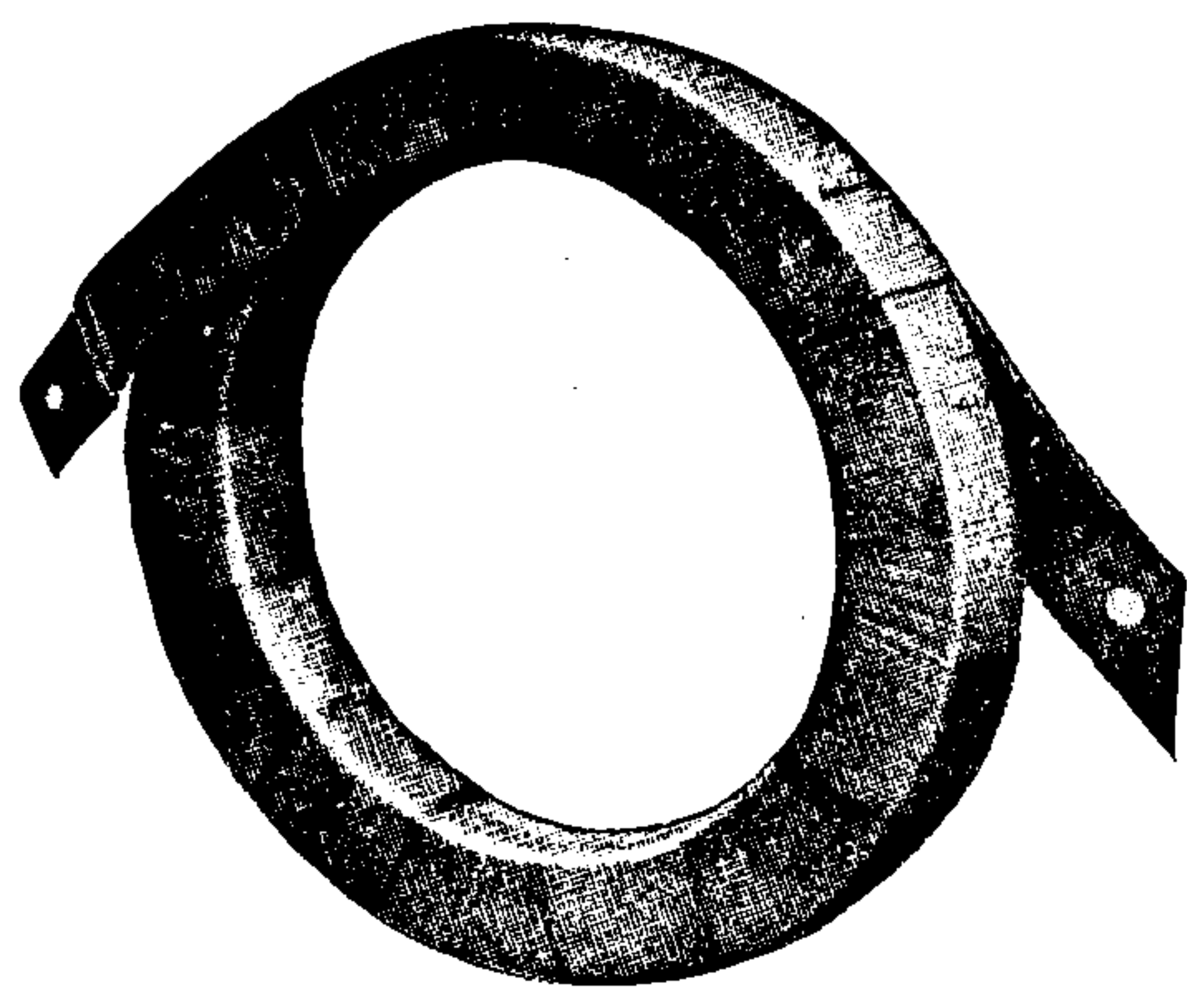


Fig. 182. Type of Form-Wound Coil

*Insulation of Magnet-Coils.* It is not necessary to use any mica for the insulation of field-magnet bobbins, several thicknesses of paper preparations being more often used, as the potentials used are not high. One-tenth inch or more thickness, if composed of several superposed layers, is generally adequate. Varnished canvas is useful as an underlay, and press-spahn or vulcanized fiber for

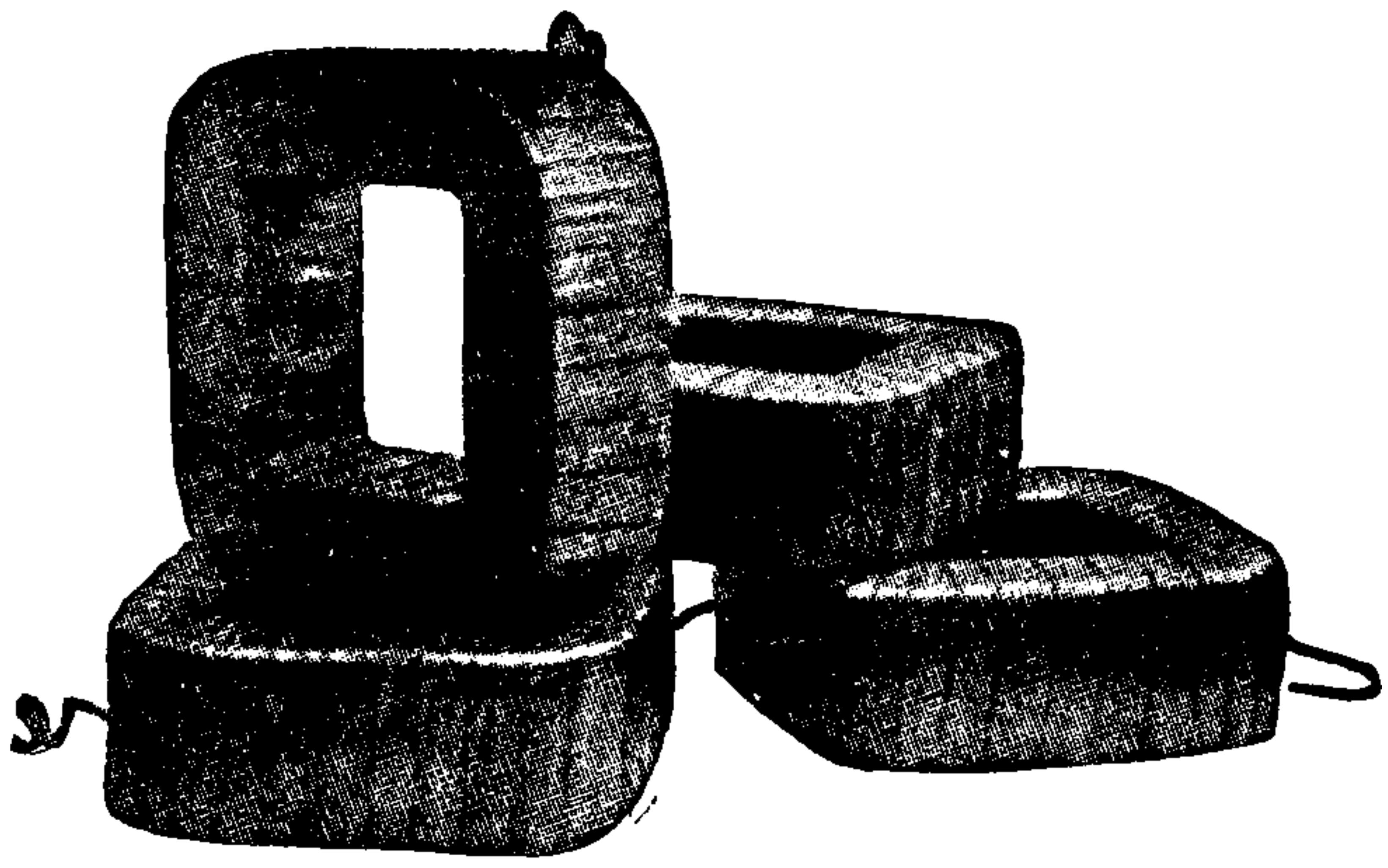


Fig. 183. Type of Form-Wound Coil

lining the flanges. It is also important to protect the joint between the cylindrical part of the bobbin and the end flanges.

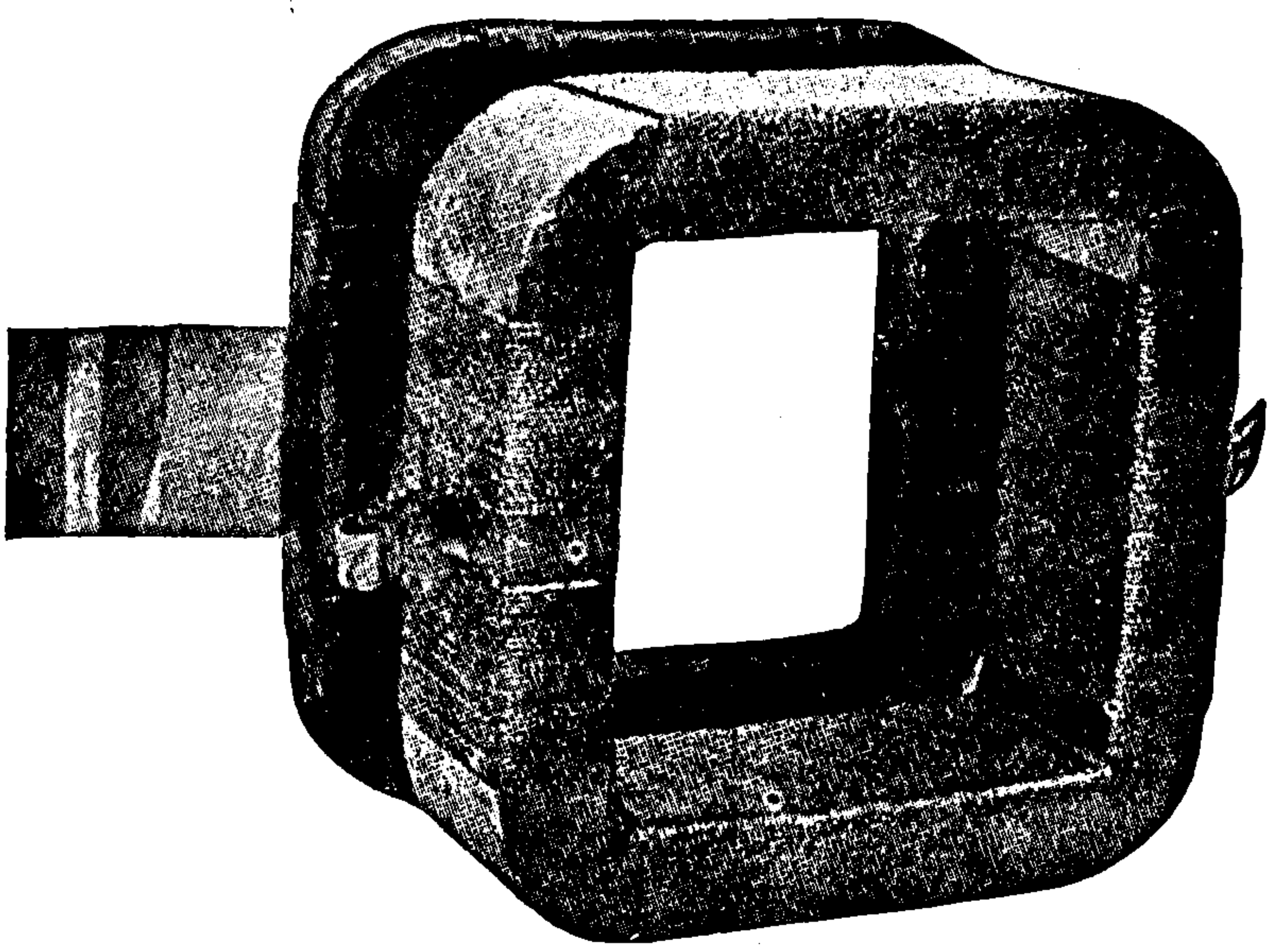


Fig. 184. Type of Form-Wound Coil

The lagging of varnished cord with which the completed coil is usually covered, acts as a mechanical protection; but this is not altogether a benefit, since it retards the dissipation of heat. Enameled wire is also being used for the outer layer.

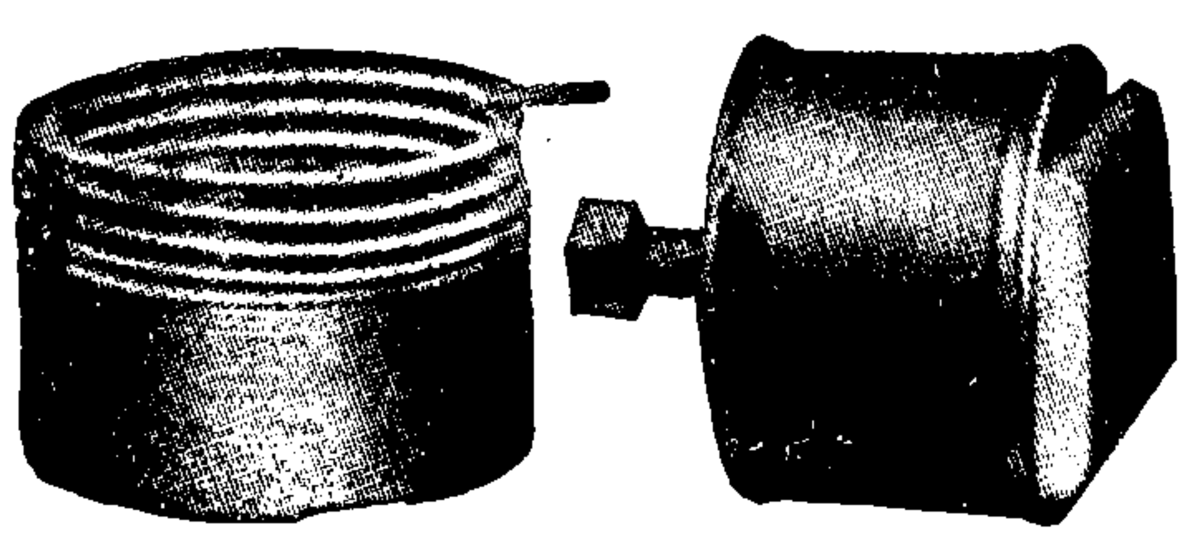


Fig. 185. Bobbin-Wound Coil

*Attachment of Magnet-Coils.* The ordinary mode of supporting the field-coils is by means of the pole-shoe, which is usually removable from the core. If not so arranged, the core and shoe together are made removable. Some machines are

## ARMATURE CONSTRUCTION

**Core-Bodies.** The cores of armatures are universally made of laminæ—thin disks—of wrought iron or mild steel. These disks are stamped out of sheet metal, and range from 0.014 inch to 0.025 inch in thickness, the former thickness being that often used at the present time. Core-disks up to about 30 inches in diameter are punched in one piece; while larger diameters are stamped out in sections, Fig. 190, and the core built up as indicated in Fig. 191, alternating

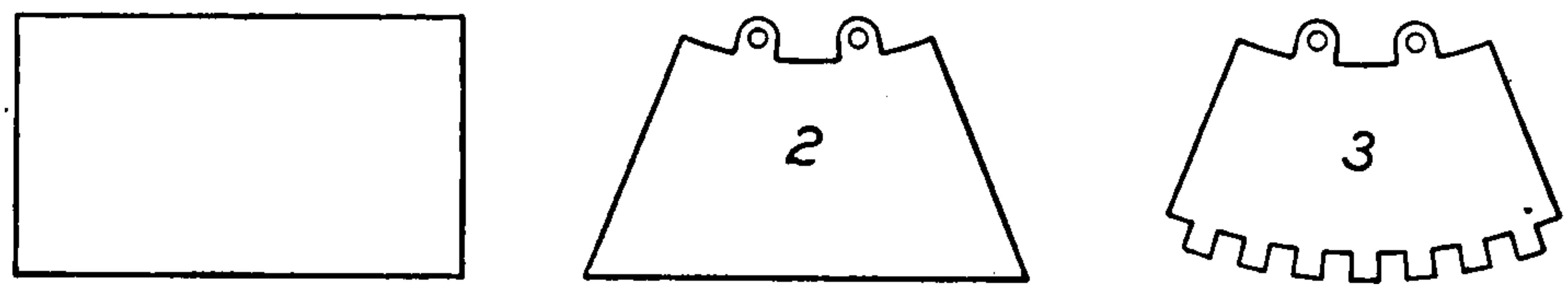



Fig. 190. Order of Stamping. Core-Segments

the joints. These stampings are now so accurately made, that, after assembling the disks into a core, the slots need not be milled out, as was formerly necessary. Milling is most objectionable because it burrs over the edges of the disks and defeats the purpose of lamination, the burrs produced connecting adjacent disks and facilitating the flow of eddy currents. For the same reason, turning after assembling also tends to increase the iron losses. Hence, if it is found that the periphery of the core-body is irregular, it should be *ground* true.

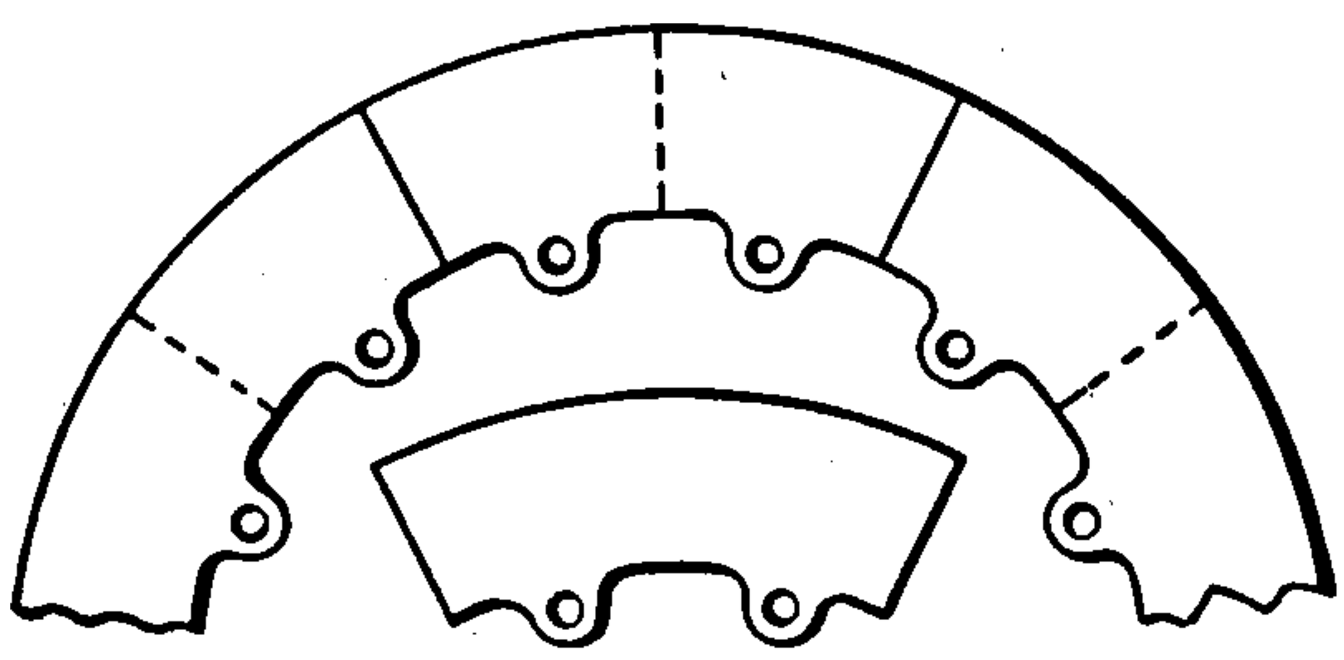


Fig. 191. Core Built of Segments

The core-disks are insulated from each other either by a thin coating of iron oxide on the disks, a thin coating of water-glass enamel applied to the sides of the disks by a machine, or a thin coating of japan varnish similarly applied. Sometimes shellac or paper is used for insulating these laminæ; but on account of the greater expense and the fact that the efficiency is only slightly bettered, the latter are applied only in special cases.

**Shapes of Armature Teeth.** A common form of armature tooth is that shown in Fig. 192, being slightly narrower at the root than at the top, the resulting slot having parallel sides. Fig. 193 illustrates a form in which the tops are slightly extended to give a larger magnetic area at the top, thus decreasing the reluctance of the air gap, and helping to retain the conductors in the slots by the insertion of a wedge of wood. The latter object is also attained by notching the teeth as in Fig. 194, in case it is not desirable to increase the area of the top of the tooth.

**End Core=Plates.** It is usual to place at the ends of the core, plates of sheet iron of a greater thickness than the laminæ, so as to support and protect the latter. They are usually 0.125 inch thick, and sometimes ribbed to give added stiffness.

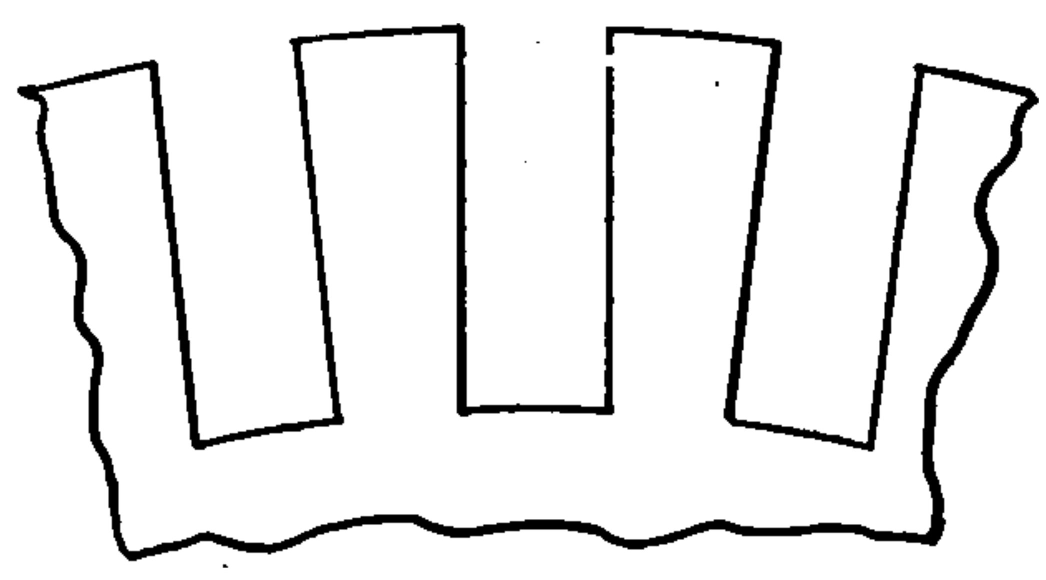


Fig. 192. Teeth with Parallel Slots

**Binding=Wire Channels.** In machines using binding wires to hold the armature conductors in the slots, it is usual to stamp some of the core-disks of slightly reduced diameter so that the binding wires may be flush with the surface of the armature. The reduction is seldom more than $\frac{1}{4}$ inch on the diameter, giving a channel not over $\frac{1}{8}$-inch deep. The width is determined by the number and the size of the binding wires. (See page 132.)

**Mounting of Core=Disks.** Some mechanical means must be provided to hold the core-disks together, and to connect them rigidly

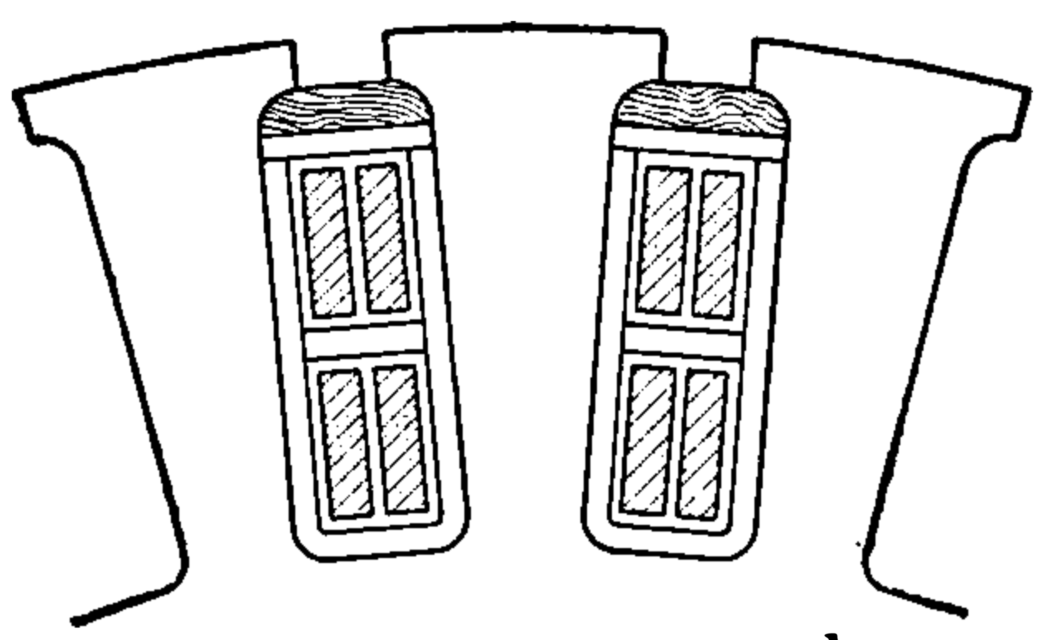


Fig. 193. Teeth with Projecting Tops

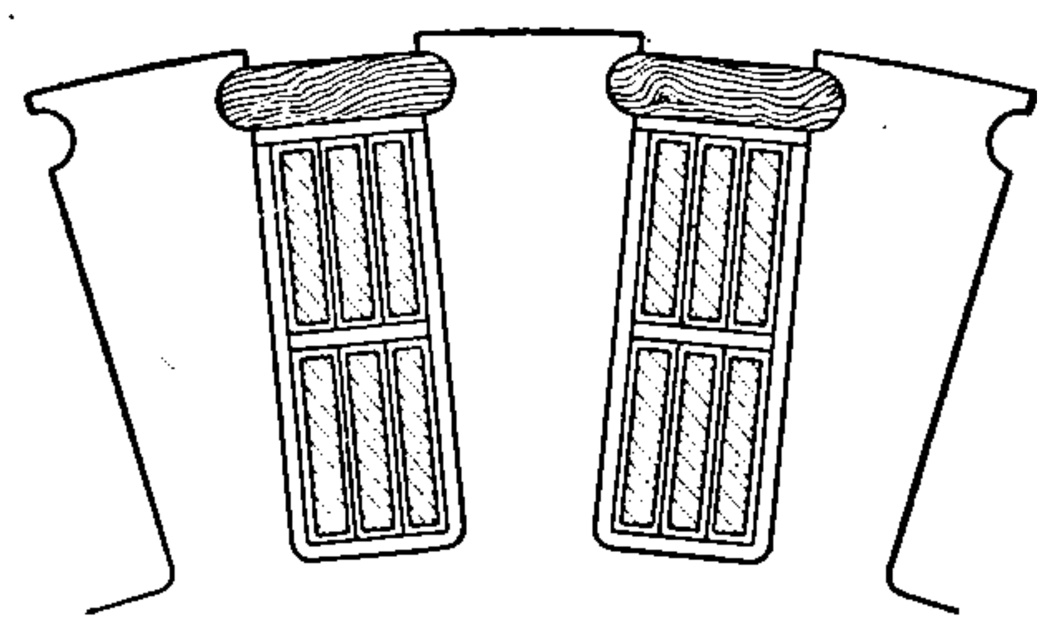


Fig. 194. Notched Teeth, to Hold a Wedge

to the shaft. The methods may be broadly divided into two classes, depending on whether the disks are keyed directly to the shaft, or to some auxiliary support attached to the shaft.

In the case of small cores not exceeding 15 inches in diameter, the core-disks take either of the forms shown in Figs. 195 and 196, the latter being preferable on account of increased ventilation. These laminæ are simply keyed to the shaft, being held together under heavy pressure by end-plates of cast steel or cast iron, which are in turn pressed inward either by nuts fitting in threads upon the shaft or by bolts passing through, but insulated from, the armature disks and end-plates.

Large cores in which the disks are made in sections, or for which the material of the core near the shaft is not required, are built upon an auxiliary support called a *spider,* which has different forms, depending on the mode of attachment between it and the core-disks.

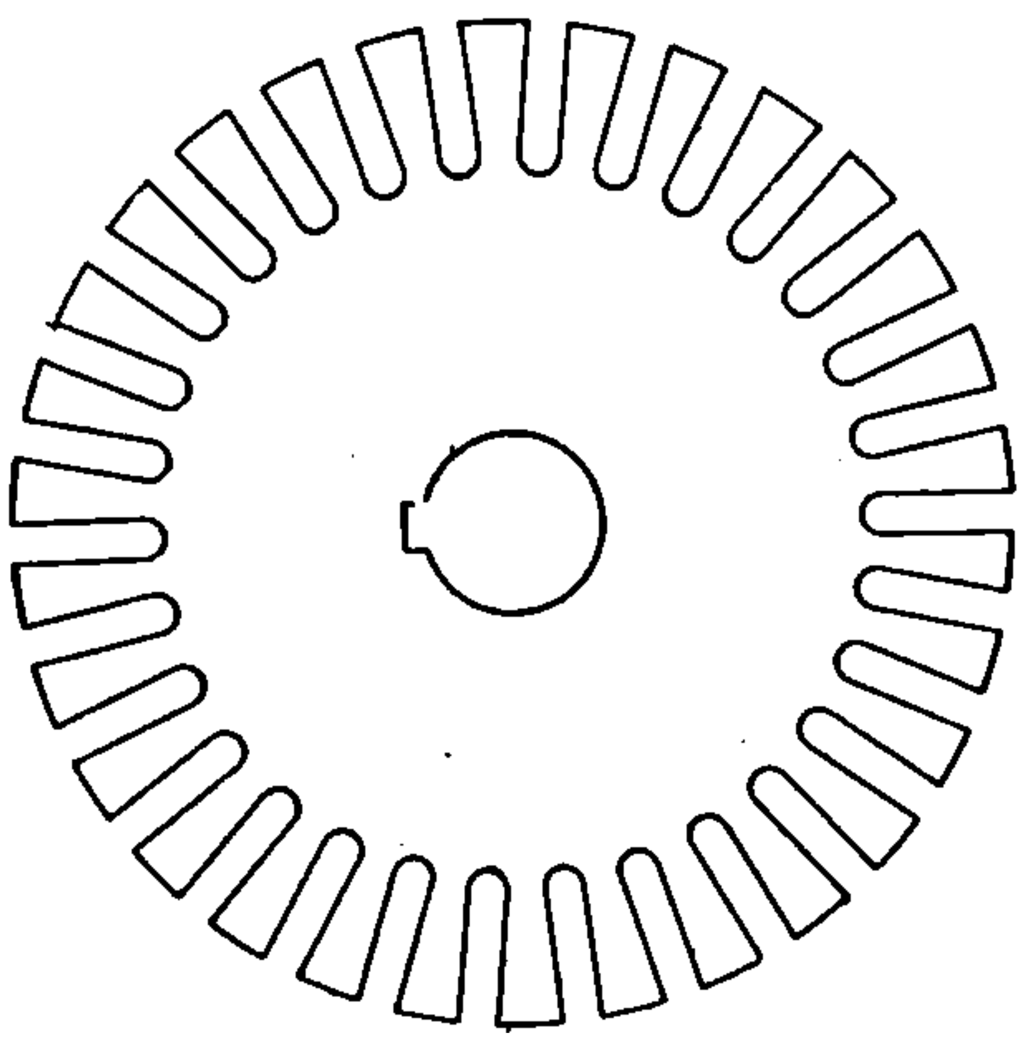


Fig. 195.

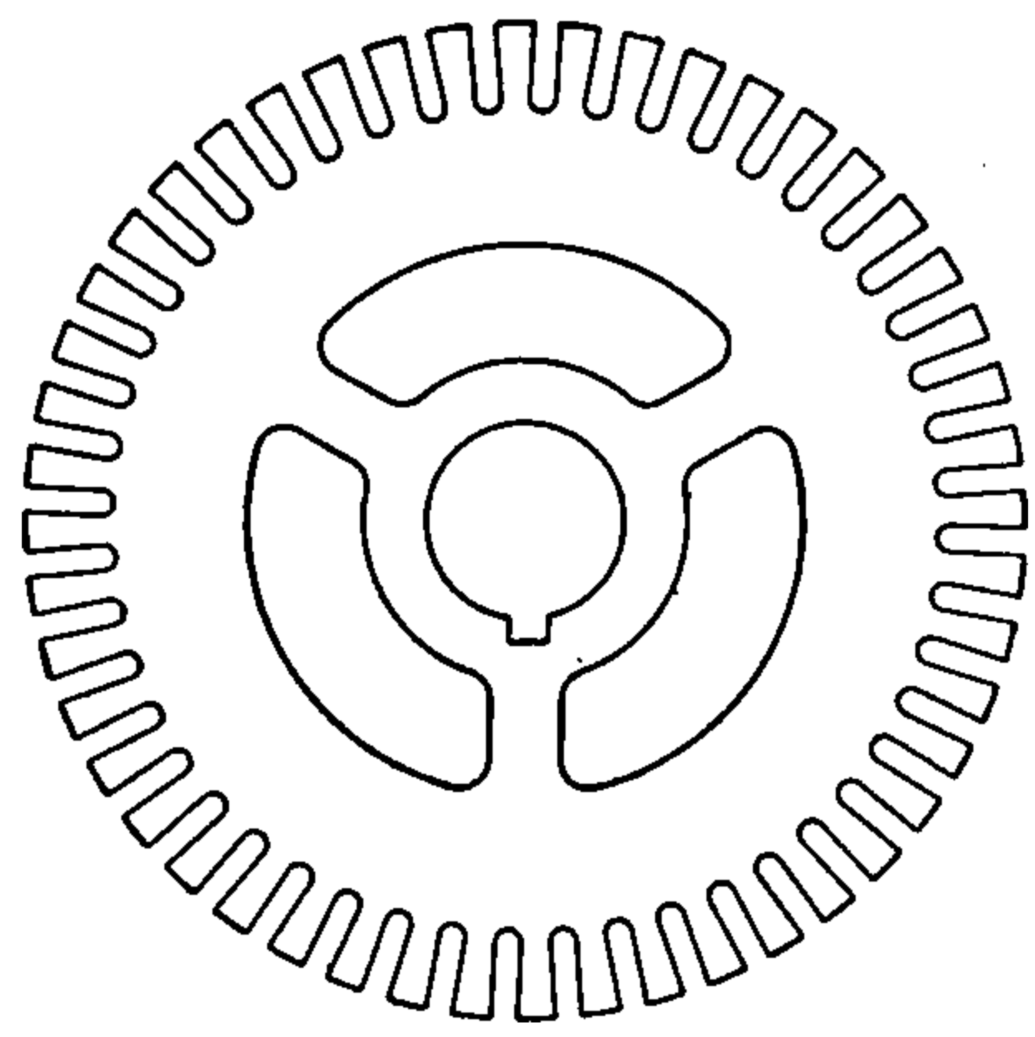


Fig. 196.

Forms of Armature Core-Disks

Fig. 197 shows the disks held together and to a skeleton pulley, or spider, by bolts passing through them, the spider being keyed to the shaft. The objection to this construction is the fact that the bolt-holes reduce the effective area of the core, thus strangling the magnetic flux. This may be overcome by placing the bolts internal to the core, as in Fig. 198, in which case they need not be so well insulated.

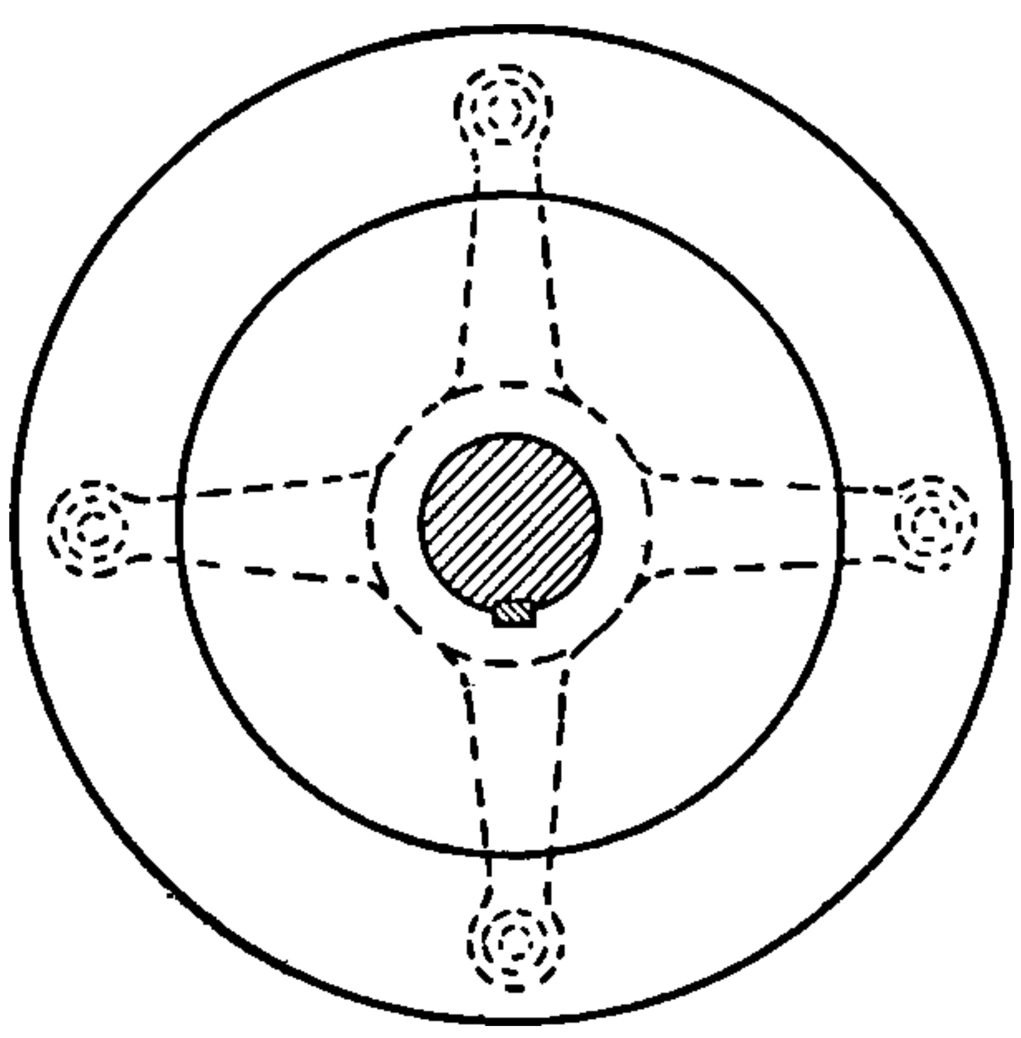


Fig. 197. Core-Disks Bolted to Spider

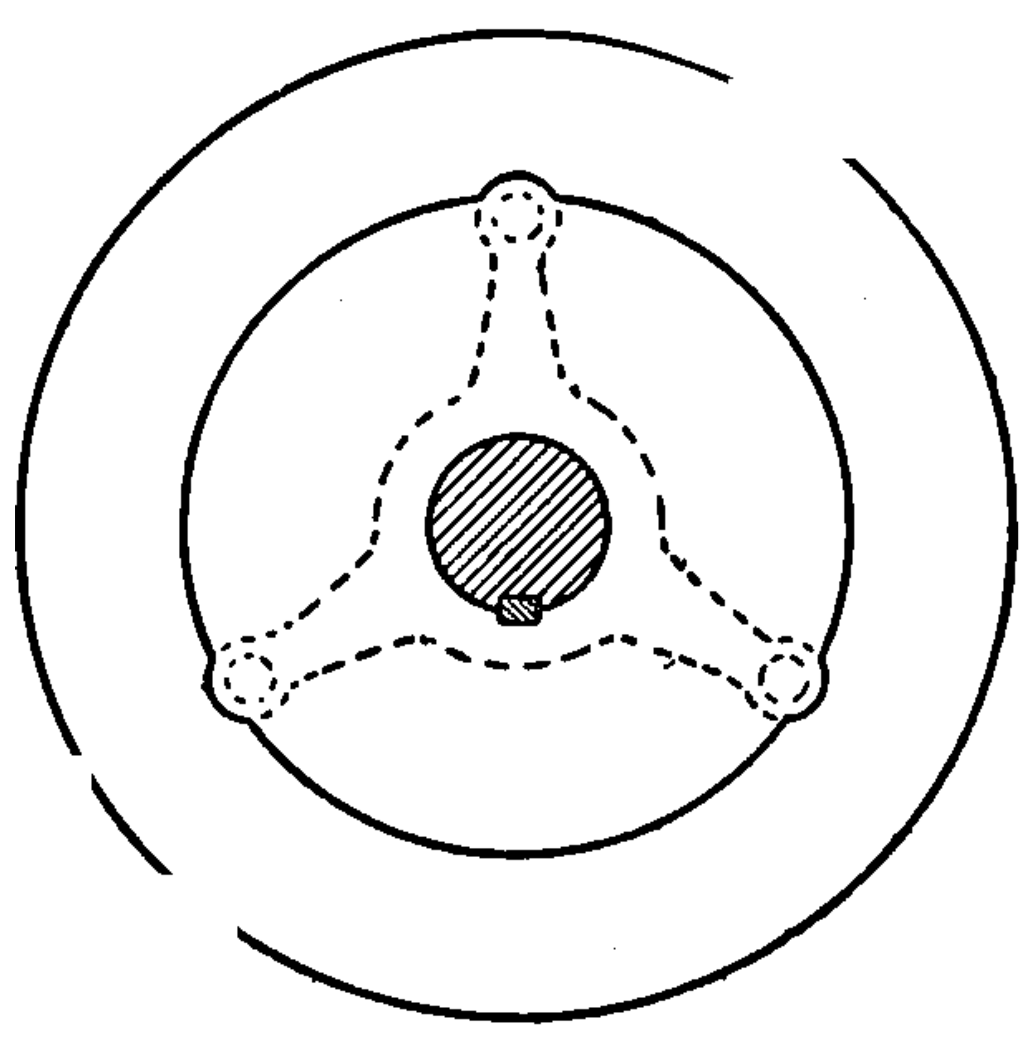


Fig. 198. Bolts Placed Internal to Core

Another arrangement which is more modern, is to provide the disks with dovetail notches or extensions, fitting into extensions or notches on the spider arms, as in Fig. 199. The sectional view shows the method of holding the laminæ together by means of bolts and end-plates, also the extension *R R* for supporting the end-connections of a barrel-winding.

has been found necessary, in the large and heavy-duty types of to-day, to resort to means of ventilation, usually consisting of ducts which lead the air out between the core-disks. To keep the core-disks apart at these ducts, it is necessary to introduce distance pieces, or *ventilators,* Fig. 203 illustrating some of these devices.

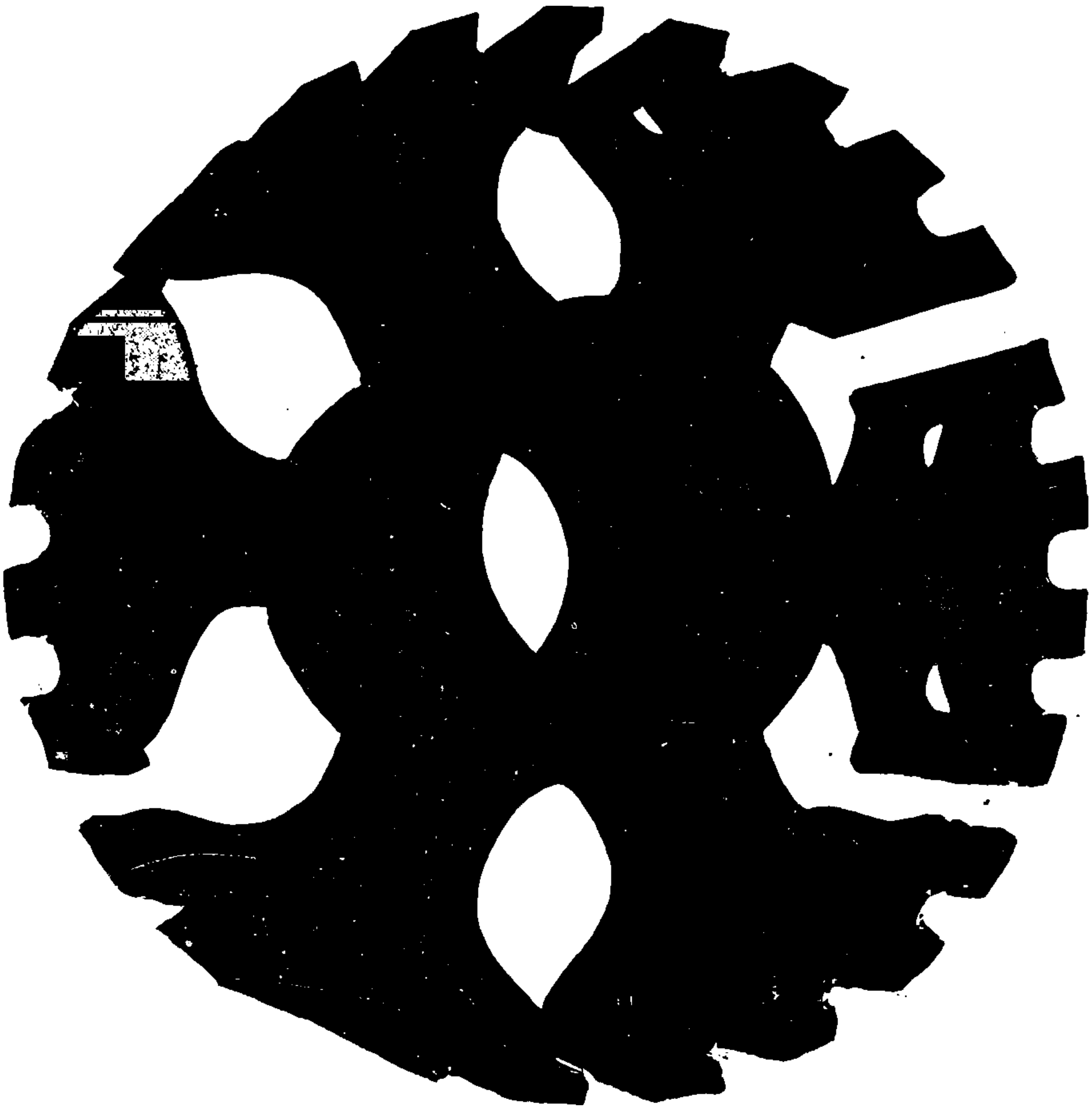


Fig. 201. Spider for Bullock Armature

In *A,* simple pieces of brass are riveted radially at intervals to a special core-disk 0.04 to 0.05 inch thick. This form fails to provide adequate support for the teeth, which is obviated in *B,* where behind each tooth there is a strip of brass about 0.4 inch wide set edgewise, being cast with or brazed to a special casting of brass riveted to a stout core-disk. In a recent construction, shown in Fig. 204, the core-plate next to the duct is ribbed, affording good support for both the core and teeth of the next plate.

**Binding Wires.** With toothed-core armatures the conductors may be held in the slots by wedges of wood, as already mentioned, or by bands of wire wound around the armature. These binding wires must be strong enough to resist the centrifugal force tending to throw the armature conductors out of the slots, and yet must occupy as little radial space as possible, in order not to interfere with the clearance between the armature and the pole-pieces. The common

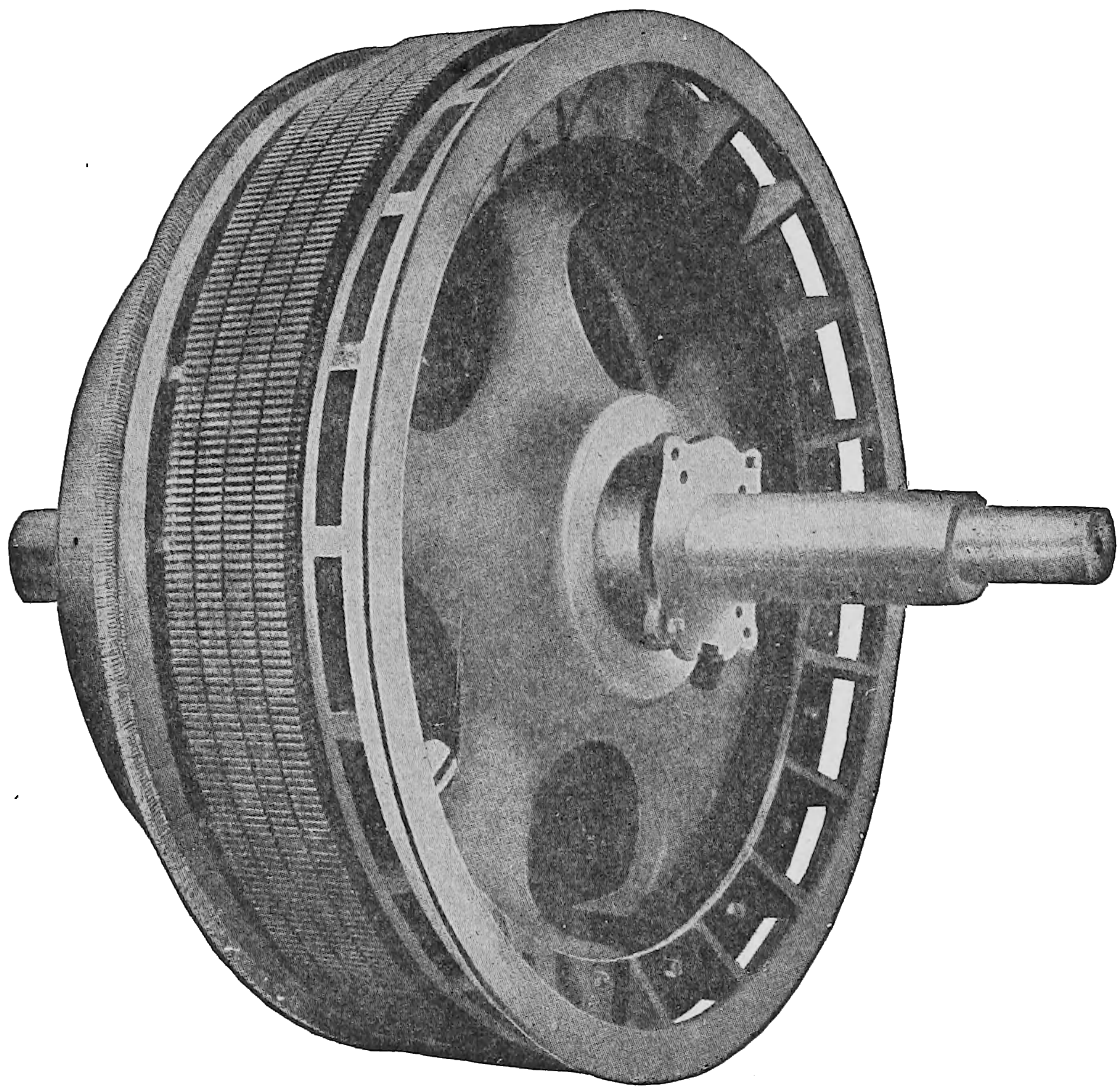


Fig. 202. Armature Core and Commutator with Temporary Shaft

practice is to employ a tinned wire of hard-drawn brass, phosphor bronze, or steel, which, after winding, can be sweated together by solder into one continuous band.

Under each belt of binding wire a band of insulation is laid, usually consisting of two layers—first, a thin strip of vulcanized fiber or of hard red varnished paper slightly wider than the belt of wire, and then a strip of mica in short pieces of about equal width. Sometimes a small strap of thin brass is laid under each belt of binding wire, having tags which can be turned over and soldered down to prevent the ends of the binding wires from flying out.

**Wedges.** In the cases where wedges are driven into grooves in the teeth, to close up the slot, the usual material employed is a well-baked hardwood, such as hornbeam or hard white vulcanized fiber. A modern method consists in using a springy strip of German silver, or a strip of *magnalium* metal.

**Conductors.** Copper is always used for the armature conductors of continuous-current machinery, either as wire strip or stranded. Wire is usually employed for machines of small or moderate current output; but rectangular conductors are preferable, especially for heavier currents, on account of better space-factor. Large, solid conductors, whether round or rectangular, are objectionable, not only on account of stiffness, but also because eddy currents may be generated in them. This is avoided by subdividing the former into several round wires or by laminating the latter.

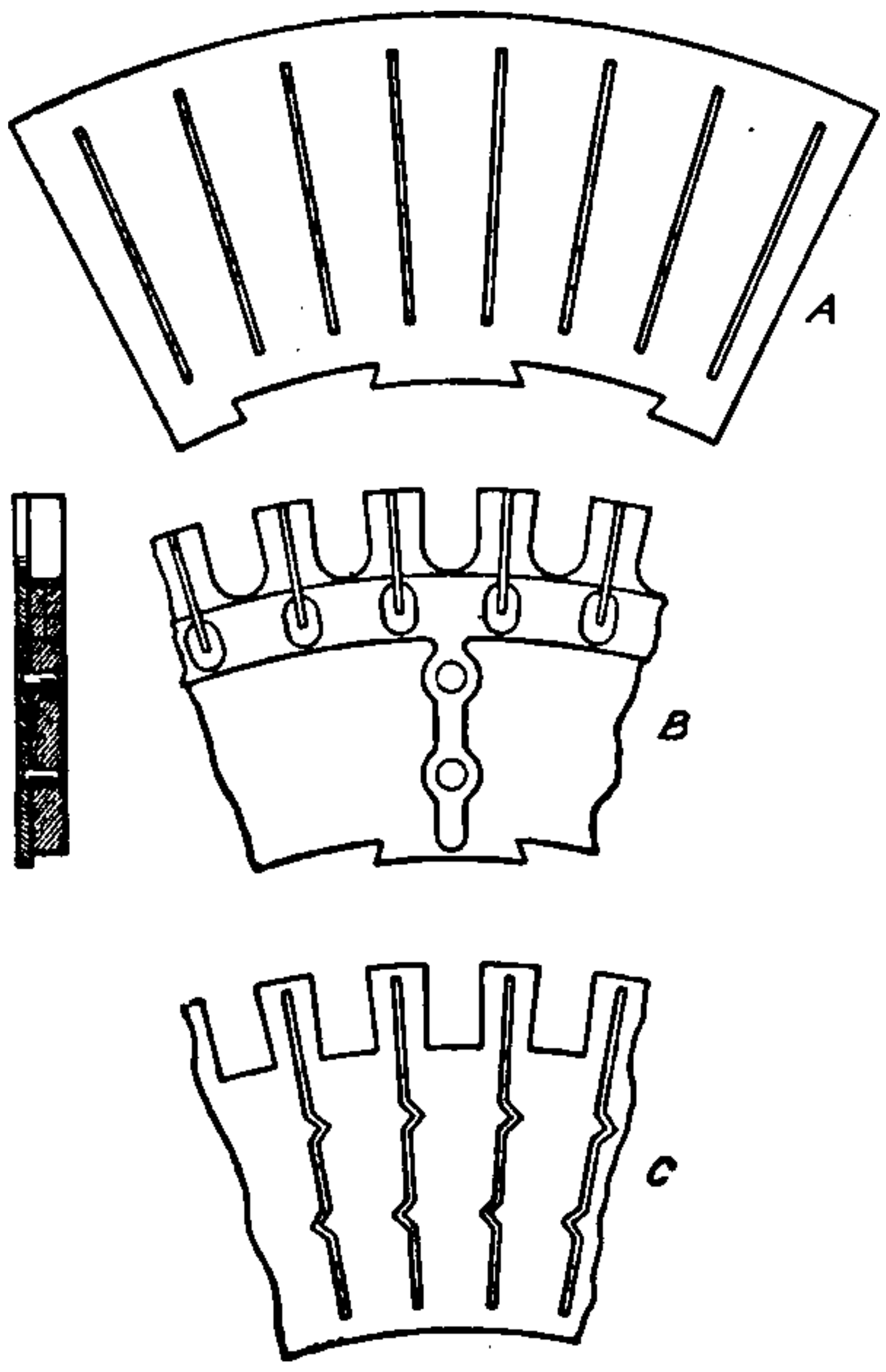



Fig. 203. Ventilating Devices

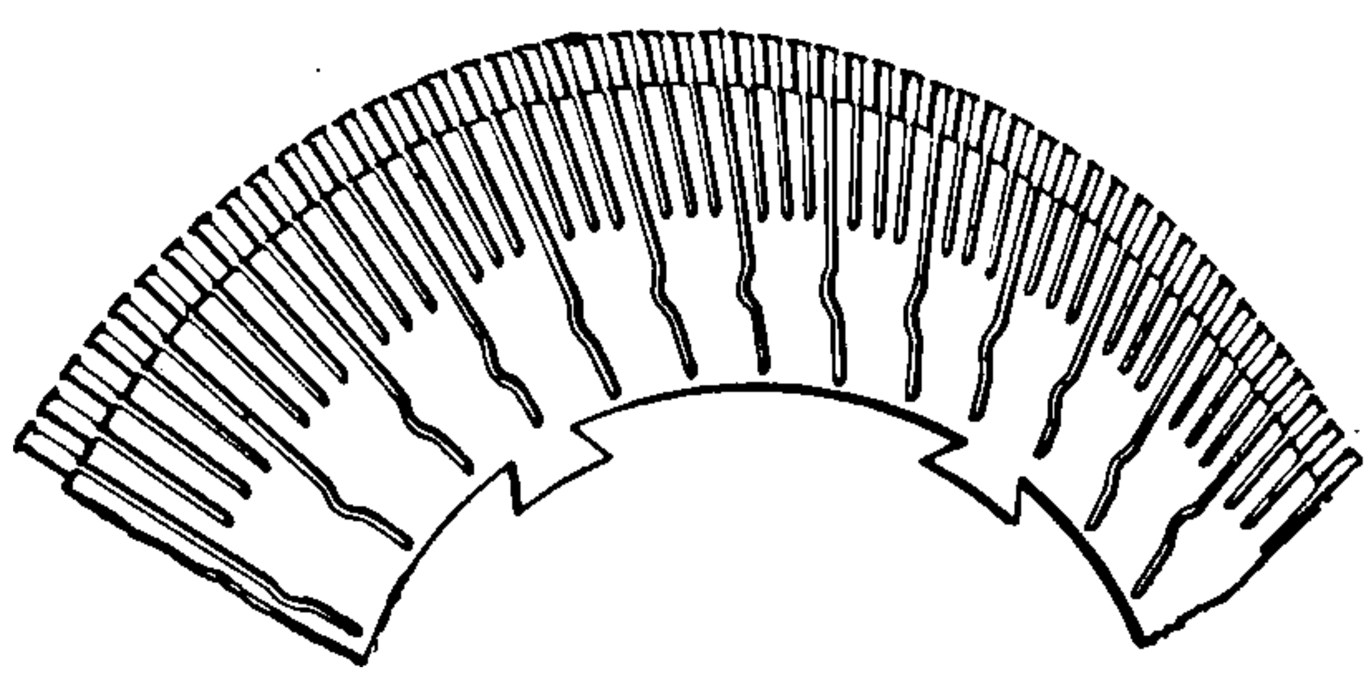


Fig. 204. Ribbed Core-Plate

## ARMATURE WINDINGS

The different methods of armature windings have already been treated theoretically, pages 87-117; it now remains to consider the mechanical arrangements or means employed to carry out the scheme of winding adopted.

**Drum Windings.** Drum windings may be subdivided into (1) hand windings; (2) evolute windings; (3) barrel windings; (4) bastard drum windings; and (5) form windings, according to the manner in which the end-connections are made. It is essential that these latter be good conductors, sufficiently well insulated from one another, allowing of repairs and ventilation, and mechanically sound.

case. Its great advantage lies in the excellent ventilation made possible by the larger cooling surface, and by permitting air to enter the interior of the armature at the ends.

A usual method of supporting the extended end-connections is to attach to the end of the armature body ventilated brackets, as indicated in Fig. 209. A simple way to construct such a winding is to take a long bar of copper, and bend it as shown at *A*, Fig. 210.

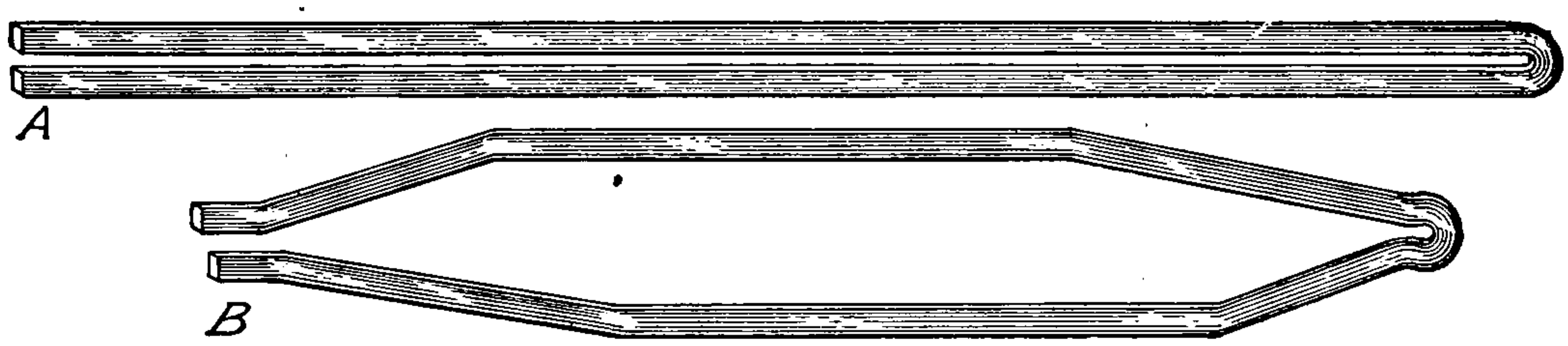



Fig. 210. Element of Lap Winding Formed from Strip

The bar may be opened out as in *B*, Fig. 210, if the winding is to be lap-wound, or as in Fig. 211, if the winding is to be wave-wound. Methods of computing the necessary length of the end-connections have been referred to on page 116, so that the required length of bar may be predetermined. In Figs. 212 and 213, finished armatures

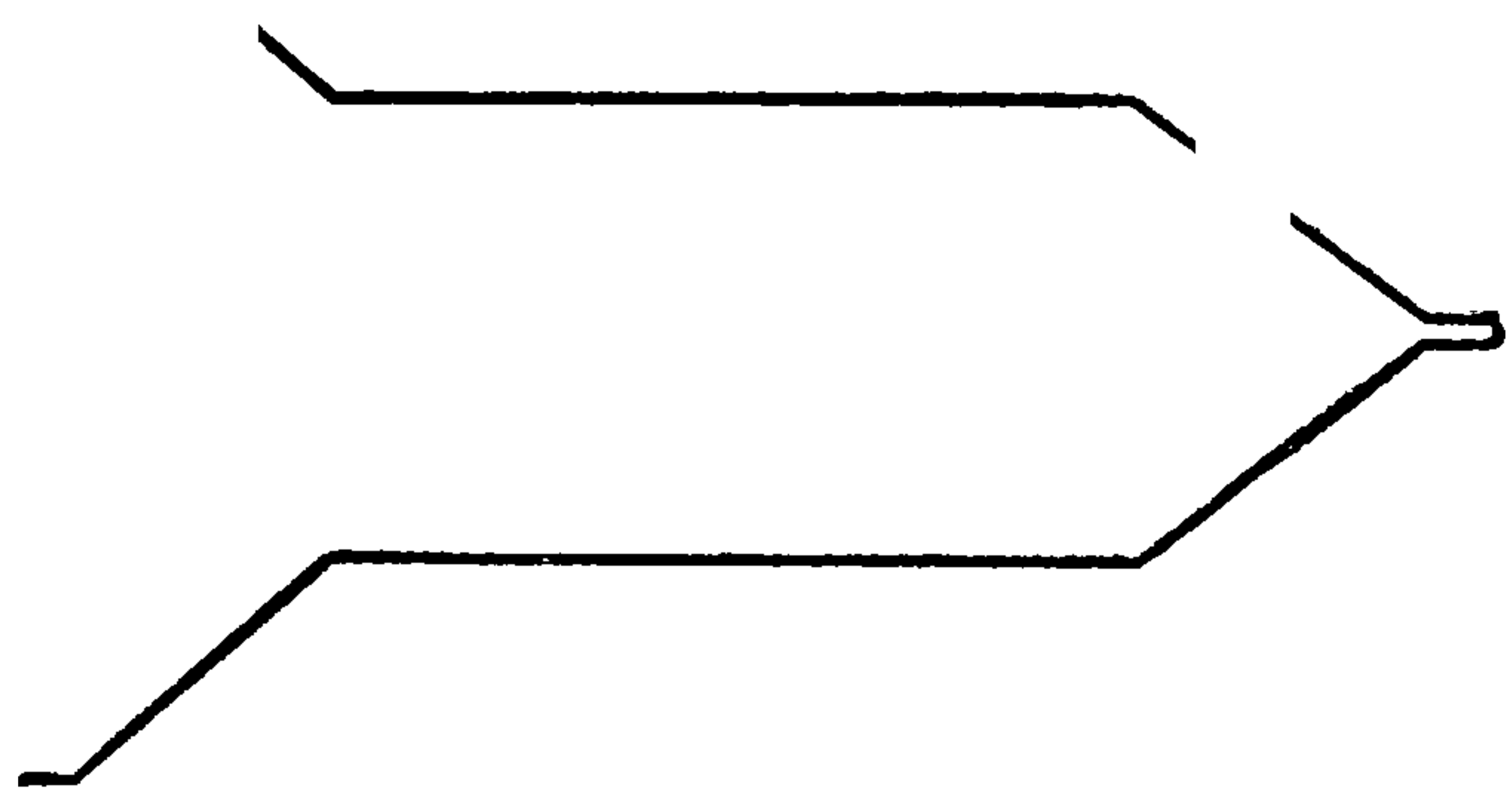


Fig. 211. Element of Wave Winding Formed from Strip

of this type are represented, while in Fig. 214 they are illustrated diagrammatically.

Thus far the windings have been described as formed of copper bars; but it is also possible to wind either of these types with wire, shaping the coils before placing the wire in the slots.

Cases also occur where more than two layers of wire are necessary, either on account of the high voltage required, or to avoid harmful induction.

*Bastard Windings.* Bastard drum-windings is the name given to that class of armature windings whose end-connections, instead of being carried in toward the shaft in evolutes or elongated cylindrically,

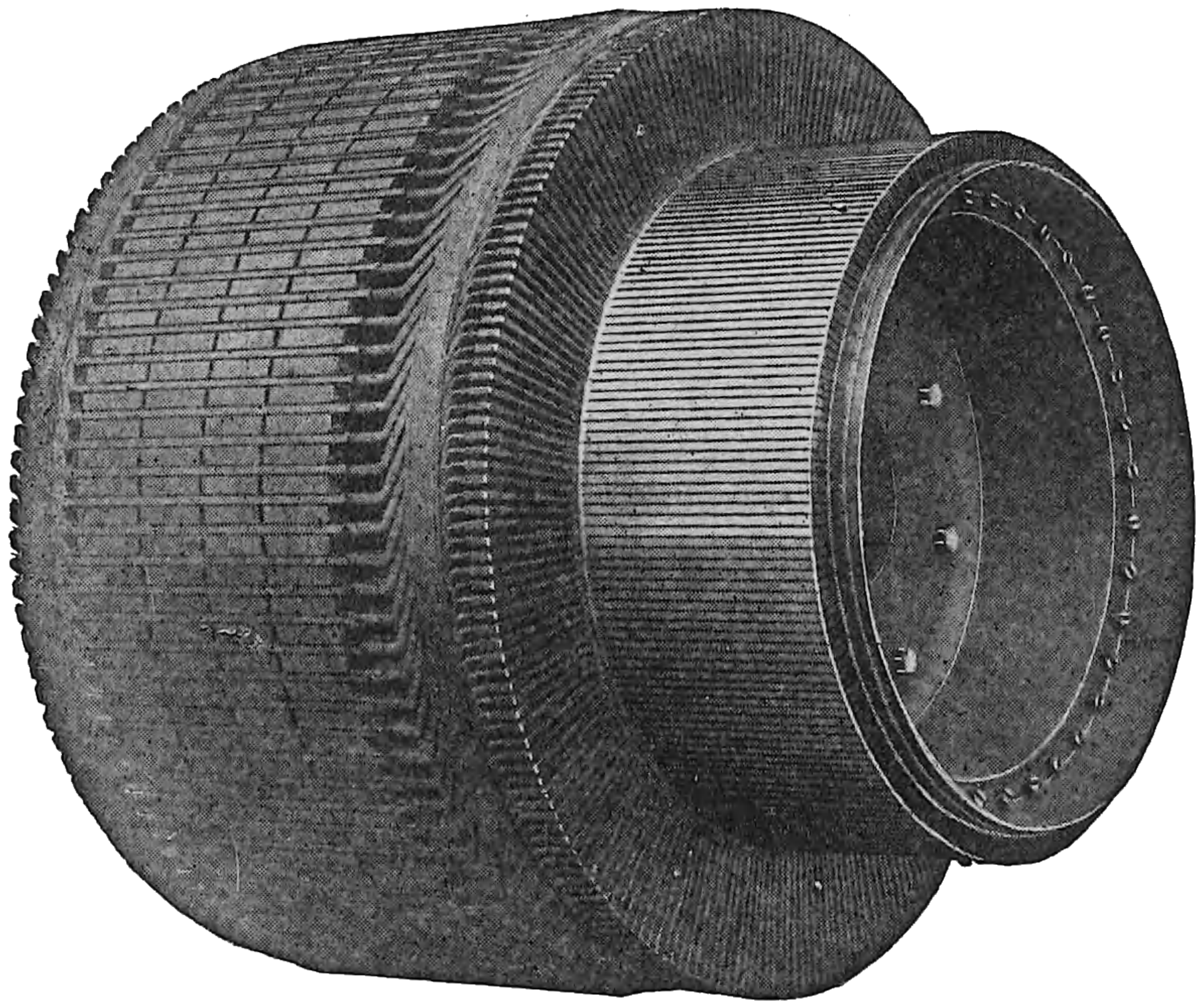


Fig. 212. Armature of Triumph Generator

are partly inward and partly cylindrical. This has the effect of making the length of the armature parallel to the shaft shorter than

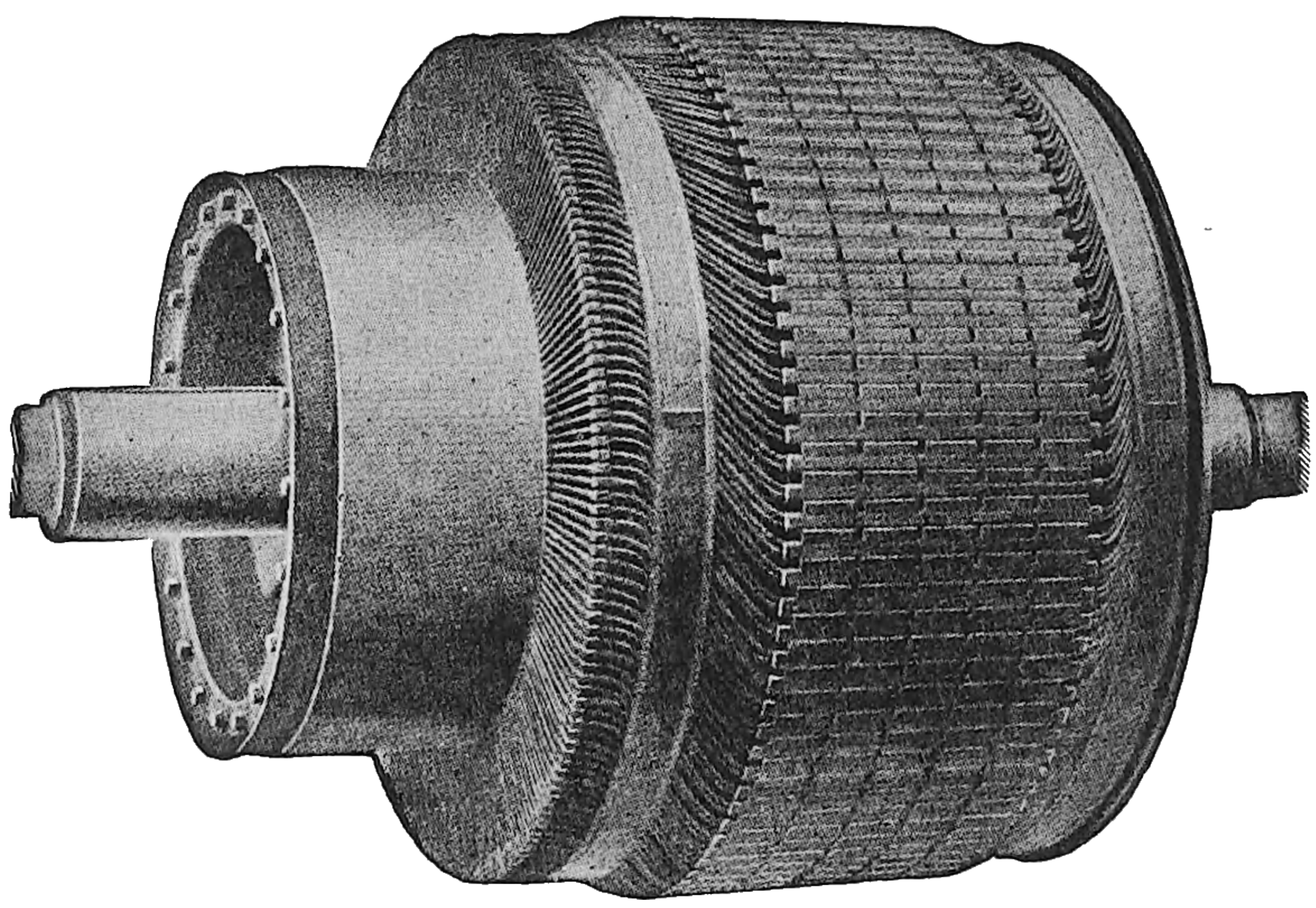


Fig. 213. Complete Armature of Crocker-Wheeler Company Engine-Type Generator

with the pure barrel winding. It requires, however, special formers, and is applicable only to bar-wound armatures. On account of

better ventilation, it is usual to combine a bastard winding at one end of the armature, with a barrel winding at the commutator end, as in

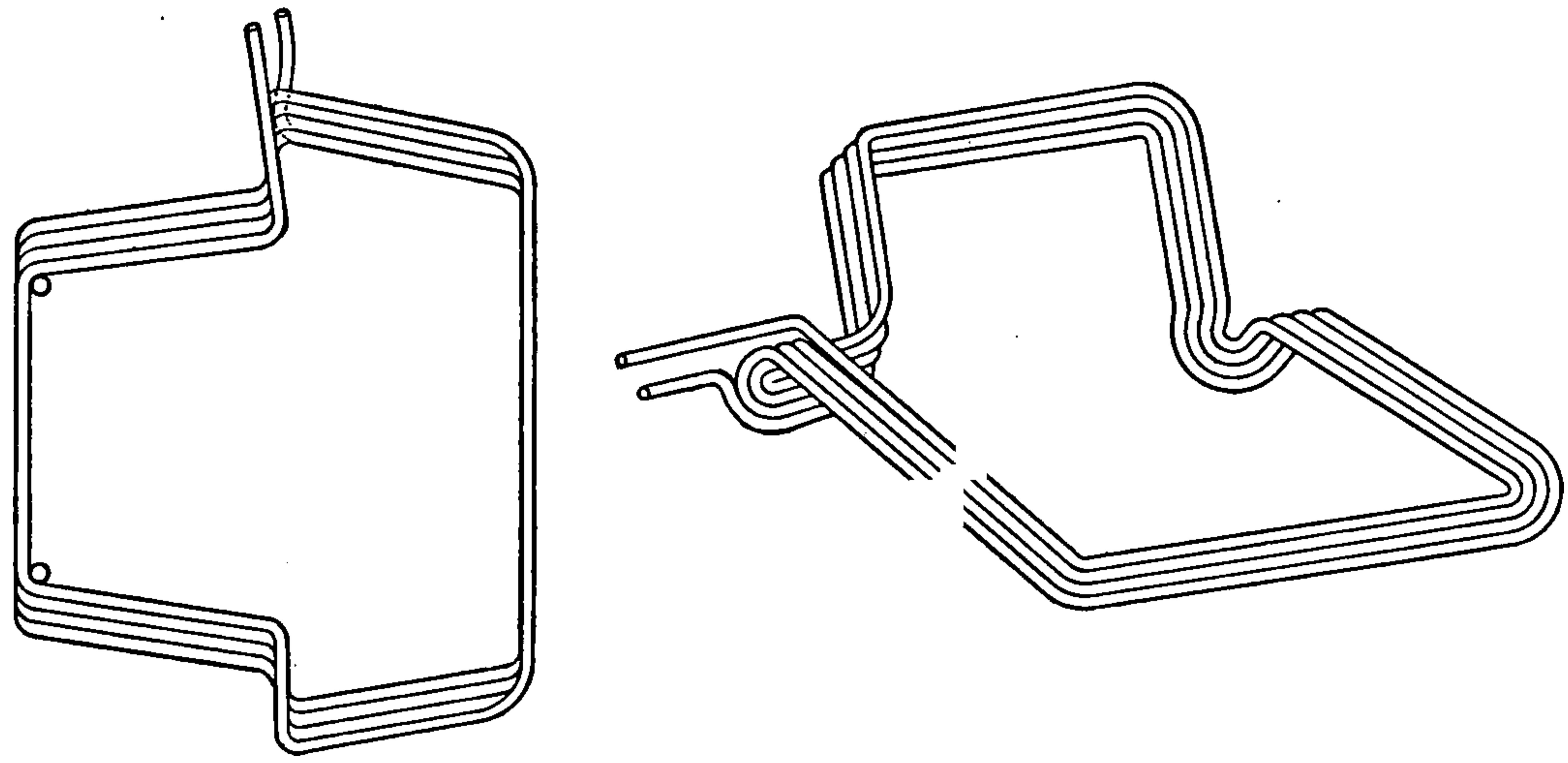


Fig. 219. Eickemeyer Former-Wound Coil, and Same Bent Up

Fig. 215; while Figs. 216, 217, and 218 show the relation of this scheme to the two previously mentioned.

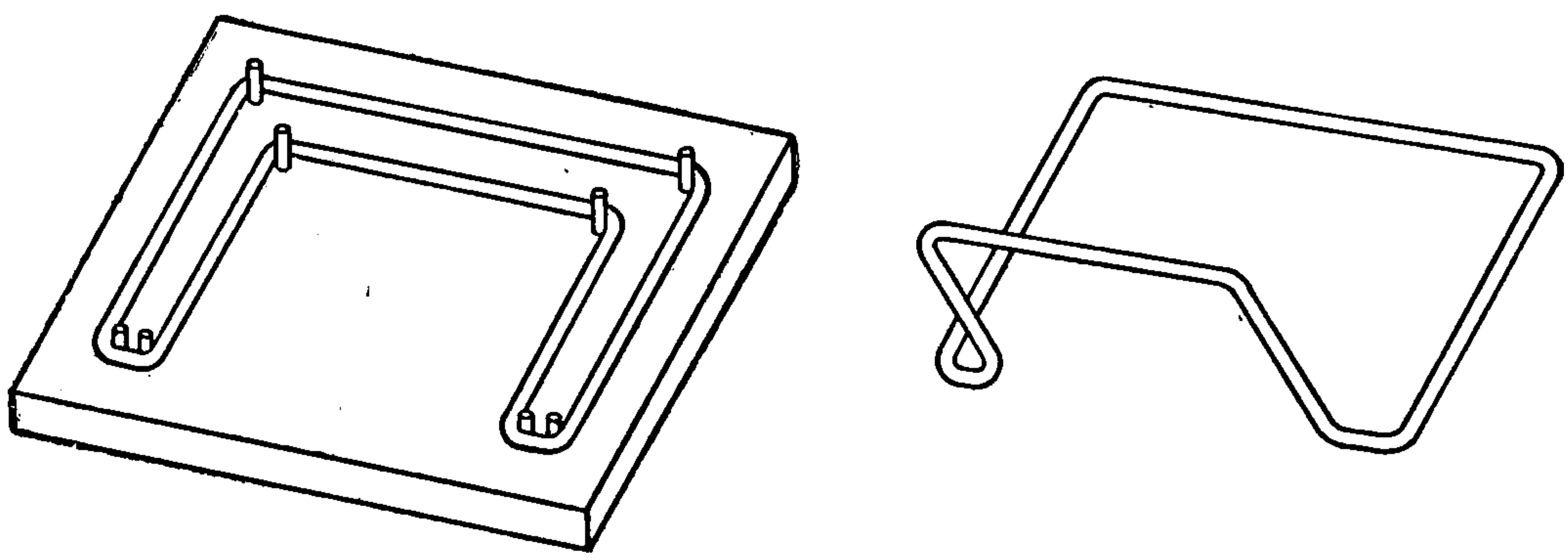


Fig. 220. Eickemeyer Coil on Former and Opened Out

*Form-Wound Drum Windings.* It was early found that hand-wound drums were both expensive in labor and unsymmetrical electrically. This resulted in the development of schemes for arranging the winding in coils on *formers,* and then laying these *formed coils* in their respective places upon the core-body. The individual sections of the winding are first wound and shaped upon a frame, or former, the wire being plain cotton-covered; and each

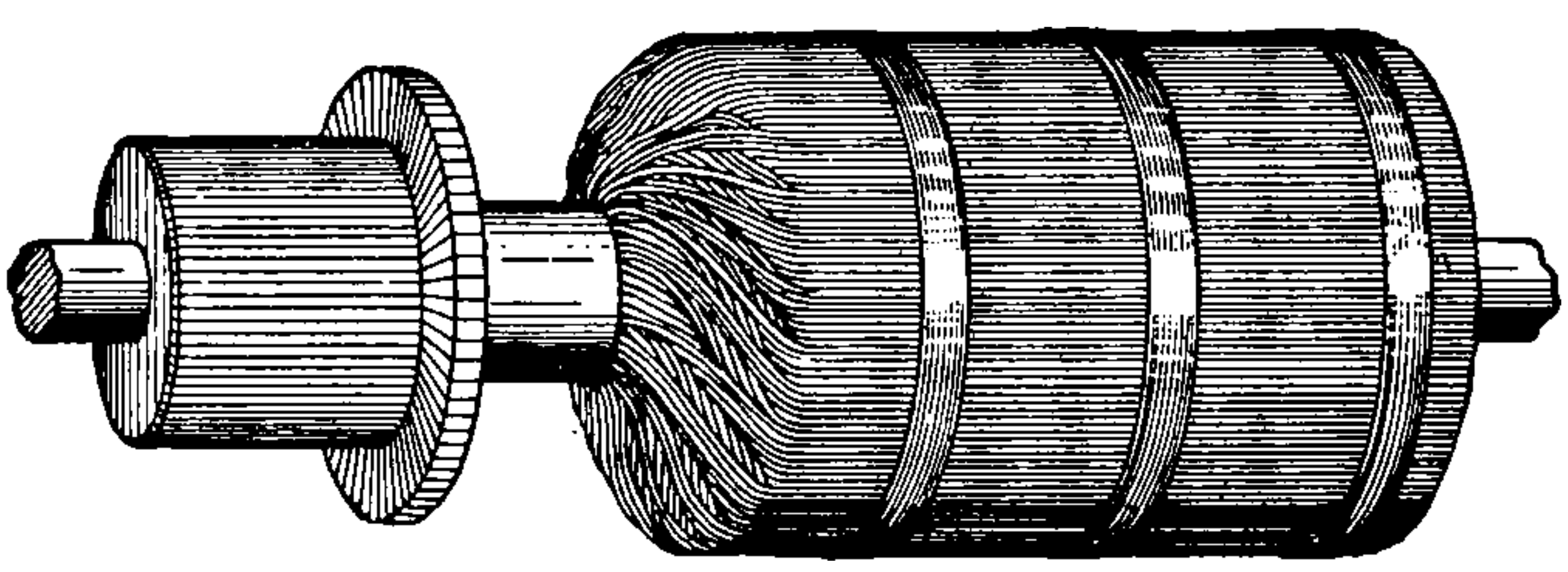


Fig. 221. Eickemeyer Armature, Complete

such section is again separately insulated by winding with tape, usually half-lapped; then baked, varnished, and baked again.

Alioth, according to the patent records, was the first to devise this plan. He was followed by Eickemeyer, who in 1888 patented a method of winding formed coils for evolute windings. This method attained almost universal use during the vogue of the evolute winding; and the first three stages in the construction of such a section are illustrated in Fig. 219; while Fig. 220 illustrates a later type of the former, and Fig. 221 a completed armature winding built up of such coils.

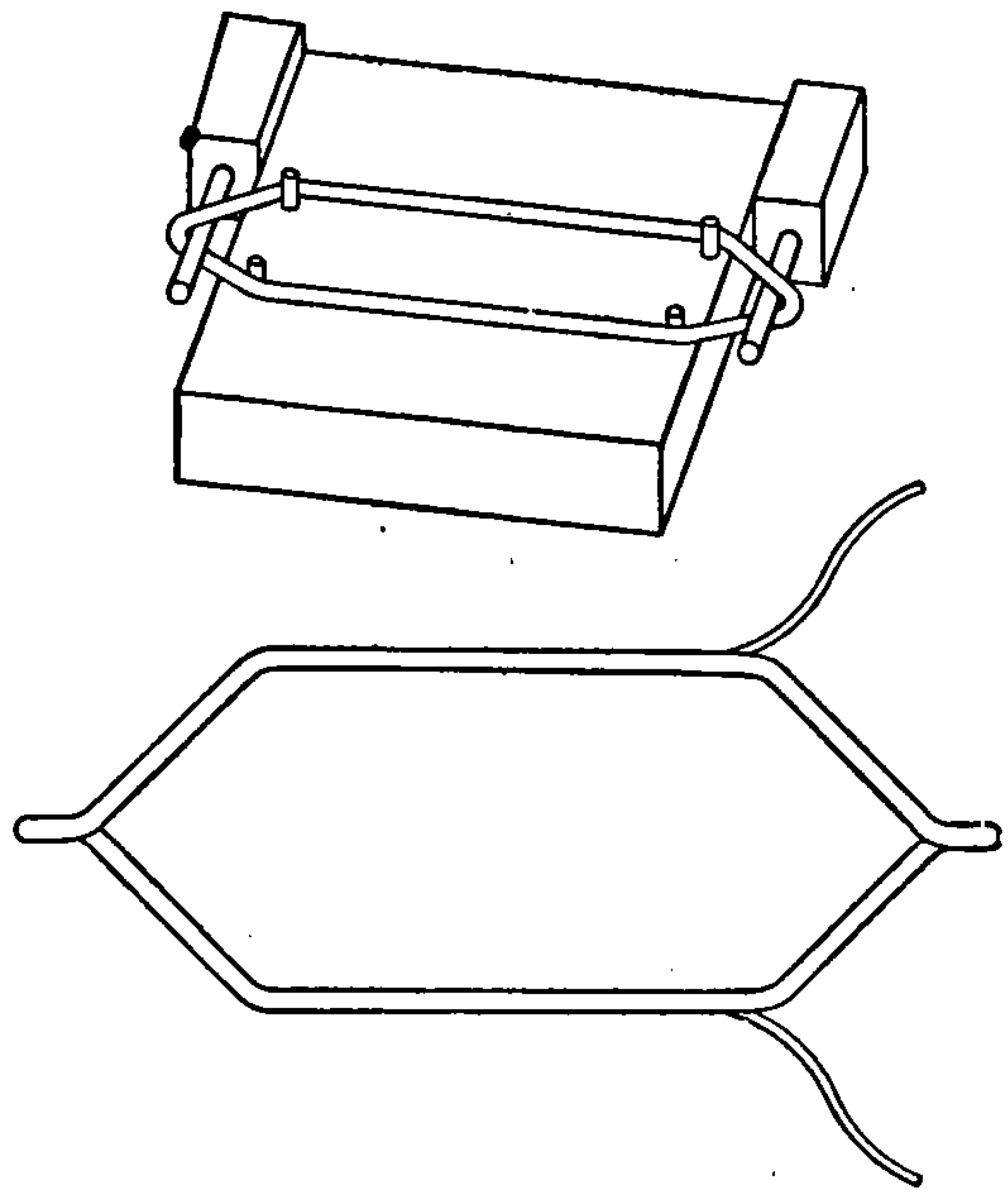


Fig. 222. "Straight-Out" Former-Wound Coil, and Coil Opened Out

What the Eickemeyer coil accomplishes for the evolute winding, may be accomplished for the barrel winding by use of "straight-out" formers. Fig. 222 illustrates a simple former of this type, upon which a coil for a wave winding has been wound and then opened out. Figs. 216, 217, and 218 illustrate the three principal types of formed windings; while Figs.

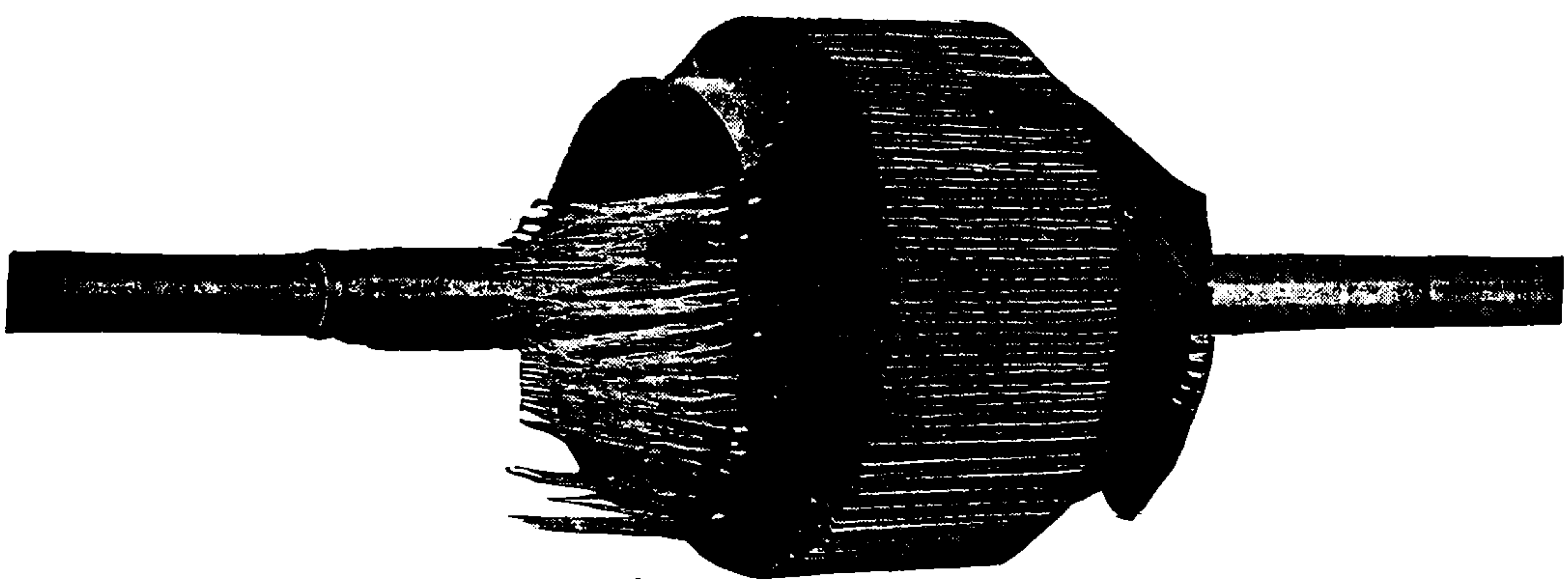


Fig. 223. Armature Body Showing Coils as Placed in Position

209, 223, and 224 illustrate successive stages in the construction of a barrel-wound armature using formed coils.

**Ring Windings.** These windings are almost always hand-wound, because the connections at the ends are not nearly so complicated as those of a drum-winding, and the winding is in general easily applied. Nevertheless care must be exercised, since the various sections are usually wound upon the core separately, the ends being left projecting. A careless workman may connect them so that some may generate in opposition, thus reducing the terminal voltage of the machine; hence it is usual to tag the ends of the coils,

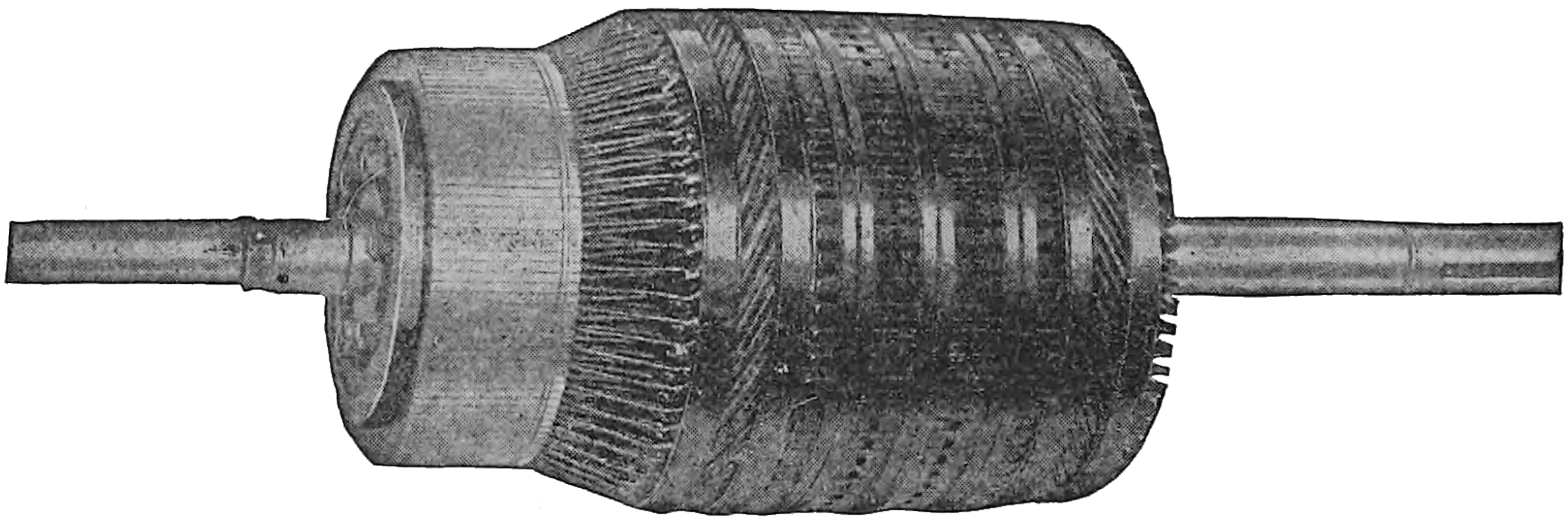


Fig. 224. Generator Armature, Complete

indicating the beginning and the end of each section. Fig. 225 illustrates a partially completed ring-wound armature, the core being made in two parts to facilitate winding.

**Arrangement of Conductors in Slots.** Various methods of arranging the conductors in the slots have been mentioned. The most frequent plan in large continuous-current generators is that of putting them in two layers, either two or more in a slot. Form-wound coils lend themselves to the two-layer arrangement, which, however, is adapted to be used only with parallel-sided slots. Yet, by grouping the conductors three or four in a slot, as indicated in Fig. 226, or eight in a slot, as in Fig. 227, **T**-shaped teeth can be employed. It must be remembered that, owing to the magnetic shielding of the teeth, the conductors are subjected practically to centrifugal force only. Unless the pole-faces are laminated, the top breadth of the slots must be kept very narrow, *i. e.*, not wider than $2\frac{1}{2}$ times the length of the air gap, because of eddy currents being otherwise generated in the pole-faces; also, if straight teeth are employed, they

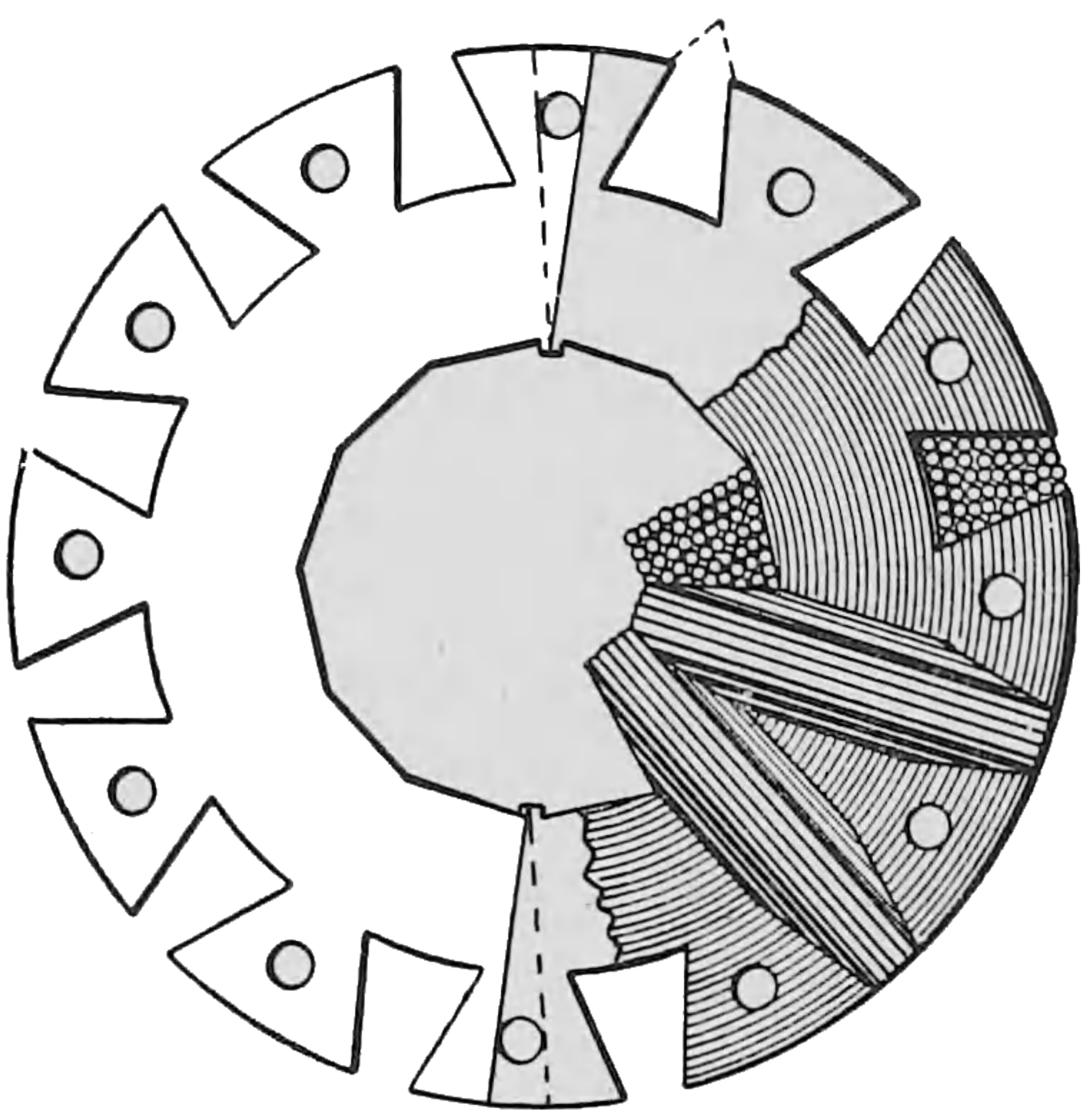


Fig. 225. Partially Completed Ring-Wound Armature

each bar and its neighbor, and especially good insulation between the bars and the sleeve or hub around which they are mounted, as well as between the bars and the clamping devices that hold them in place, since the voltage between bars is not as great as that between the bars and the metal-work of the machine. It is essential that the insulating material be such that it will not absorb oil or moisture; hence asbestos, plaster, and vulcanized fiber are inadmissible. The end insulation rings may be of micanite, or, if for low voltage, of that preparation of paper pulp known as *press-board* or *press-spahn*. The conical rings, used to insulate the dovetails on the bottom of the bars from the hub, are usually built of micanite moulded under pressure while hot. Fig. 228 illustrates such an end-ring, cut away to show its section.

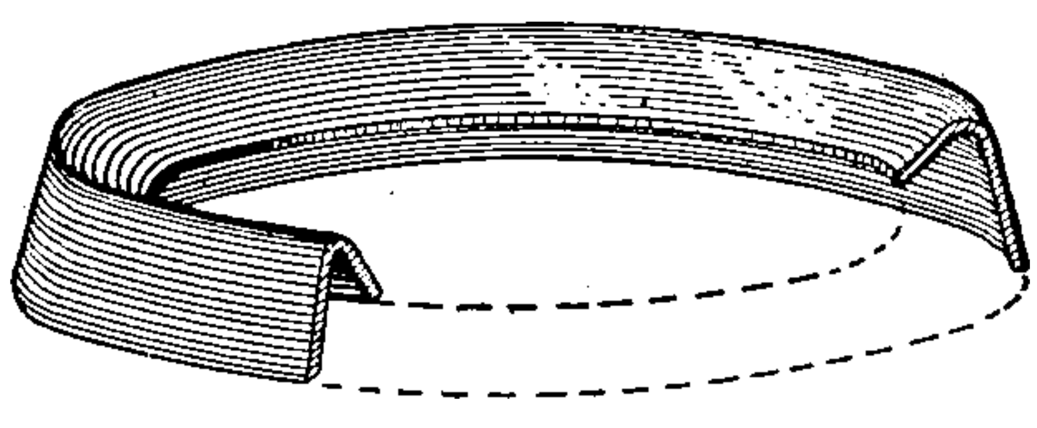


Fig. 228. End Insulation Ring of Commutator

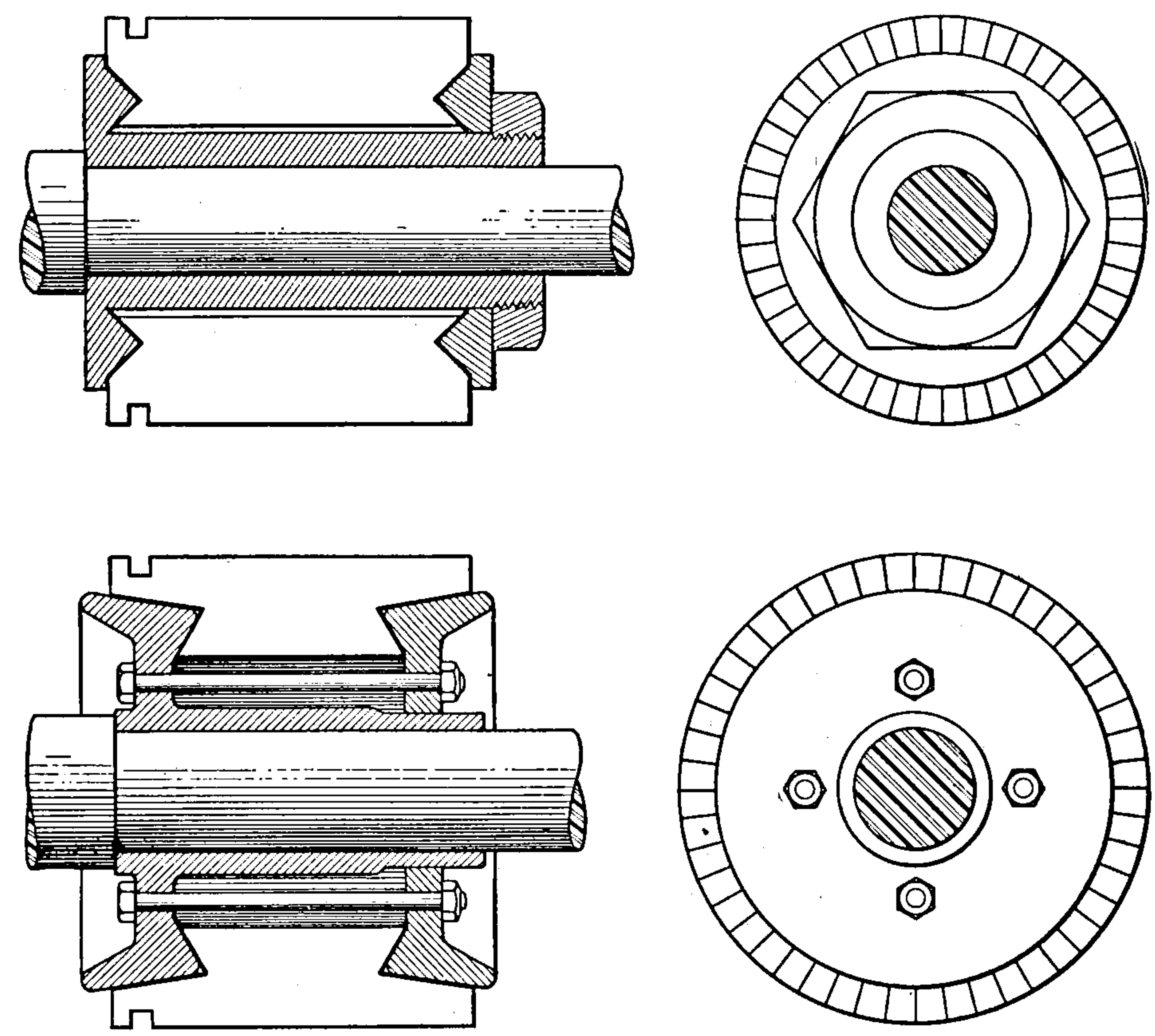


Fig. 229. Common Method of Commutator Construction for Small Machines

Commutators using air gaps between the segments as insulation have been tried; but, excepting in the case of arc-lighting machines where the segments are few in number and the air gap large, they

**TABLE XVIII**
**Thickness of Commutator Insulation**

| Voltage of Machine | Thickness of Mica | |
|---|---|---|
| | Between neighboring segments | Between segments and shell and between segments and clamping device |
| Less than 150 | 0.020 to 0.03 in. | 0.06 to 0.10 in. |
| Less than 300 | 0.025 to 0.04 in. | 0.08 to 0.13 in. |
| Less than 1,000 | 0.04 to 0.06 in. | 0.10 to 0.16 in. |

have not proven successful, owing to trouble in keeping the gaps free from metallic dust.

It is of importance that the mica selected for insulating the bars from one another should be soft enough to wear away at the same rate as the copper bars, and not project above the segments. Amber mica, soft and of rather cloudy color, is preferred to the harder clear white or red Indian variety. The usual thicknesses are as given in Table XVIII.

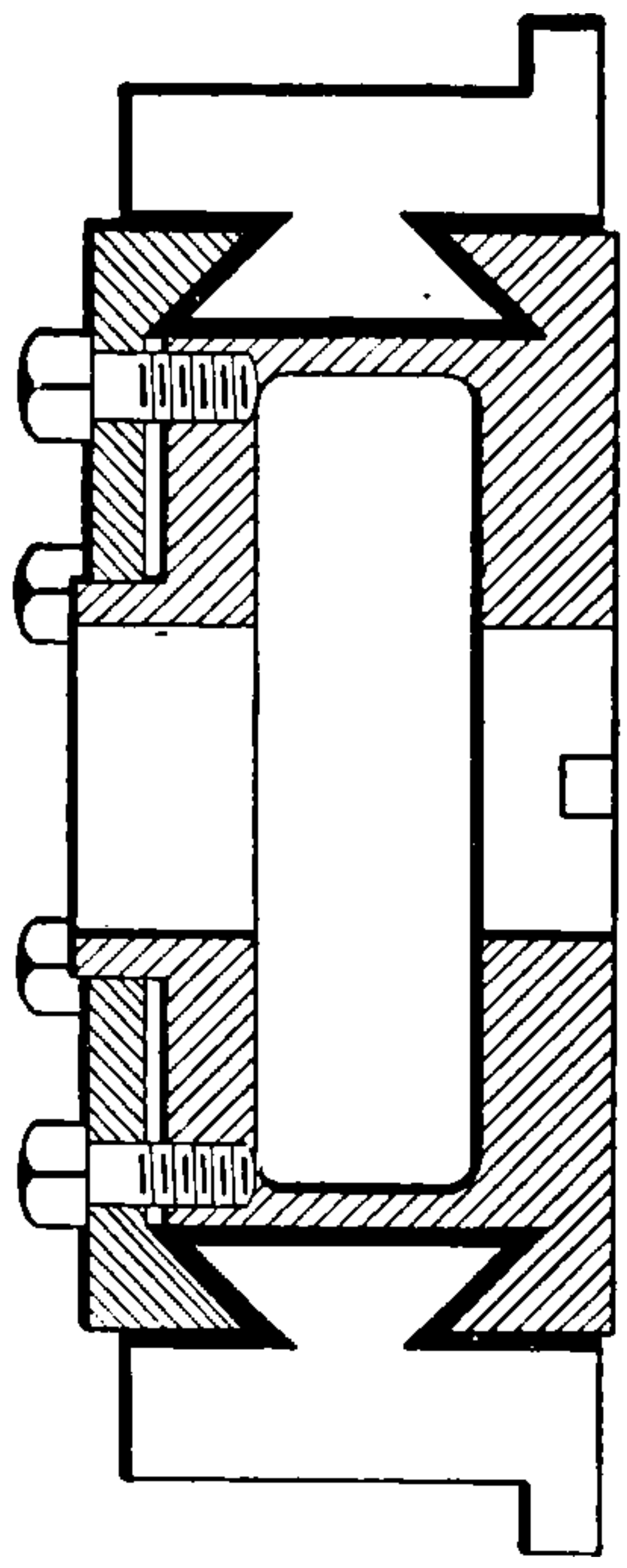


Fig. 230. Construction of Commutator of Medium Size

**Commutator Construction.** For small machines two common constructions are shown in Fig. 229. The commutator segments are secured between a bushing or hub and a clamping ring, the latter being mounted on the hub, and forced to grip the bars by means of a nut on the hub or by bolts passing through the ring and hub, as in Fig. 230. The ends of the bars are beveled so that the ring and bushing draw the segments closer together on tightening.

The hub in small machines is usually of cast iron keyed to the shaft; but in large machines, the commutator is built upon a strong flange-like support or shell, bolted to the armature spider, as indicated in Fig. 212 and Fig 231, or mounted on a separate spider secured to the shaft, as in Fig. 232.

When drawn copper strip is used, the design should be such that the available surface for the brushes takes up nearly the whole length of the bar, and the beveled ends should be as simple as possible. With drop-forged segments, this is not so important.

In building commutators it is usual to assemble the bars to the proper number, with the interposed pieces of mica, clamping them

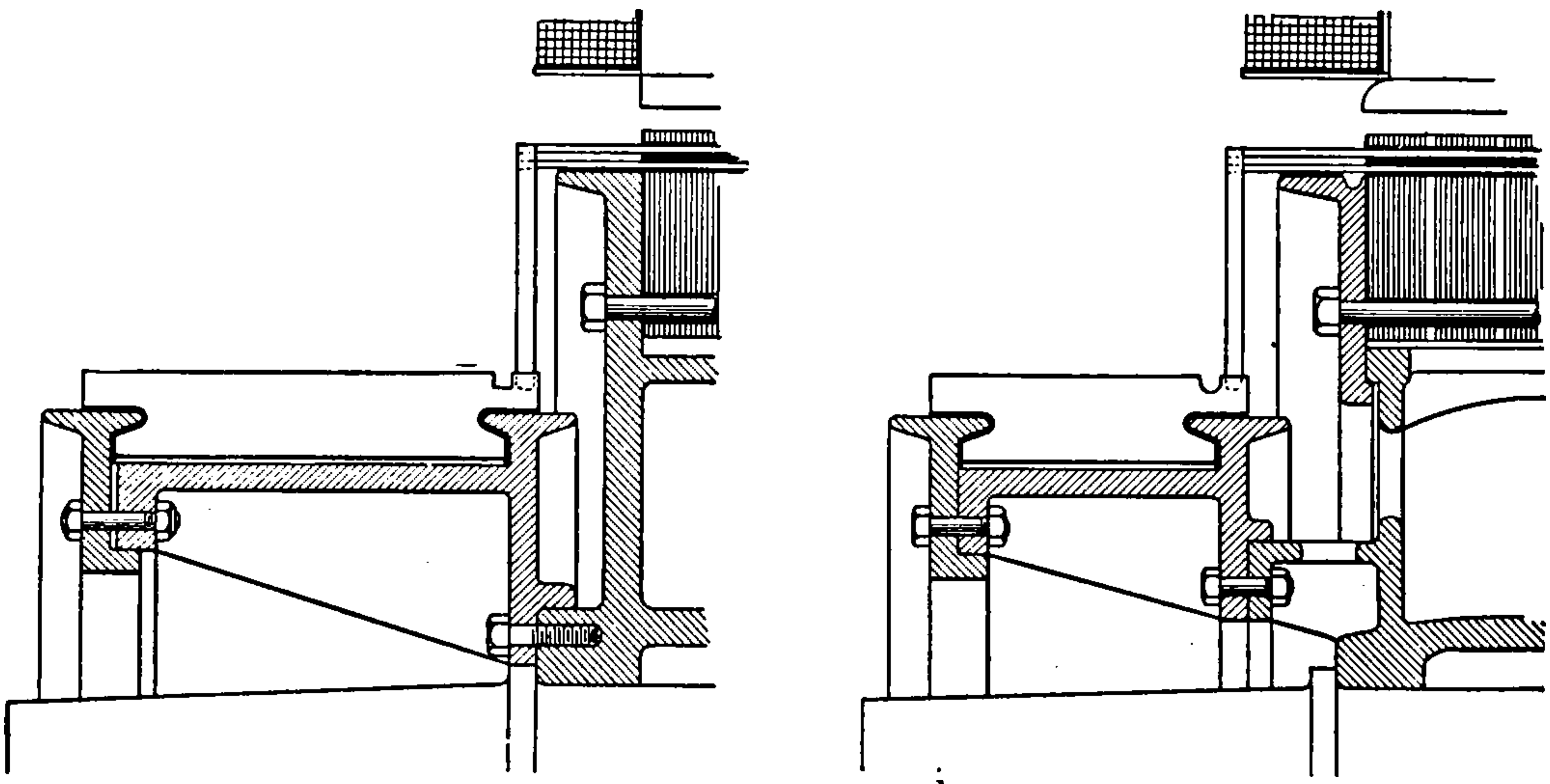


Fig. 231. Commutator Construction for Large Machines. Support for Commutator is Bolted to Armature Spider

temporarily around the outside with a strong iron clamp, or forcing them into an external steel ring under hydraulic pressure. They are then put into a lathe, and the interior surface is bored out, after

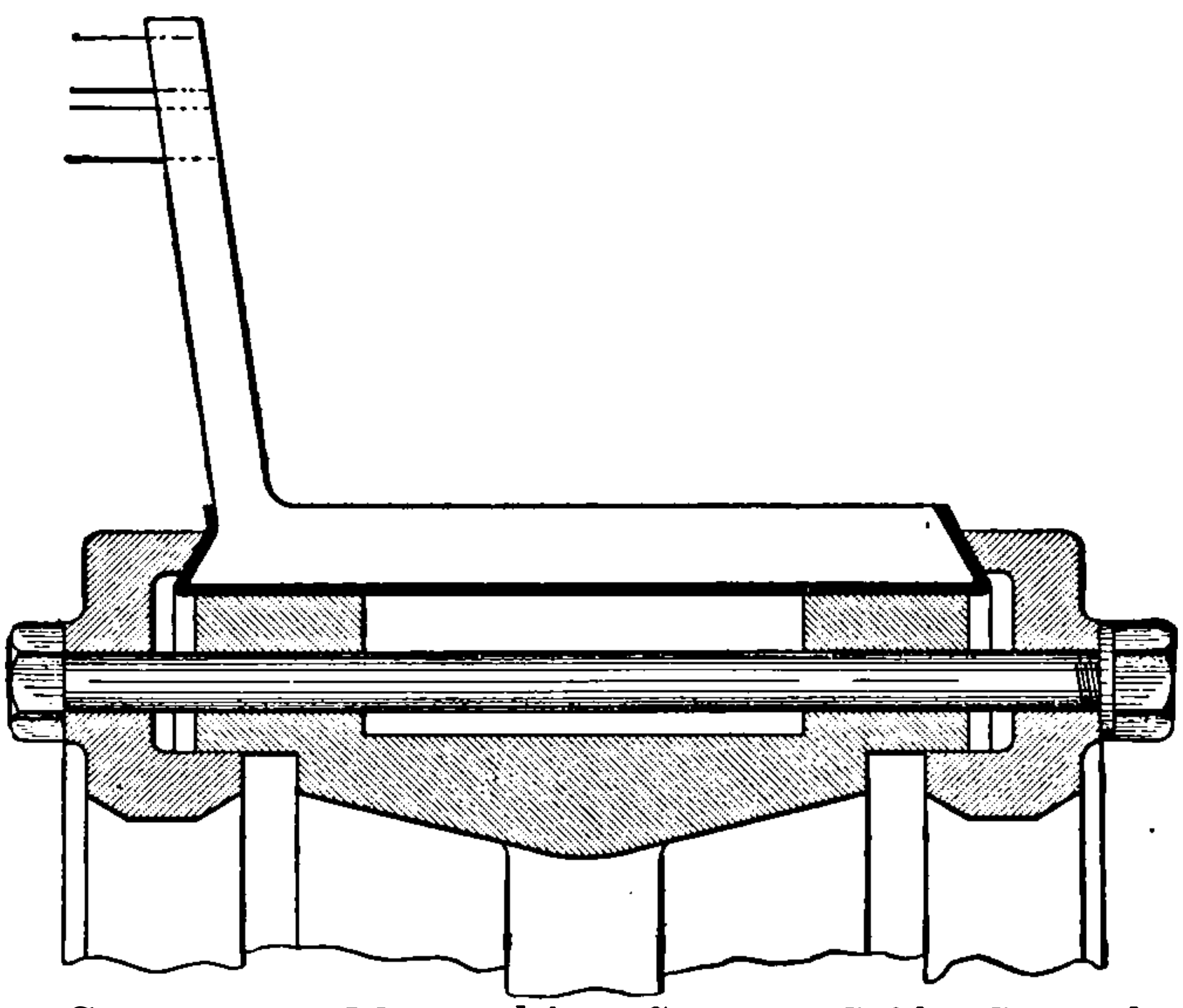


Fig. 232. Commutator Mounted in a Separate Spider Secured to Shaft

which the ends are turned up, with the angular hollows to receive the clamping pieces. The whole is then mounted with proper insulation upon the sleeve, and the clamping end-pieces are screwed up.

3. Spring pressure must be adjustable, and *the spring must not carry current.*

4. The springs must not have too great inertia, in order that they may readily fulfil condition 1, in regard to following the commutator.

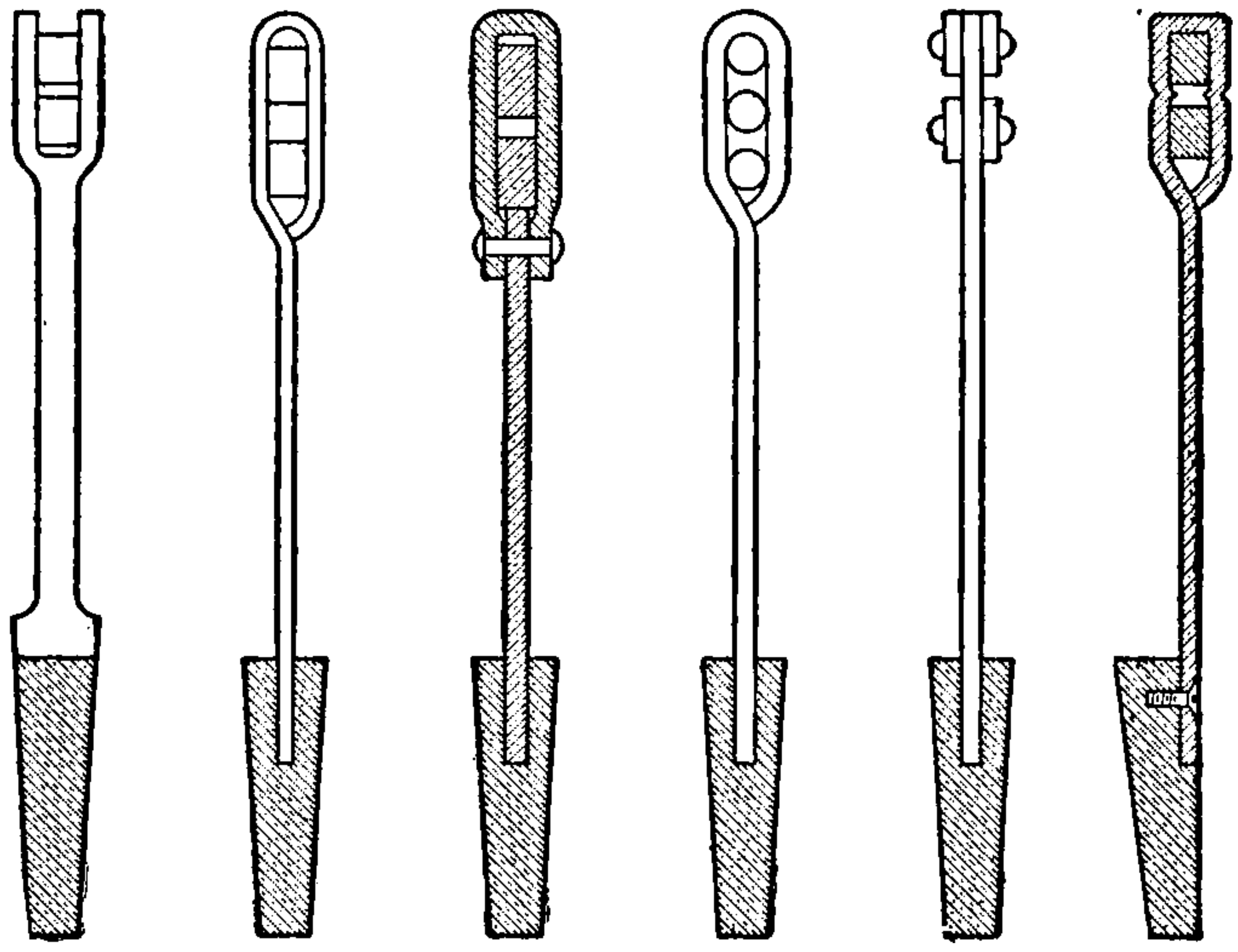


Fig. 236. Methods of Connecting Commutator Risers to Armature Winding

5. Insulation must be very thorough.

6. The mechanism must be so arranged as to permit of the position of the brushes being shifted.

7. All parts must be firm and strong, so as not to permit of the brushes chattering as the result of vibration while running.

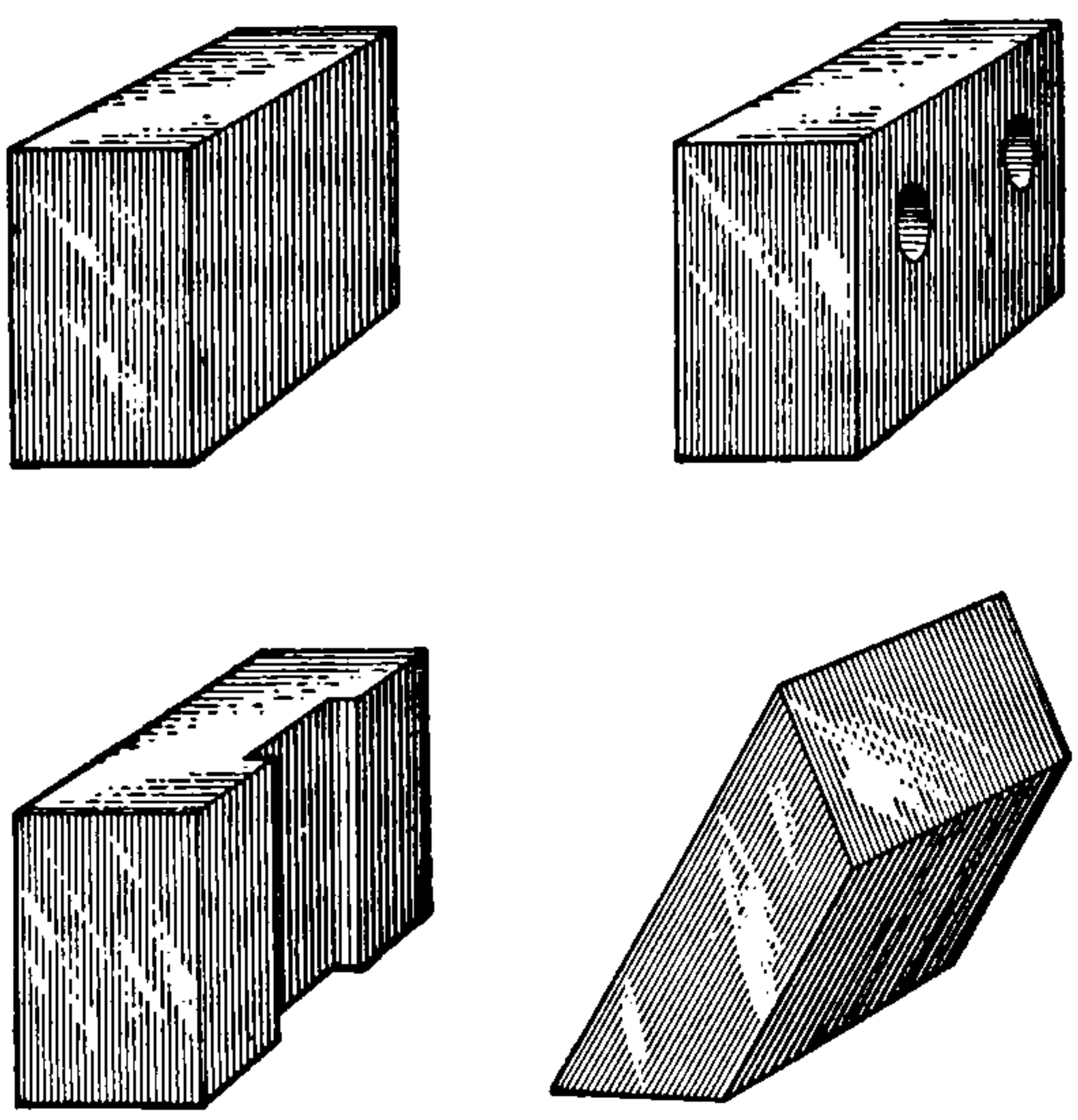


Fig. 237. Various Forms of Carbon Brushes

The commercial forms of holders for carbon brushes may be classified under three types: *hinged structures; parallel spring holders;* and *reaction holders.*

Fig. 238 illustrates a *hinged brush-holder,* and an arm holding several. The carbon moves in a light frame, being held against the commutator by a spring whose tension may be adjusted. Connection between the brush and the holder is made by means of a flexible lead, tinned and laid in a slot in the upper part of the carbon. A metal cap placed over the top and sweated in place makes a permanent contact. This is shown by the two illustrations of the brush.

Fig. 239 illustrates a *parallel-movement type,* which is also shown in Fig. 145, page 126. The brush is held firmly in the holder by a clamping screw, the whole arrangement then being pressed against the commutator by the spring, whose tension may be varied by means of the adjusting screw. Connection is made between the brush and the stationary part of the holder by means of two sets of rolled-copper leaves which at the same time act as flexible joints.

In Fig. 240 is shown a *reaction type* of brush-holder. The brush $C$ is pressed against the commutator by the adjustable spring $L$, the holder $B$ being secured firmly to the rocker arm $P$ by means of the set-screw $q$. The brush is furnished with a dovetail-shaped

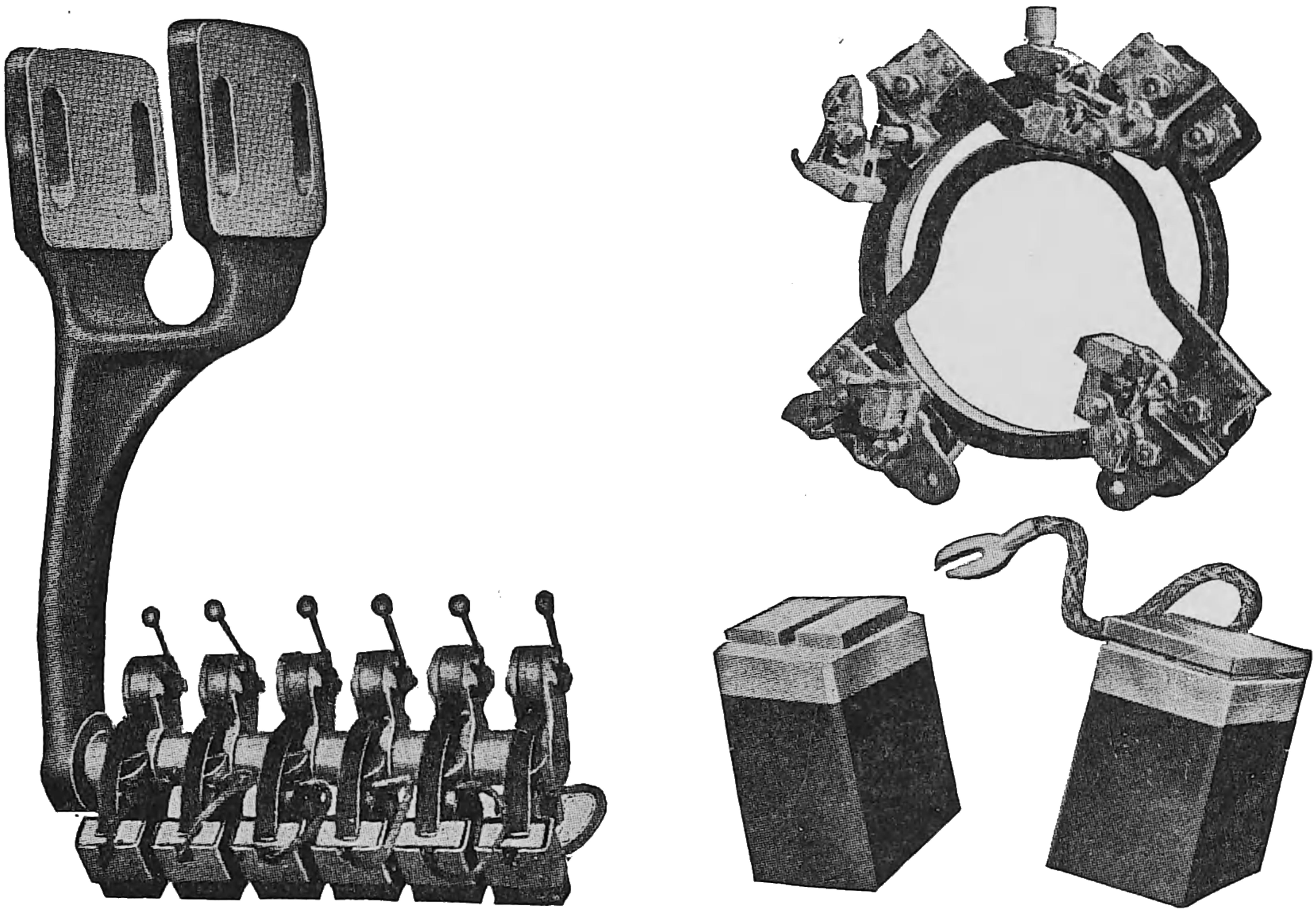


Fig. 238. Brush Rigging and Brushes

groove along its entire inner edge into which a screw in the face of the holder $B$ is fitted.

**Rockers and Rocker Arms.** For small machines the rocker is usually clamped upon a shoulder turned upon the bearing pedestal as indicated in Fig. 239. For large multipolar generators, the rocker arms, that is, the rods on which the brush-holders are held, are fixed at equidistant points around a cast-iron rocker ring, which is itself supported on brackets projecting from the magnet-yoke. This construction is shown in Fig. 241.

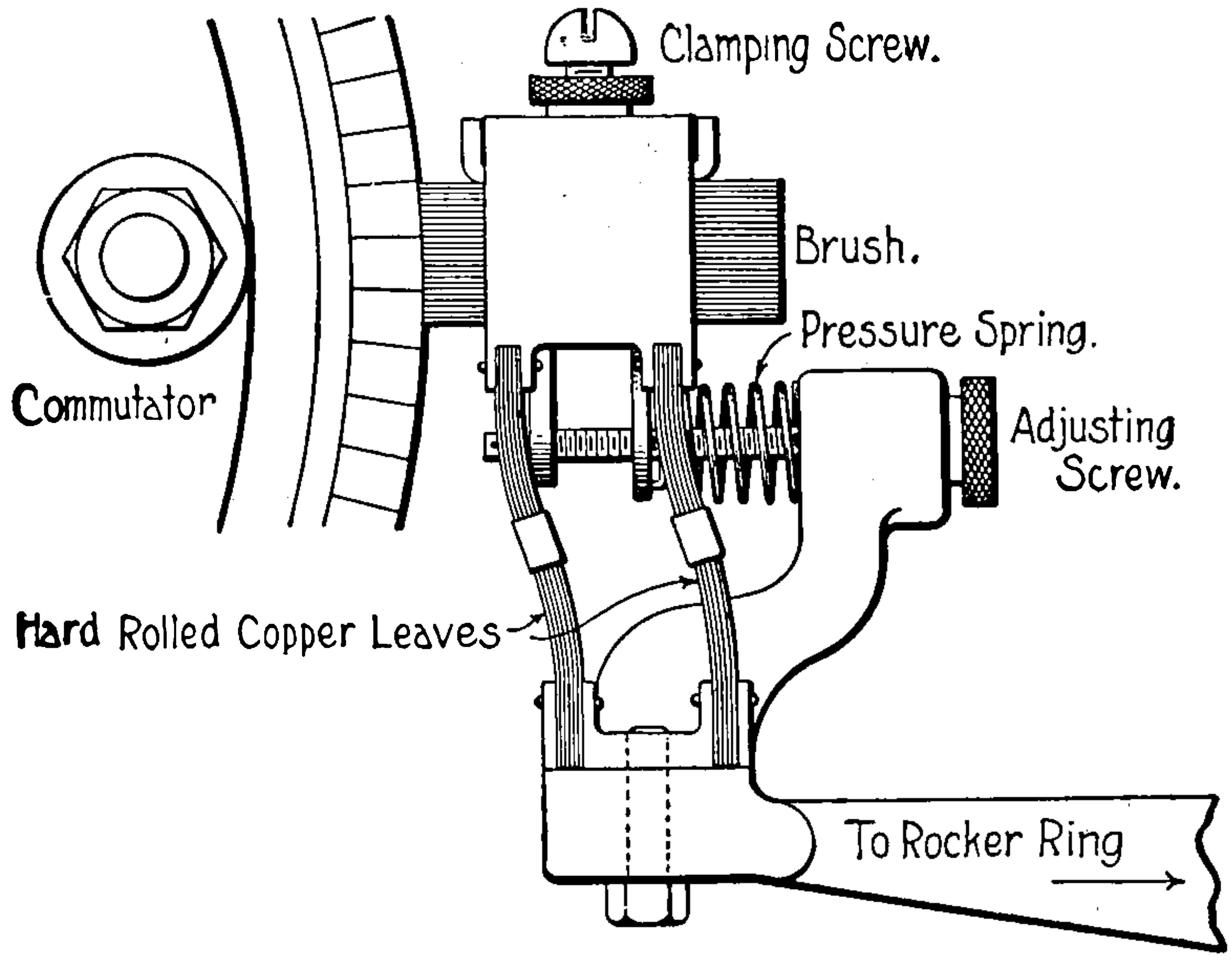



Fig. 239. Parallel-Movement Type of Brush-Holder

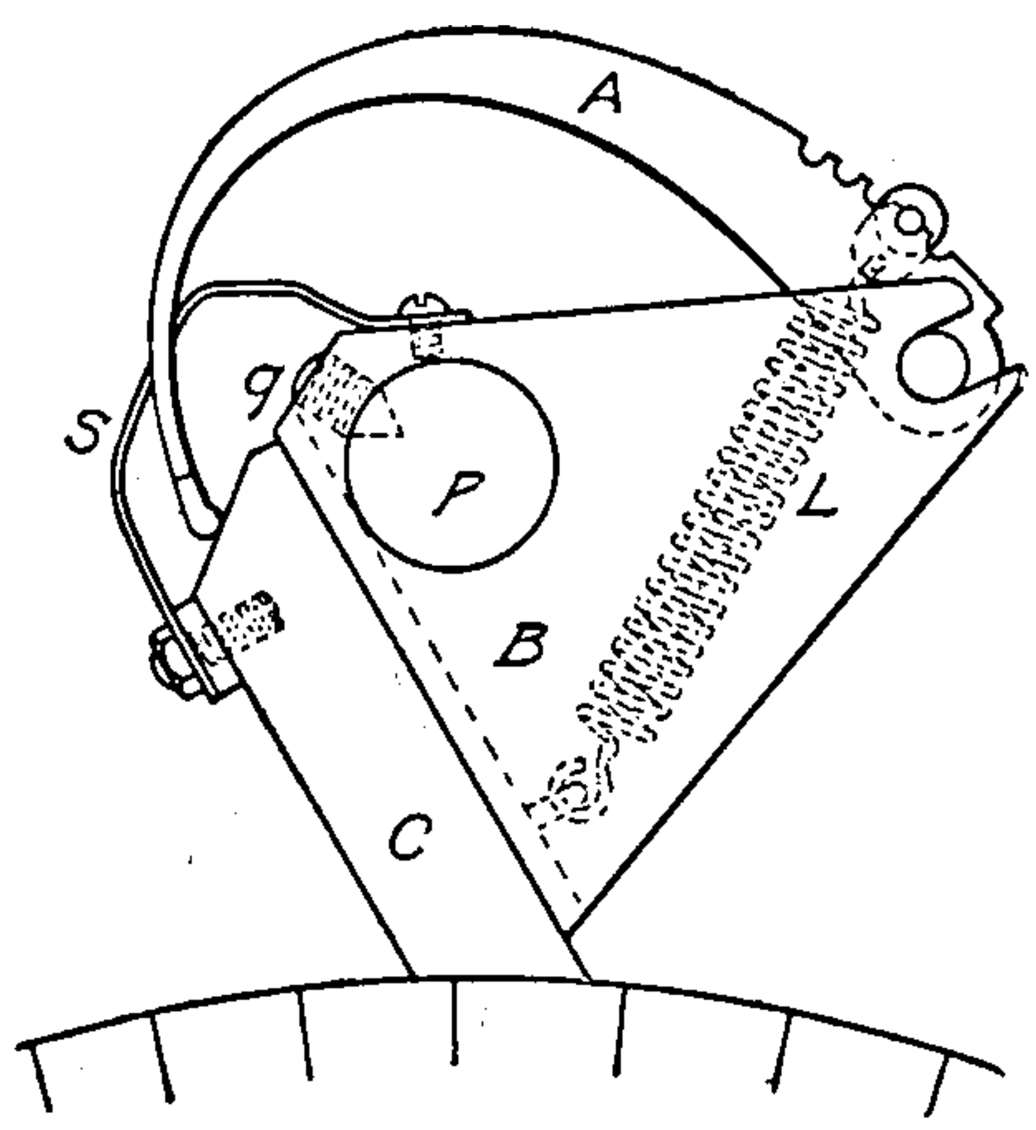



Fig. 240. Reaction Type of Brush-Holder

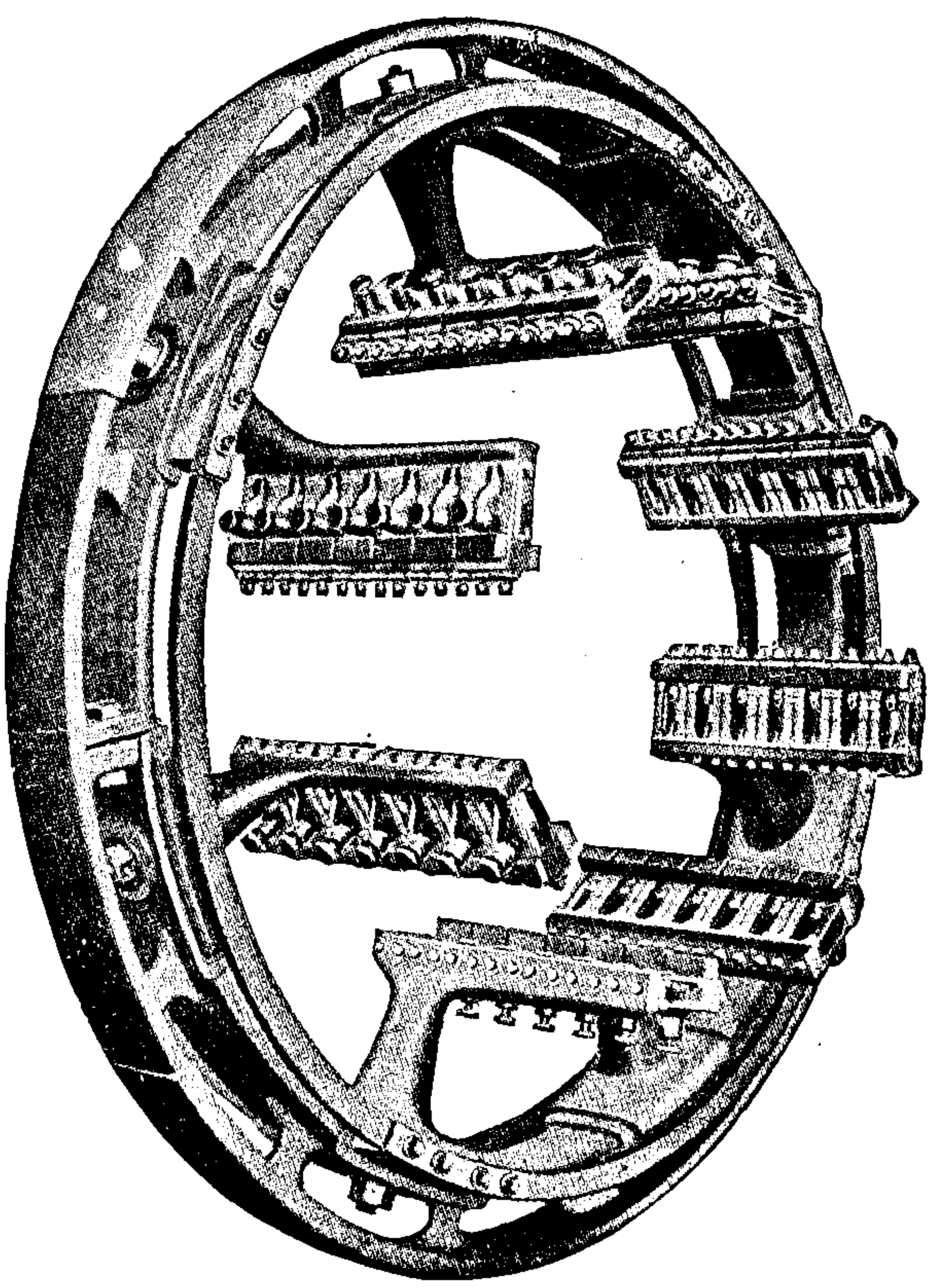


Fig. 241. Rocker Ring and Brush-Gear

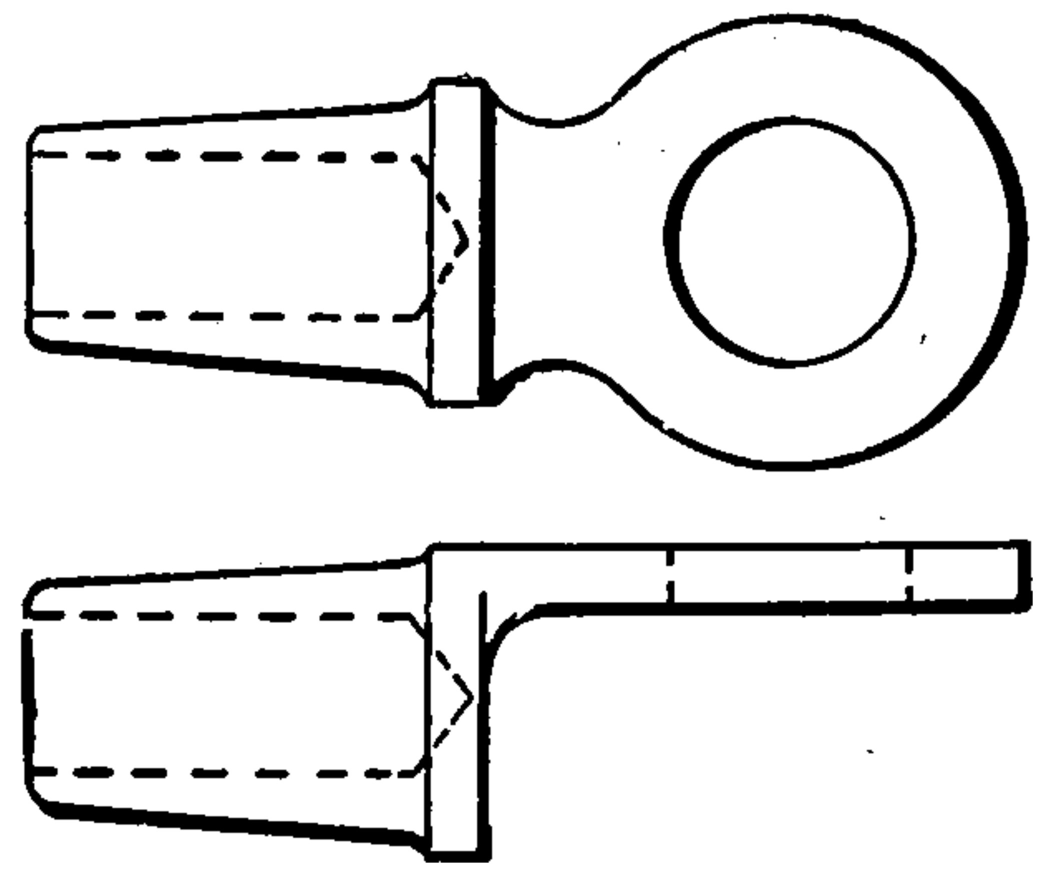


Fig. 242. Sweating Lug

seat formed in the pedestal by turning, milling, or by casting Babbitt or other fusible metal around it, thus allowing the bearing to adjust itself to the exact direction of the shaft. The upper half of the box can be taken off to facilitate renewal, etc. Fig. 246 also shows a bearing of this type; while in Fig. 247 is a simple bearing showing the division of the pedestal.

*Ball-bearings* have recently been applied to generators and motors—particularly the latter, on account of their low static friction. Where space and low friction losses are essential, and where there is little lateral dragging due to belts, these bearings have given excellent results.

Figs. 248 and 249 show ball-bearing mountings for horizontal and vertical motors, respectively. The section at the left of Fig. 248

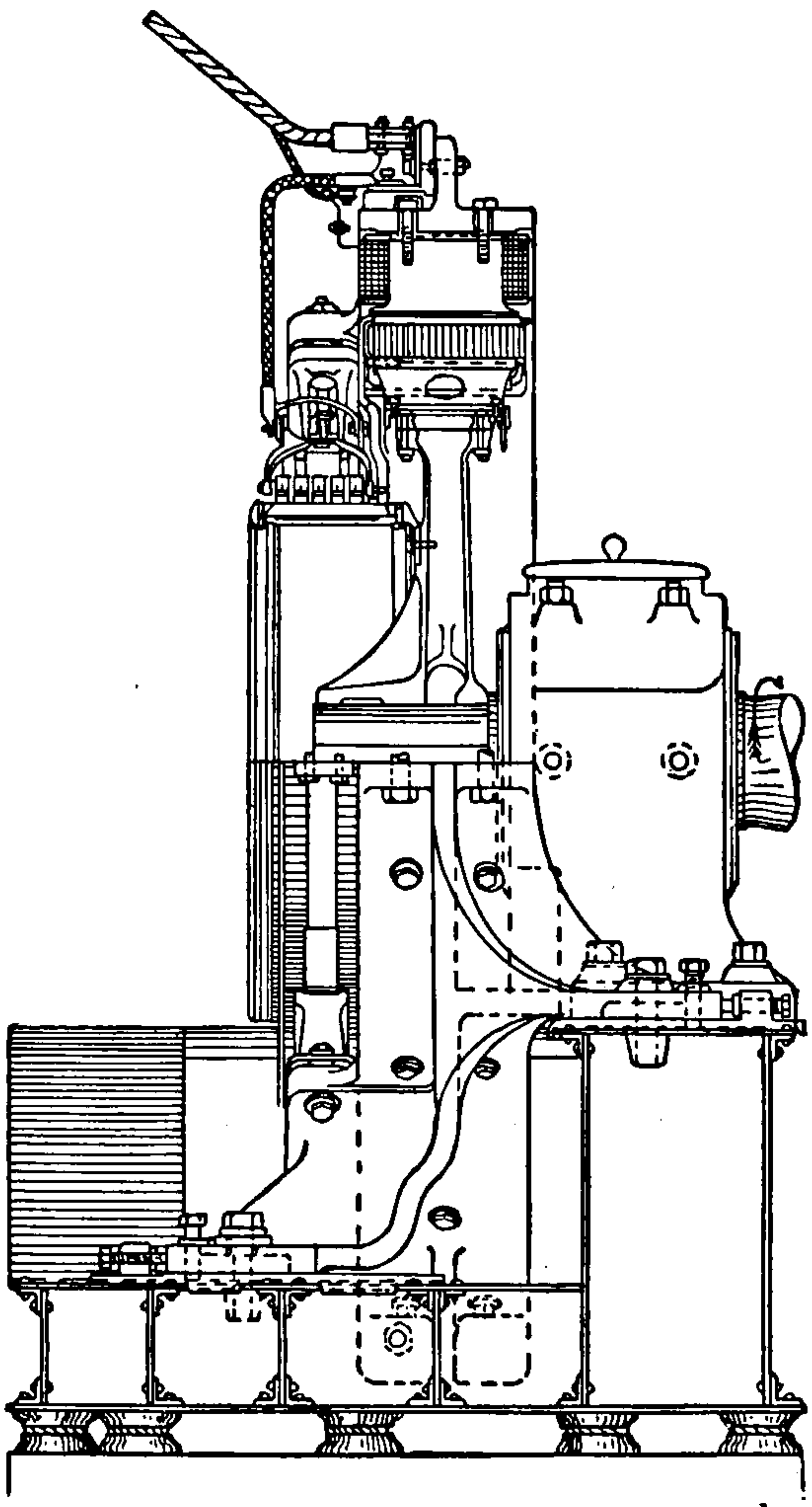


Fig. 244. Direct-Connected Generator with Overhung Armature

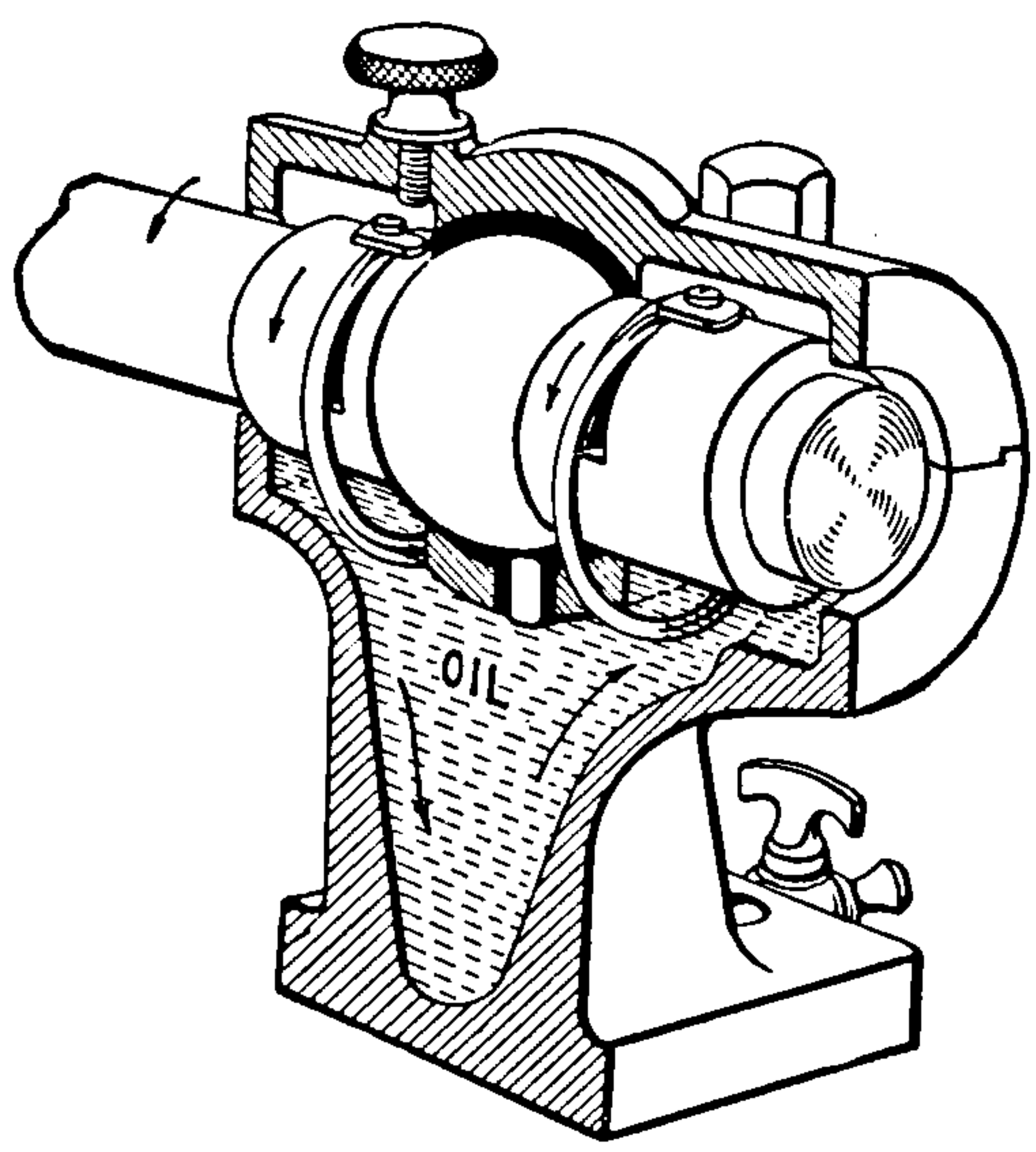
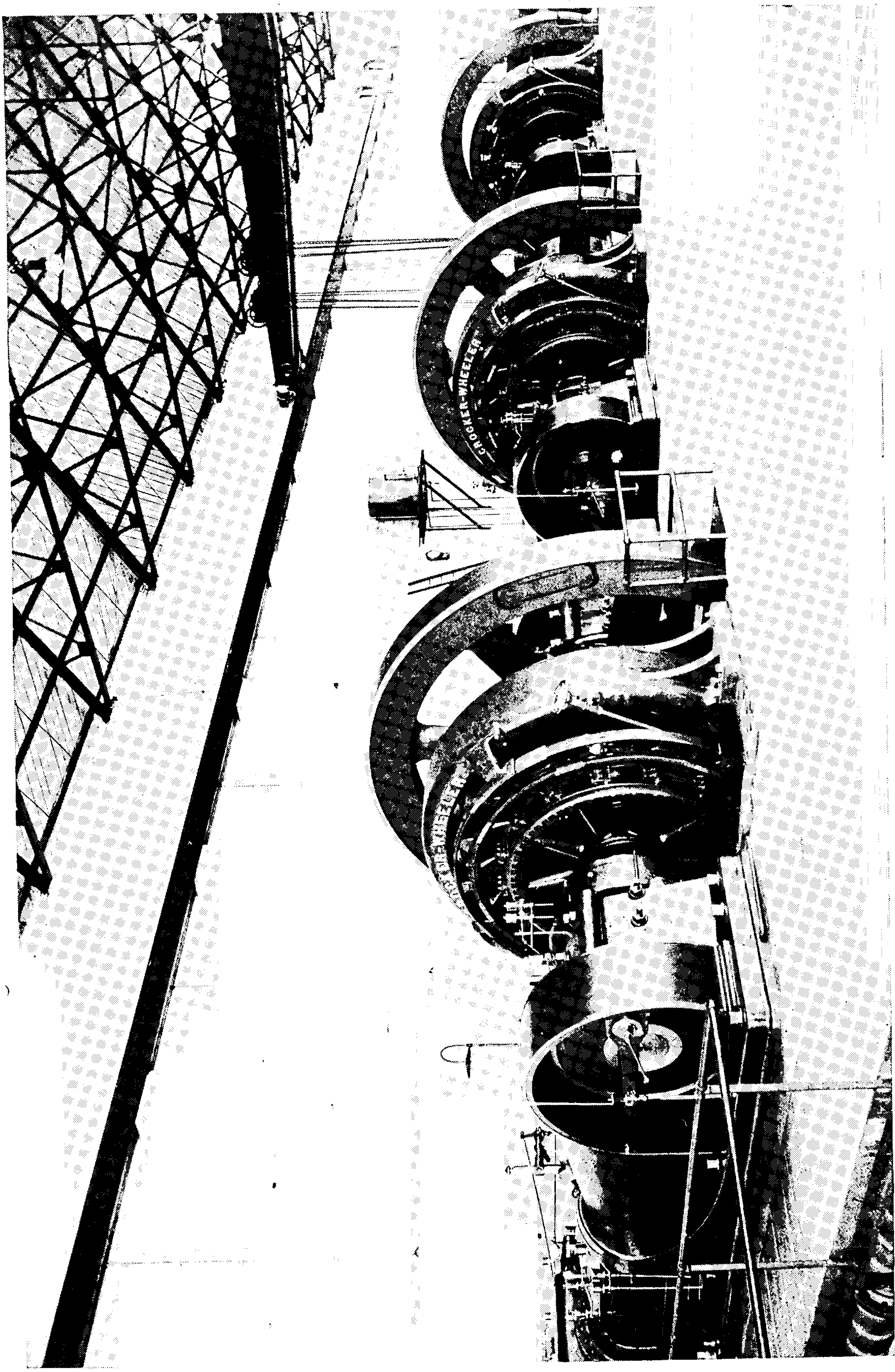



Fig. 245. Self-Oiling Bearing

is for the pulley end, while that at the right is for the commutator end. Fig. 249 shows a form of mounting for vertical motors. It is differentiated from the horizontal type, simply by the introduction of devices for keeping sufficient lubricant in the bearing to permit the balls always to drop through it. Fig. 250 illustrates a side view of a portion of one of these bearings, showing the steel balls with elastic separa-


CROCKER-WHEELER

tors between them. The separators contain felt plugs which incidentally store up lubricant to guard the bearings for a time against neglect.

An advantage that attends the use of these bearings is that the feature of non-wear permits making them oil-proof and dust-proof without the usual added complications.

**Lubricators.** Provision must be made for supplying the bearings with oil or grease, and for this purpose it is usual to provide an oil-well in the hollow casting of the pedestals, into which the oil drains from the brasses. Self-lubricating bearings are now almost universal in the ordinary types of generators. Fig. 245 illustrates one of this type. The rings here shown revolve with the shaft, being dragged around by the latter, and feed it with oil, which they con-

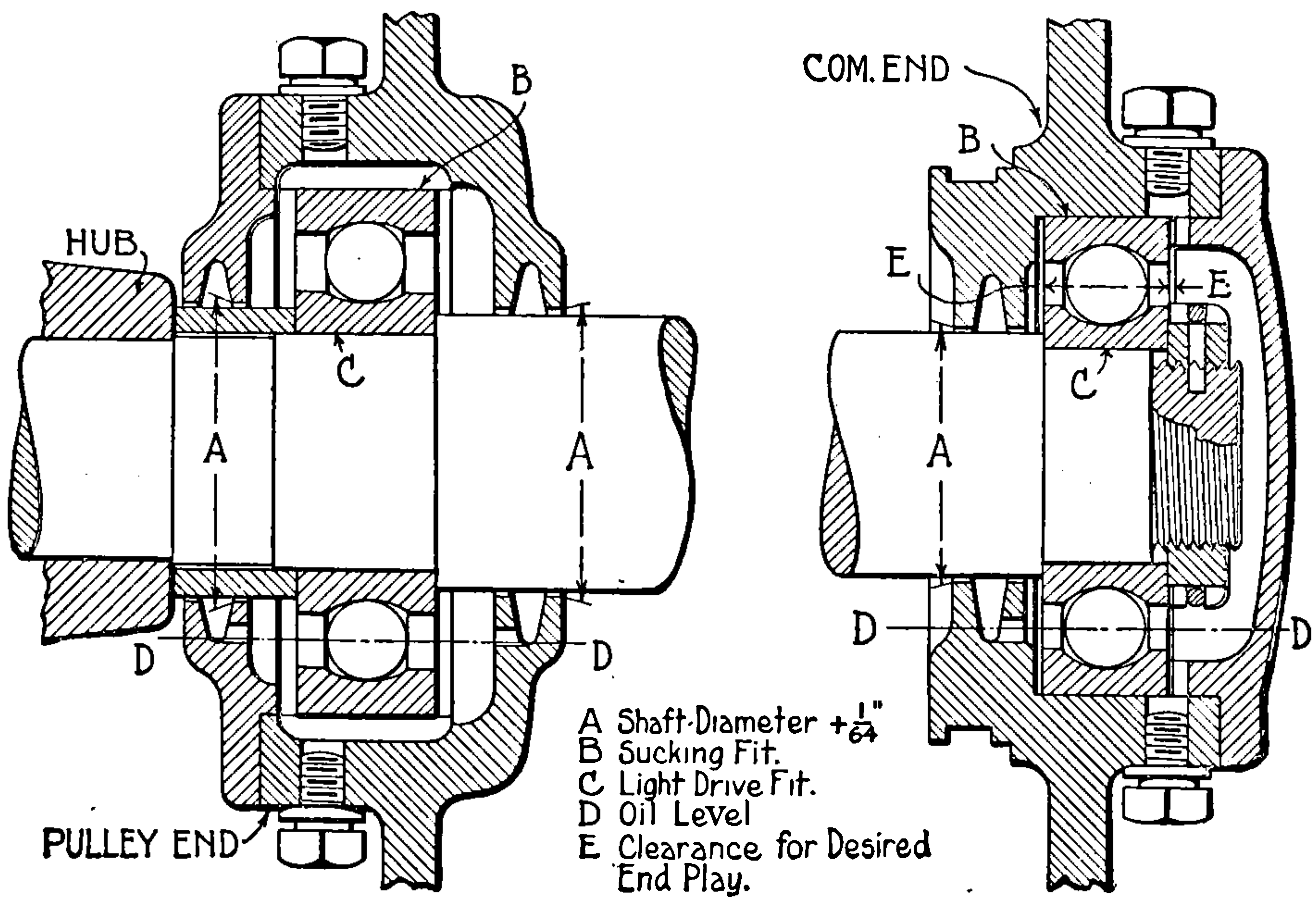



Fig. 248. Ball-Bearing Mounting for Horizontal Motor-Shaft

tinuously bring up from the reservoir below. The dirt settles to the bottom and the upper portion of the oil remains clean for a long period, after which it is drawn off through the spigot, and a fresh supply poured in through openings provided at the top. The latter are often located directly over the slots in which the rings are placed, so that the bearings can be lubricated directly by means of an oil-cup, if the rings stick or the reservoir becomes exhausted.

**Bed-Plates.** In most cases a generator is supplied with a cast-iron base or bed-plate which supports the bearings and magnet-yoke. It consists of a simple box, open at the bottom in order to give stiffness without great weight. It must be sufficiently rigid to withstand any reasonable strain without bending.

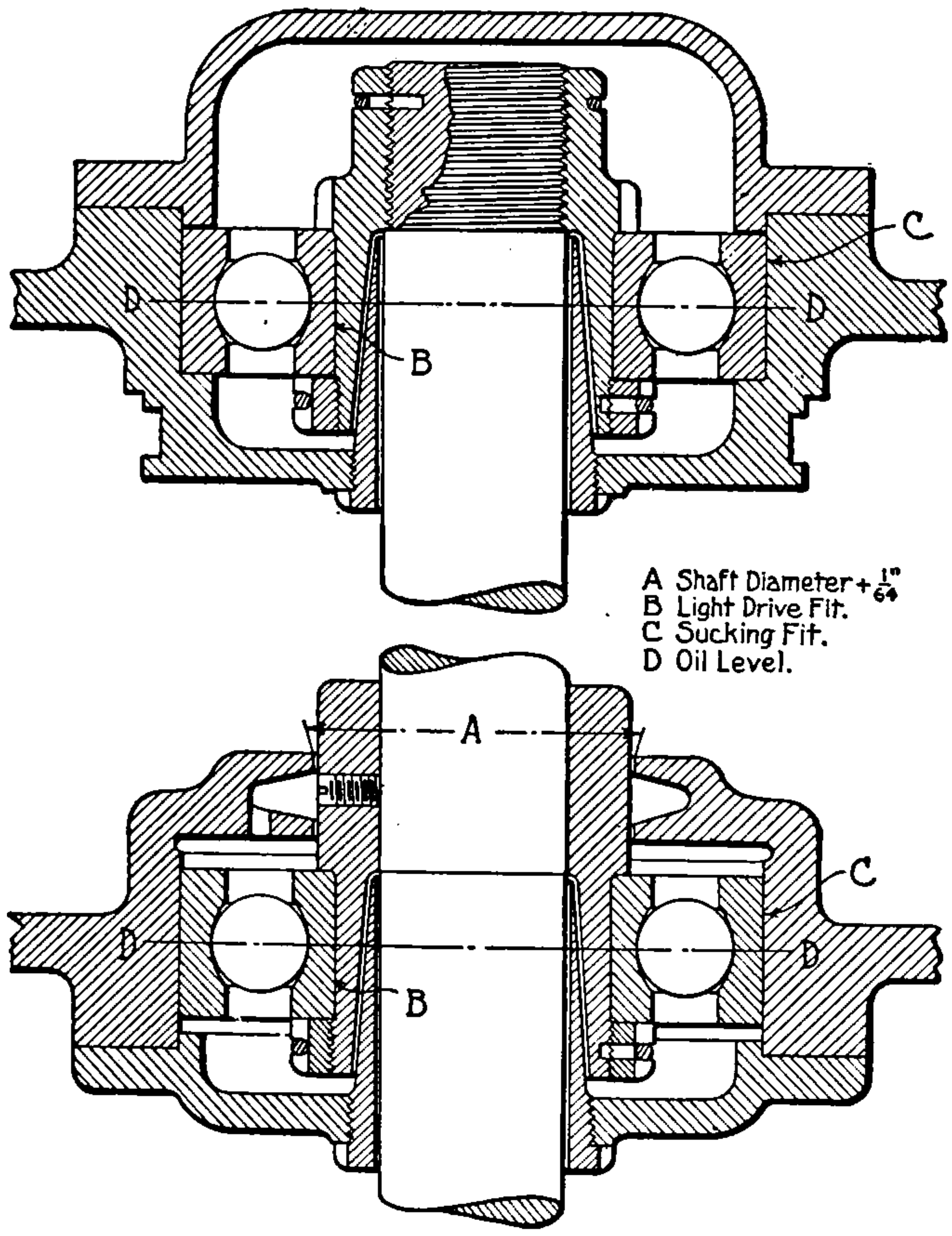



Fig. 249. Ball-Bearing Mounting for Vertical Motor-Shaft

In belt-connected machines the iron base usually rests upon rails bolted to the foundations, the base being arranged to slide back and forth upon these rails in order to regulate the tension of the belt by means of set-screws. A direct-connected generator of small or medium size is usually bolted to an extension cast-iron base or sub-base of the engine. In some cases a generator and engine are coupled together, each being complete in itself and having its own base. Very large direct-connected generators and engines are set on separate foundations.

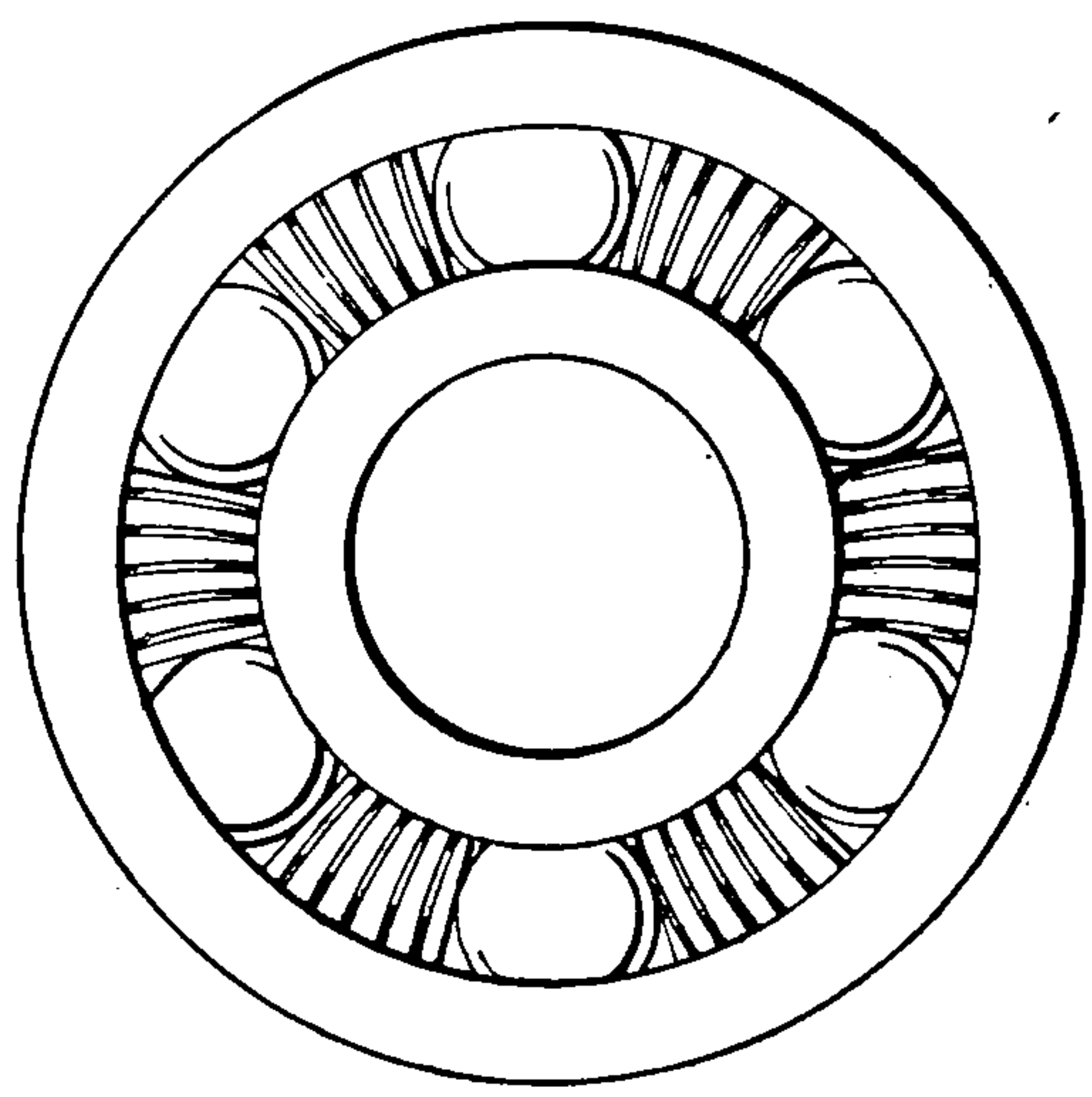


Fig. 250. Side View of Ball-Bearing Mounting, Showing Steel Balls with Elastic Separators between Them

## STUDY OF A CONTINUOUS-CURRENT GENERATOR

The design of a generator may be considered in the light of a problem in which it is required to produce a machine which shall operate satisfactorily at all loads from no load to 50 per cent overload, which shall be efficient and shall conform to the conditions of prescribed speed, voltage, and current output. This involves the theoretical and practical features already considered. In order to guide the student, it has been thought advisable to follow through the complete design of a particular modern generator. No hard-and-fast rules can be given covering all cases which come up, so that the following tables should be used only as guides, each machine requiring a separate solution of the general problem.

**Specifications.** To design a continuous-current generator, it is sufficient to be given the capacity of the machine in kilowatts, the terminal voltage at rated load (also at no load, if compound-wound), and the speed of rotation of the armature, although Table XIX will supply the latter quantity, if absent. Let us assume for the purposes of this design, shown in Figs. 251 and 252, the following specifications:

| | |
|---|---|
| Kw. output | 150 |
| Terminal volts, rated load | 250 |
| Terminal volts, no load | 240 |
| Armature r. p. m. | 225 |

The generator is direct-connected to the engine driving it, and it must be compound-wound in order that its terminal voltage at rated load shall be 10 volts higher than at no load.

Since the generator is rated at 150 kw. at 250 volts, the rated load current will be

$$\frac{150 \times 1{,}000}{250} = 600 \text{ amperes}$$

**Number of Poles.** We must decide upon the number of poles. This may be fixed either with a view to keeping down the iron losses in the armature, or to keeping the current collected per brush set low. In the former case, the frequency of magnetic reversal should not exceed 20 per second in shunt-wound machines, and 25 per second in compound-wound machines. The frequency of magnetic reversal is equal to the pairs of poles multiplied by the revolutions per second. In the second case, in order that the current may be

**Fig. 251.** Crocker-Wheeler Generator of Type Whose Constructicn is Des [illegible] ts, at 225 r. p. m.

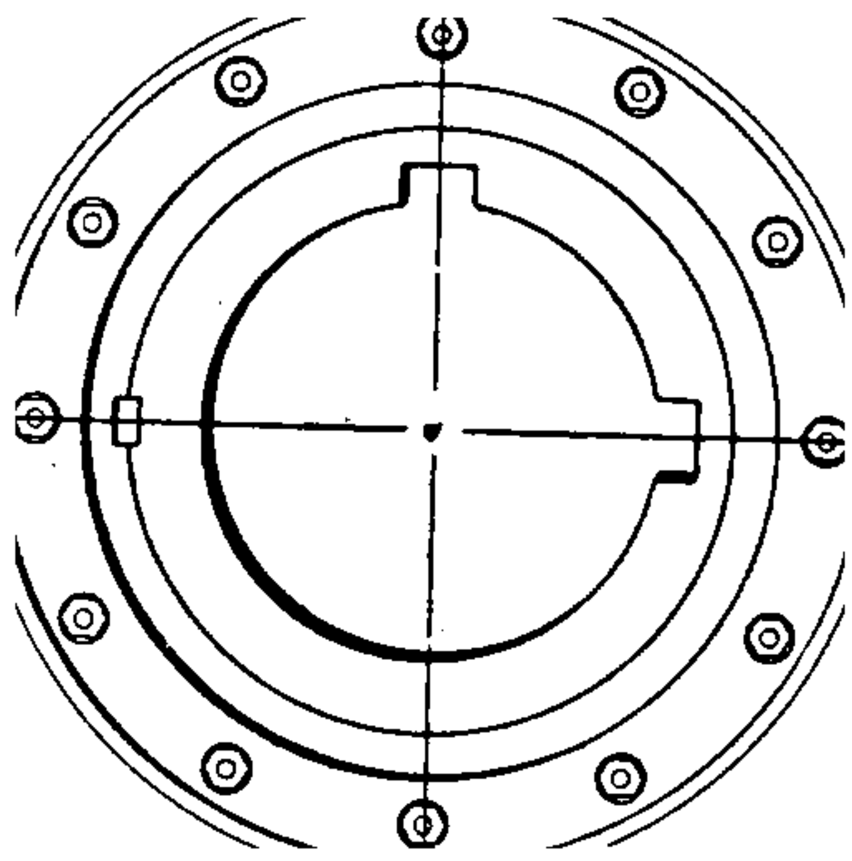


TABLE XX

Relation of Capacity and Type to Number of Poles

| Type | Output in Kilowatts | Number of Poles |
|---|---|---|
| Direct-Connected | 1 to 2,030 | 4 |
| | 15 to 400 | 6 |
| | 90 to 400 | 8 |
| | 200 to 900 | 10 |
| | 300 to 1,800 | 12 |
| | 600 to 2,200 | 14 |
| | 800 to 2,500 | 16 |
| Low-Speed, Belted | 1 to 600 | 4 |
| | 15 to 600 | 6 |
| High-Speed, Belted | 1 to 20 | 2 |
| | 1 to 200 | 4 |
| | 60 to 800 | 6 |

To be quite sure of avoiding trouble as to sparking, and since an odd number of poles cannot be employed, let us take 8 poles, which, as we see from Table XX, is good practice for this size and type of machine.

**Diameter and Length of Armature.** The diameter of armature is limited by the peripheral speed allowable, Table XXI. It is also dependent upon the size of the magnet-poles and their number, the size, number, and arrangement of the armature conductors, and the output of the machine, the length being also a function of these quantities. Various empirical formulas have been proposed for computing the length and diameter of armatures, but they all contain constants whose values must be learned by experience.

TABLE XXI

Peripheral Velocities of Direct-Current Armatures

| Type of Generators | Peripheral Speeds in Feet per Minute | | |
|---|---|---|---|
| | Minimum | Mean | Maximum |
| Bipolar high-speed, belted | 2,000 | 3,000 | 3,500 |
| Multipolar high-speed, belted | 3,500 | 4,000 | 5,500 |
| Multipolar slow-speed, belted | 2,000 | 2,800 | 3,500 |
| Direct-connected | 1,800 | 2,400 | 3,300 |

### TABLE XXIII
**Diameters of Direct-Connected Armatures***

| Capacity (kilowatts) | Outside Diameter (in inches) | | | Ratio of Length to Diameter | | |
|---|---|---|---|---|---|---|
| | Minimum | Mean | Maximum | Minimum | Mean | Maximum |
| 5 | 15 | 20 | 25 | 0.15 | 0.25 | 0.50 |
| 15 | 17 | 22 | 27 | 0.15 | 0.25 | 0.48 |
| 25 | 18 | 24 | 29 | 0.15 | 0.25 | 0.46 |
| 50 | 21 | 27 | 34 | 0.15 | 0.25 | 0.44 |
| 75 | 24 | 30 | 39 | 0.15 | 0.25 | 0.42 |
| 100 | 26 | 34 | 44 | 0.15 | 0.25 | 0.40 |
| 150 | 31 | 41 | 52 | 0.14 | 0.24 | 0.38 |
| 200 | 35 | 47 | 61 | 0.14 | 0.23 | 0.36 |
| 300 | 44 | 58 | 77 | 0.14 | 0.22 | 0.34 |
| 400 | 52 | 69 | 89 | 0.14 | 0.21 | 0.32 |
| 500 | 60 | 80 | 100 | 0.13 | 0.20 | 0.30 |
| 600 | 67 | 87 | 108 | 0.13 | 0.19 | 0.28 |
| 700 | 74 | 95 | 115 | 0.13 | 0.18 | 0.26 |
| 800 | 80 | 100 | 121 | 0.13 | 0.17 | 0.24 |
| 900 | 87 | 107 | 127 | 0.12 | 0.16 | 0.23 |
| 1,000 | 92 | 112 | 131 | 0.12 | 0.16 | 0.22 |
| 1,200 | 100 | 120 | 140 | 0.12 | 0.15 | 0.21 |
| 1,400 | 116 | 130 | 148 | 0.11 | 0.15 | 0.20 |
| 1,600 | 122 | 133 | 152 | 0.11 | 0.14 | 0.19 |

*It is to be noted that for any given output and speed, the product of the diameter by the length of the armature is practically a constant.

lines to 55,000 lines per square inch, as given in Table XXV, while a usual value for the fraction of the armature covered by the poles is $\psi = 0.75$. We may then write

$$\Phi = B_g \times d \times \pi \times l \times \psi \div 2p$$

Assuming in our case, $\psi = 0.72$, and $B_g = 46{,}000$, we have

$$\Phi = 46{,}000 \times 45 \times 13 \times 3.1416 \times 0.72 \div 8 = 7{,}600{,}000$$

as the assumed flux entering the armature. The value thus found will require adjustment after $Z$ has been determined, the fundamental equation of dynamo-electric machines being used for this purpose. From equation (12), page 65, this is

$$(\text{Average})\ E = \frac{Z \times \text{r. p. m.} \times \Phi \times 2p}{60 \times 10^8 \times c}$$

That is

$$\Phi = \frac{E \times c \times 60 \times 10^8}{Z \times 2p \times \text{r. p. m.}}$$


Fig. 253. Details of Armature and Spider of Generator Whose Construction is Described in Text

**Number of Armature Conductors.** Having obtained a trial value for the magnetic flux per pole, we can compute the corresponding value for $Z$ from the preceding formula, adjusting $\Phi$ and $Z$ until the latter comes out properly for the winding selected, Table X, page 114. In our case

$$Z = \frac{263.5^* \times 8 \times 10^8 \times 60}{225 \times 7{,}600{,}000 \times 8} = 924 \text{ (say 928 as a trial number)}$$

**Number of Commutator Segments.** This is, of course, equal to the number of conductors divided by 2, 4, 6, etc., although in all but the smallest modern machines $K = Z \div 2$. The considerations which fix the number have been discussed on page 122. Hence we have

$$K = 928 \div 2 = 464 \text{ commutator segments}$$

**Size of Commutator.** As a rule the diameter of the commutator, Fig. 254, should be at least three-fourths that of the armature, while for large machines, it should be from 12 inches to 18 inches smaller than the armature. Using this as a trial value, divide the periphery by $K$ to see whether the width allowed per segment is suitable. This should be about 0.2 to 0.8 inch, inclusive of insulation between segments. The necessary provisional length may be found by assuming that the (carbon) brushes will cover from $2\frac{1}{2}$ to 3 segments, and that about 40 amperes may be collected by each square inch of brush-contact area. A margin should be added to this, the working face. (See page 123). The result so obtained should be checked later when the watts lost in commutator heating have been estimated, by seeing whether the surface of the commutator is sufficiently large to dissipate the heat generated without undue temperature-rise. (See page 126). A commutator ought to have about 0.4 square inch of peripheral surface per watt to be dissipated.

Having decided in our case that the commutator shall have about 464 segments, and as each segment plus the necessary insulation cannot be less than about 0.2 inch wide at the face of the armature, the periphery of the commutator must be at least $464 \times 0.2 = 92.8$ inches long. That is, the diameter should be about $92.8 \div \pi = 29.5$ inches.

---

*Note.—Corrected to provide for lost volts (see pages 140 and 141 and Table XVIII, page 141).

Allowing 40 amperes per square inch of brush contact, and assuming that a brush covers 3 segments, we have for the net length of the commutator, parallel to the shaft,

$$l_{com} = \frac{150}{3 \times 0.2 \times 40} = 6.25 \text{ in.}$$

each brush set collecting 150 amperes, as there are 4 pairs of brush sets and the total current output of the machine at rated load is 600 amperes. Adding to the length thus obtained $\frac{1}{3}$ as a margin, we have as the length of the commutator

$$6.25\ (1 + 0.33) = 8.3 \text{ inches}$$

**Commutator Brushes.** Allowing 40 amperes per square inch of brush contact, the area of all the positive (or negative) brushes = 15 square inches, *i.e.*, $3\frac{3}{4}$ square inches per set. Let us have 3 brushes 3 inches long, $2\frac{1}{4}$ inches wide, and $\frac{1}{2}$ inch thick per set. From the curve of Fig. 142, page 124, brush-contact drop = 1.5 volts.

**Style of Armature Winding.** We must now settle upon the type of armature winding to be employed. Modern practice tends toward preserving the utmost simplicity, that is to say, it favors the lap-wound drum executed as a barrel winding so as to have ample cooling surface, the conductors being in two layers so as to take advantage of form winding, and placing two, four, six, or eight conductors in each slot.

Choosing in our case a simplex, singly re-entrant, lap-wound drum winding, the maximum winding pitch will be $y_f = 115$; $y_b = -113$, since we must span about $\frac{1}{8}$ of the periphery, there being eight poles. Compare page 114, Table X. As we have assumed a pole span of about 0.75, the minimum values would be about $y_f = 87$; $y_b = -85$. Assuming that the conductors are placed 8 in each slot, there will be about 14 slots to the pole-pitch, requiring the coils to span 14 teeth if we select the largest possible value of the winding-pitch, and 10 teeth if we select the smallest value. Suppose, therefore, that we span over 13 teeth, in which case we shall have $y_f = 107$; $y_b = -105$.

**Apportionment of Losses and Checking Size of Armature.** We must apportion the losses in order to check up our previous computations in regard to permissible heating limits. Assuming an efficiency of 92 per cent, Table XVI, we may allow 2.2 per cent for armature copper loss, 1.6 per cent for armature iron loss, 2.75 per cent for excitation loss, 1.05 per cent for commutator loss, and 0.4 per cent for friction loss, as suggested by the above-mentioned table. The periphery of the armature being $45 \times \pi = 141.4$ inches, and the length over conductors being 27 inches*, the total cylindrical radiating surface will be $141.4 \times 27 = 3{,}820$ square inches; and as the total armature losses are assumed to be 1.6 per cent + 2.2 per cent = 3.8 per cent, or $0.038 \times \frac{150{,}000}{0.92} = 6{,}200$ watts, the peripheral surface will have to dissipate $6{,}200 \div 3{,}820 = 1.63$ watts per square inch. As the peripheral speed is assumed to be 2,650 feet per minute, we see from curve *C*, Fig. 140, page 120, that the probable temperature-rise will be $26° \times 1.63 = 42.5°$ C., which will not be too high, since 50° C. rise is permitted by the Standardization Rules of the American Institute of Electrical Engineers. A useful and fairly accurate empirical rule states that *the exposed surface of the armature should not be less than 24 square inches for each kilowatt of output.* Hence, we should need $24 \times 150 = 3{,}600$ square inches. As the armature has 3,820 square inches, there should be ample surface.

**Number and Dimensions of the Slots.** We may now settle upon the number and dimensions of the slots. The former depends upon the type of winding used and upon the number of commutator segments. It is almost universal practice to wind all but small armatures with copper strip, the current-density varying from 2,000 to 3,000 amperes per square inch. Assuming, in our case, 2,700 amperes per square inch, we require a conductor $\frac{600}{8} \div 2.700 =$ 0.0278 square inch in cross-section (say 0.028 square inch). As we have decided to place the conductors 8 in a slot, page 206, the total copper section per slot will be $8 \times 0.028 = 0.224$ square inch. Assuming a space-factor, page 83, of, say 0.34, we have as the area of the slot, $0.224 \div 0.34 = 0.66$ square inch, nearly. As there will be $928 \div 8 = 116$ slots—which is within the limits set by Table XXIV—and an equal number of teeth in a total perimeter of 141.4 inches, the width of a slot and a tooth at the face of the armature

*Assuming length over conductor of barrel-wound armatures to equal twice length over core.

TABLE XXIV

**Number and Size of Armature Slots and Teeth**

| Diameter of Armature (in inches) | Number of Slots or Teeth | Depth of Slots or Teeth (in inches) |
|---|---|---|
| 10 | 25 to 75 | 0.40 to 1.70 |
| 20 | 50 to 135 | 0.60 to 1.80 |
| 30 | 75 to 190 | 0.80 to 1.90 |
| 40 | 95 to 240 | 1.00 to 2.00 |
| 50 | 110 to 280 | 1.10 to 2.05 |
| 60 | 125 to 320 | 1.20 to 2.10 |
| 80 | 150 to 400 | 1.30 to 2.20 |
| 100 | 175 to 450 | 1.35 to 2.25 |
| 120 | 190 to 500 | 1.40 to 2.30 |
| 140 | 200 to 540 | 1.45 to 2.35 |
| 160 | 210 to 580 | 1.50 to 2.40 |

Ratio $\frac{\text{Depth of slots}}{\text{Width of slots}}$, from 1.5 to 4

Ratio $\frac{\text{Width of slot}}{\text{Width of tooth}}$, from 0.75 to 1.5

cannot exceed 141.4 ÷ 116 = 1.22 inches. Making the ratio $\frac{\text{Width of slot}}{\text{Width of tooth}} = 1.18$, we have the width of a tooth $= \frac{1.22^*}{1 + 1.18}$ = 0.56 inch, so that the width of a slot is 1.22 − 0.56 = 0.66 inch. Hence the depth of the slot will be 0.66 square inch ÷ 0.66 inch = 1 inch, Fig. 255. These values for the sizes of slots and teeth are seen to lie within the limits suggested by Table XXIV.

An enlarged drawing of the slot, showing to scale the arrangements of conductors, is now made, Fig. 256. Each conductor is wrapped with tape to a thickness of 30 mils on each side, and allowing a slot insulation at each side of, say 24 mils of press-board—two thicknesses, and a wrapping for four conductors of manila 25 mils thick—each conductor must be 80 mils wide, which leaves a clearance of 2 mils. The depth of conductor will be 0.028 ÷ 0.080 = 0.35 inch, or 350 mils. Allow, say 12 mils of press-board between the upper and lower layers, and 60 mils between the lower layer and

*Or let $x$ = Width of slot; $y$ = Width of tooth. Then $x + y = 1.22$, and $\frac{x}{y} = 1.18$. Hence $x = 1.18\,y$; and we have $y + 1.18\,y = 1.22$, or $y = \frac{1.12}{1 + 1.18}$.

the bottom of the slot. We may then account for the contents of a slot as follows:

| WIDTH | | |
|---|---|---|
| 4 Conductors side by side, bare | 4 × 0.080 | = 0.320 inch |
| 8 Thicknesses of taping | 8 × 0.030 | = 0.240 inch |
| 2 Thicknesses of slot lining | 2 × 0.024 | = 0.048 inch |
| 2 Thicknesses of manila | 2 × 0.025 | = 0.050 inch |
| Total | | 0.558 inch |

| DEPTH | | |
|---|---|---|
| 2 Conductors deep | 2 × 0.350 | = 0.700 inch |
| 4 Thicknesses of tape | 4 × 0.030 | = 0.120 inch |
| 4 Thicknesses of manila paper | 4 × 0.025 | = 0.100 inch |
| 6 Thicknesses of lining | 6 × 0.012 | = 0.072 inch |
| Total | | 0.992 inch |

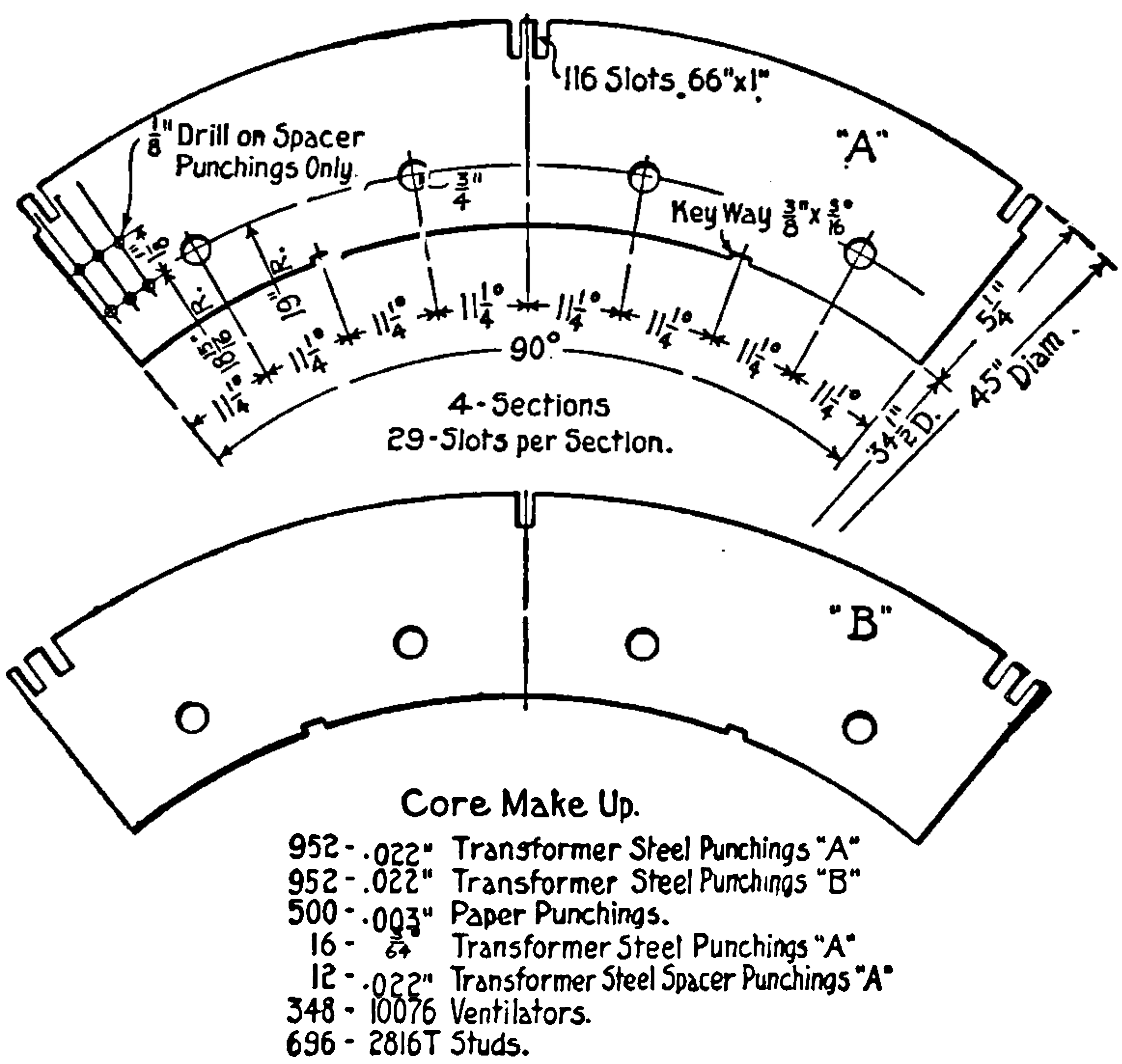



Fig. 255. Lamination Stamping of Armature Whose Construction is Described in Text

Now, the length of one armature turn—found by drawing the winding to scale and then measuring it—is 87.5 inches. The resistance of a copper conductor whose area of cross-section is 1 square inch, and whose length is 1 foot, at 50° C., is 0.000009088 ohm. Thus, we have as the total resistance of the armature winding at 50° C. $r_a$ = 0.000009088 × length of one armature turn in feet × $\frac{Z}{2} \div \left[\overline{\text{circuits in parallel}}^2 \times \text{area of one}\right.$

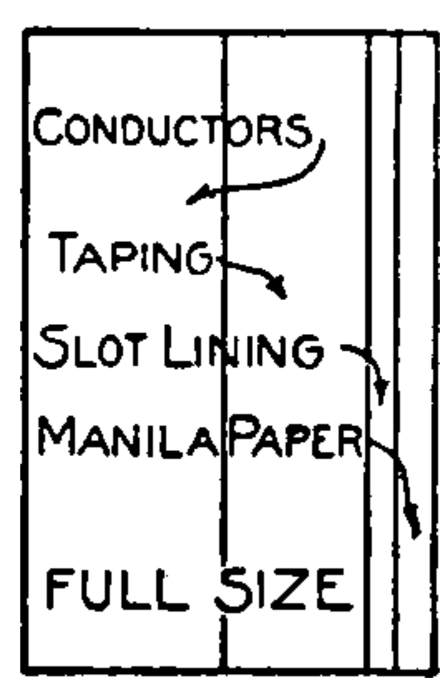



Fig. 256. Section of Part of an Armature Slot

**TABLE XXV**

**Flux-Densities in Armature Cores**

| Type | Flux-Density (in lines per square inch) |
|---|---|
| Bipolar drum-core | 50,000 to 90,000 |
| Bipolar ring-core | 65,000 to 95,000 |
| High-speed multipolar ring-core | 45,000 to 85,000 |
| Slow-speed multipolar ring-core | 65,000 to 97,000 |

conductor in square inches, ] or substituting,

$$r_a = \frac{0.000009088 \times 87.5 \times 464}{64 \times 0.028 \times 12} = 0.0172 \text{ ohm}$$

**Internal Diameter of Core.** The internal diameter of the core may now be fixed by ascertaining the requisite radial depth of the

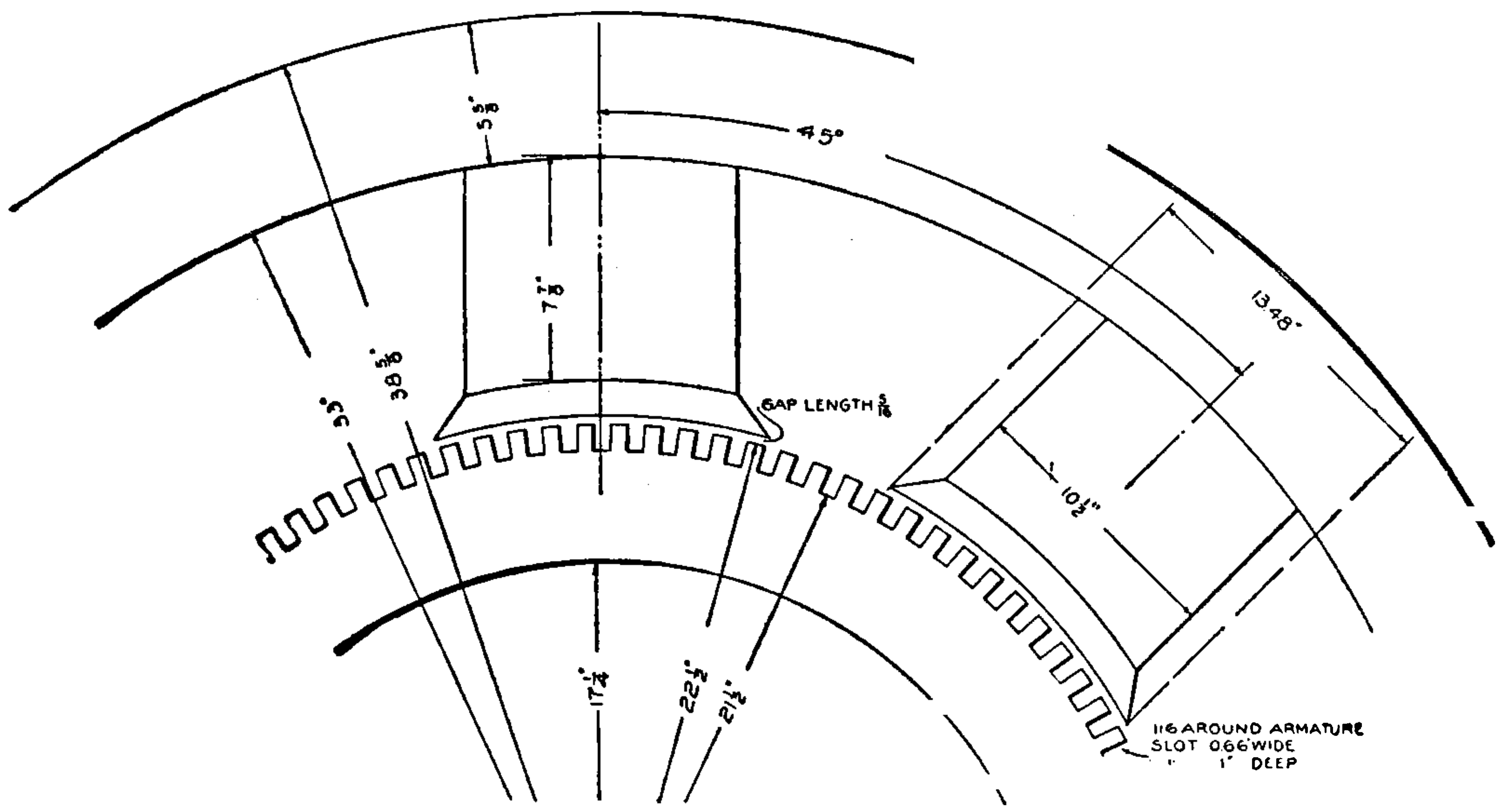



Fig. 257. Dimensioned Diagram of Magnetic Circuit of Generator Whose Construction is Described in Text

core to give an adequate cross-section of iron below the teeth, Fig. 257. The final value of this depends upon the permissible iron-loss, which limits the flux-density possible. Table XXV gives values for average flux-densities in armature cores; and as our design contemplates a slow speed multipolar ring-core armature, we may select a flux-density of, say 83,000 lines per square inch.

TABLE XXVI

**Approximate Values of Density in Air Gap with Multipolar Machines Having Slotted Armatures**

| OUTPUT OF MACHINE (in kilowatts) | DENSITY IN AIR GAP (in lines per sq. in.) |
|---|---|
| 1 | 30,000 |
| 5 | 35,000 |
| 10 | 37,500 |
| 25 | 40,000 |
| 50 | 42,500 |
| 100 | 45,000 |
| 200 | 47,500 |
| 300 | 50,000 |
| 500 | 53,000 |
| 1,000 | 56,000 |
| 2,000 | 59,000 |

and $2p$ = number of pairs of poles. Making $k_4 = 5$, in our design, we have

$$l_g = 5 \times \frac{\frac{928 \times 75}{141.4} \times 45}{8 \times 46{,}000} = 0{\cdot}302 \text{ inch (say } \tfrac{5}{16} \text{ inch)}$$

The flux-density in the air gap $B_g$, is found in Table XXVI.

**Dimensions of Magnet-Pole Cores.** These must have sufficient cross-section to carry the flux required at rated load, including that which forms by leakage—the stray flux. The densities in this portion vary from 75,000 to 100,000 lines per square inch, Table IV, page 73, and the usual leakage coefficients are given in Table III, page 71. The length of the core must be sufficient to carry the field-exciting winding; and, as a trial value, we may take this equal to from $\frac{3}{4}$ to 1 times the diameter (if the core is cylindrical), reducing the value so assumed, if necessary, later on. In case the core is not cylindrical, we may take the length of the pole-core as 20 times the length of the air gap if the machine is shunt-wound, and 40 times the length if it is compound-wound.

In our case, the total flux entering the armature at rated load was assumed to be 7,600,000 lines; and if we assume a leakage coefficient of 1.09, the total flux in the pole-cores will be 7,600,000 × 1.09 = 8,300 000 lines at rated load. Assuming a flux-density in


Fig. 258. Details of Magnet-Frame and Poles of Generator Whose Construction is Described in Text

the pole-cores of 96,000 lines per square inch, we have 8,300,000 ÷ 96,000 = 86.5 square inches as the area of cross-section of a pole-core. Making them circular in cross-section, we have $2\sqrt{86.5 \div \pi}$ = 10.5 inches, as the diameter of the pole-cores, Fig. 258. Making the radial length of the cores three-fourths the diameter, we get $\frac{3}{4} \times 10.5 = 7\frac{7}{8}$ inches, as a trial value. The details of the pole-shoes are given in Fig. 259.

**Cross-Section of the Yoke.** We may now decide upon the requisite area of cross-section of the yoke, this being fixed when we

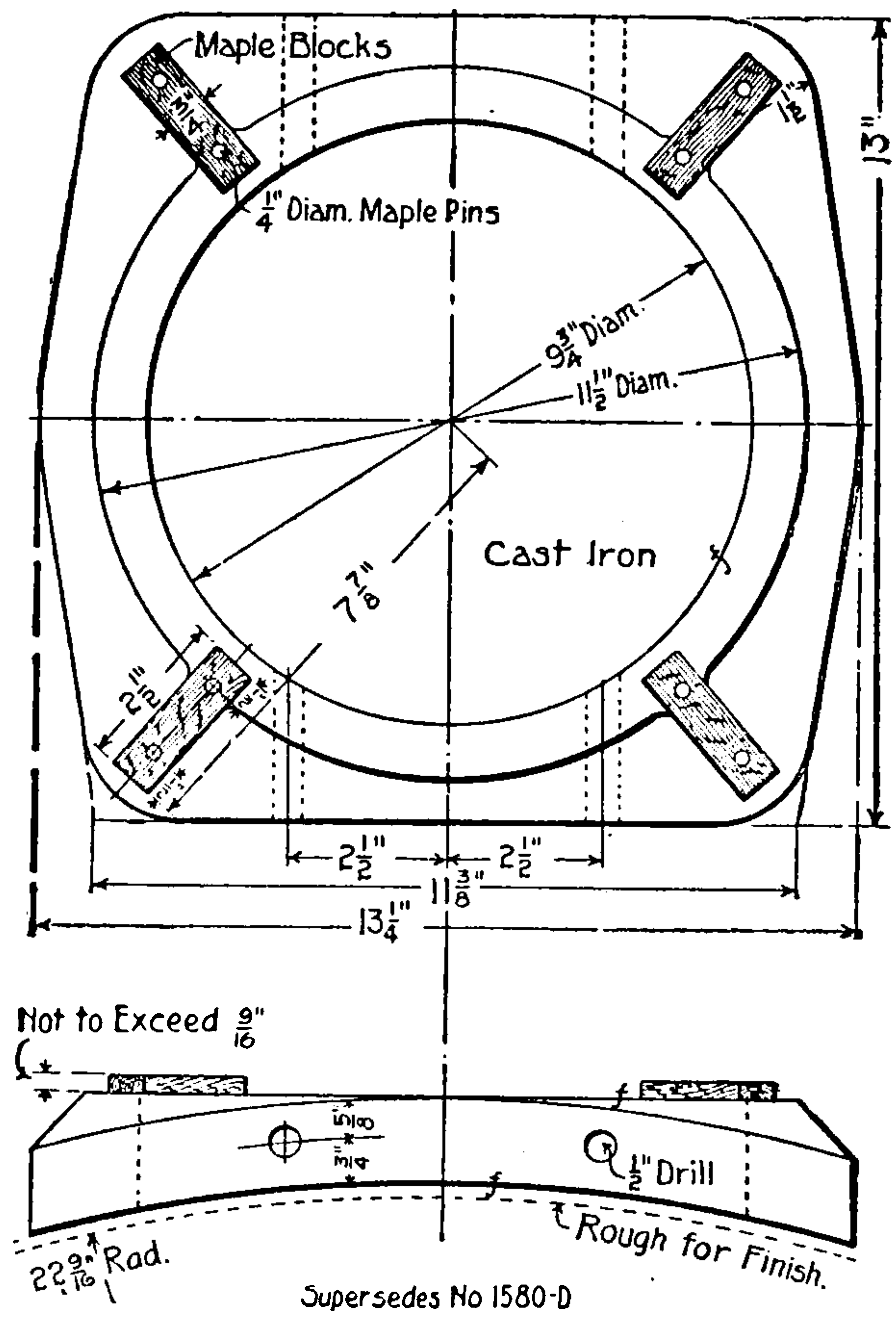



Fig. 259. Make-Up of Pole-Shoe of Generator Whose Construction is Described in Text

know the flux-density and the total flux. The latter is 8,300,000 ÷ 2 = 4,150,000, page 76; while, if we make the yoke of cast iron, the flux-density should be about 41,000, Table IV; 4,150,000 ÷ 41,000 = 101 square inches, say 100 square inches, making a flux-density of 41,500 lines per square inch.

TABLE XXVI

**Flux in Armature and Magnet-Cores for Various E. M. F's**

| Generated E. M. F. | Flux Entering Armature per Pole ( $\Phi_a$ ) | Flux per Pole in Magnet Cores ($\Phi_a \times 1.09$) |
|---|---|---|
| 180 | 5,180,000 | 5,650,000 |
| 200 | 5,750,000 | 6,260,000 |
| 220 | 6,320,000 | 6,890,000 |
| 240 | 6,900,000 | 7,520,000 |
| 260 | 7,470,000 | 8,150,000 |
| 280 | 8,050,000 | 8,780,000 |
| 300 | 8,620,000 | 9,400,000 |
| 330 | 9,490,000 | 10,320,000 |
| 360 | 10,340,000 | 11,290,000 |

sparking, and efficiency; this will presently be done. From the results of such calculations, it is then easy to see how to alter the original design in order to fulfil the required conditions.

**Excitation.** We shall first construct the magnetization curve of the machine by the method described on page 135. We have

$$E = \frac{Z \times 2p \times \text{r.p.m.} \times \Phi_a}{60 \times 10^8 \times c}$$

$$= \frac{928 \times 225 \times 8}{60 \times 10^8 \times 8}\Phi_a$$

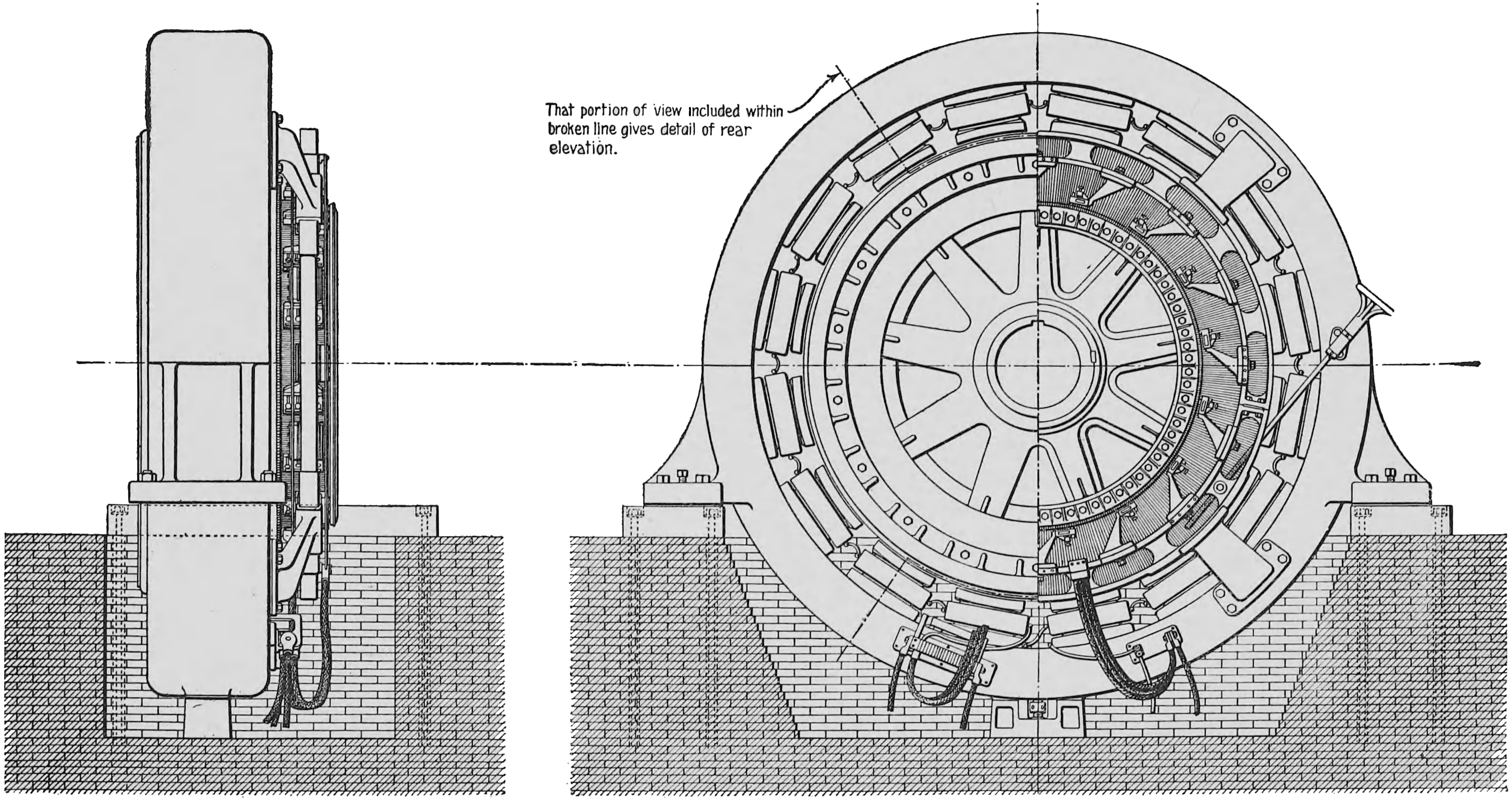
$$= 0.0000348\ \Phi_a$$

With the aid of this equation, we may compute Table XXVI, the leakage coefficient of the machine being 1.09 by actual measurement.

From the drawings, Figs. 257 and 258, we obtain the following dimensions:

| | |
|---|---|
| Mean length of magnetic path in magnet-yoke, in inches | 29 |
| Mean length of magnetic path in two magnet-cores, in inches | 15.75 |
| Mean length of magnetic path in armature core, in inches | 10 |
| Mean length of magnetic path in two teeth, in inches | 2 |
| Mean length of magnetic path in two air gaps, in inches | 0.625 |
| Magnetic area of magnet-yoke, in square inches | 100 |
| Magnetic area of magnet-cores, in square inches | 86.5 |
| Magnetic area of armature core, in square inches | 45.6 |

The polar angle being 32°, we have the number of teeth under each pole $\frac{32°}{360°} \times 116 = 10.3$, say 11 teeth, with the allowance for fringing.




Elevations and Plan of 600-Kw. Railway Generator, 550 Volts. *Crocker-Wheeler Company*

# TABLE XXVII

## Computation of Ampere-Turns for Various Generated E. M. F.'s

| Portion of Magnetic Circuit | Material | Mean Length of Magnetic Path (Inches) | Magnetic Area (Square Inches) | $E = 180$, $\Phi_a = 5,180,000$, $\Phi_m = 5,650,000$ | | | $E = 200$, $\Phi_a = 5,750,000$, $\Phi_m = 6,260,000$ | | | $E = 220$, $\Phi_a = 6,320,000$, $\Phi_m = 6,890,000$ | | | $E = 240$, $\Phi_a = 6,900,000$, $\Phi_m = 7,520,000$ | | | $E = 260$, $\Phi_a = 7,470,000$, $\Phi_m = 8,150,000$ | | | $E = 280$, $\Phi_a = 8,050,000$, $\Phi_m = 8,780,000$ | | | $E = 300$, $\Phi_a = 8,620,000$, $\Phi_m = 9,400,000$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Flux-Density | Ampere-Turns per Inch Length | Ampere-Turns | Flux-Density | Ampere-Turns per Inch Length | Ampere-Turns | Flux-Density | Ampere-Turns per Inch Length | Ampere-Turns | Flux-Density | Ampere-Turns per Inch Length | Ampere-Turns | Flux-Density | Ampere-Turns per Inch Length | Ampere-Turns | Flux-Density | Ampere-Turns per Inch Length | Ampere-Turns | Flux-Density | Ampere-Turns per Inch Length | Ampere-Turns |
| Magnet-Yoke | Cast Iron | 29 | 2 × 100 | 28,250 | 24 | 695 | 31,300 | 28 | 812 | 34,450 | 38 | 1,100 | 37,600 | 46 | 1,332 | 40,750 | 58.5 | 1,698 | 43,900 | 72.5 | 2,102 | 47,050 | 81.5 | 2,362 |
| Two Magnet-Cores | Cast Steel | 15.75 | 86.5 | 65,400 | 5 | 79 | 72,500 | 15 | 236 | 79,500 | 19 | 300 | 86,900 | 25.4 | 400 | 94,200 | 39.5 | 622 | 101,500 | 56 | 882 | 108,900 | 85 | 1,339 |
| Two Air Gaps | Air | 0.625 | 163 | 31,800 | 9,960 | 6,230 | 35,300 | 11,020 | 6,900 | 38,800 | 12,120 | 7,590 | 42,400 | 13,250 | 8,280 | 45,900 | 14,360 | 8,960 | 49,400 | 15,450 | 9,650 | 53,000 | 16,600 | 10,380 |
| Two Teeth | Sheet Steel | 2 | 59.5 | 87,000 | 23 | 46 | 96,600 | 52.5 | 105 | 106,200 | 99 | 198 | 11,600 | 287 | 574 | 127 800 | 524 | 1,048 | 135,300 | 762 | 1,524 | 145,000 | 1,003 | 2,006 |
| Armature Core | Sheet Steel | 10 | 2 × 45.6 | 56,700 | 2.5 | 25 | 63,000 | 3.8 | 38 | 69,300 | 6.4 | 64 | 75,600 | 10.8 | 108 | 81,900 | 16.5 | 165 | 88,200 | 25.4 | 254 | 94,500 | 43 | 430 |
| Ampere-turns per pair of poles | | | | ....... | ....... | 7,075 | ....... | ....... | 8,091 | ....... | ....... | 9,252 | ....... | ....... | 10,694 | ....... | ....... | 12,493 | ....... | ....... | 14,412 | ....... | ....... | 16,517 |

At rated load the brushes are given a lead of 5 segments, that is, a lead of 8.6 per cent. Hence, the percentage of demagnetizing ampere-turns = 17.2 per cent of the total armature turns. As there are 464 turns on the armature, each carrying 75 amperes, the demagnetizing ampere-turns per pair of poles will be

$$\frac{464 \times 75 \times .172}{4} = 1496.4$$

Multiplying this by the coefficient of magnetic leakage, the compensating ampere-turns per pair of poles will be $1.09 \times 1496.4 = 1,631$.

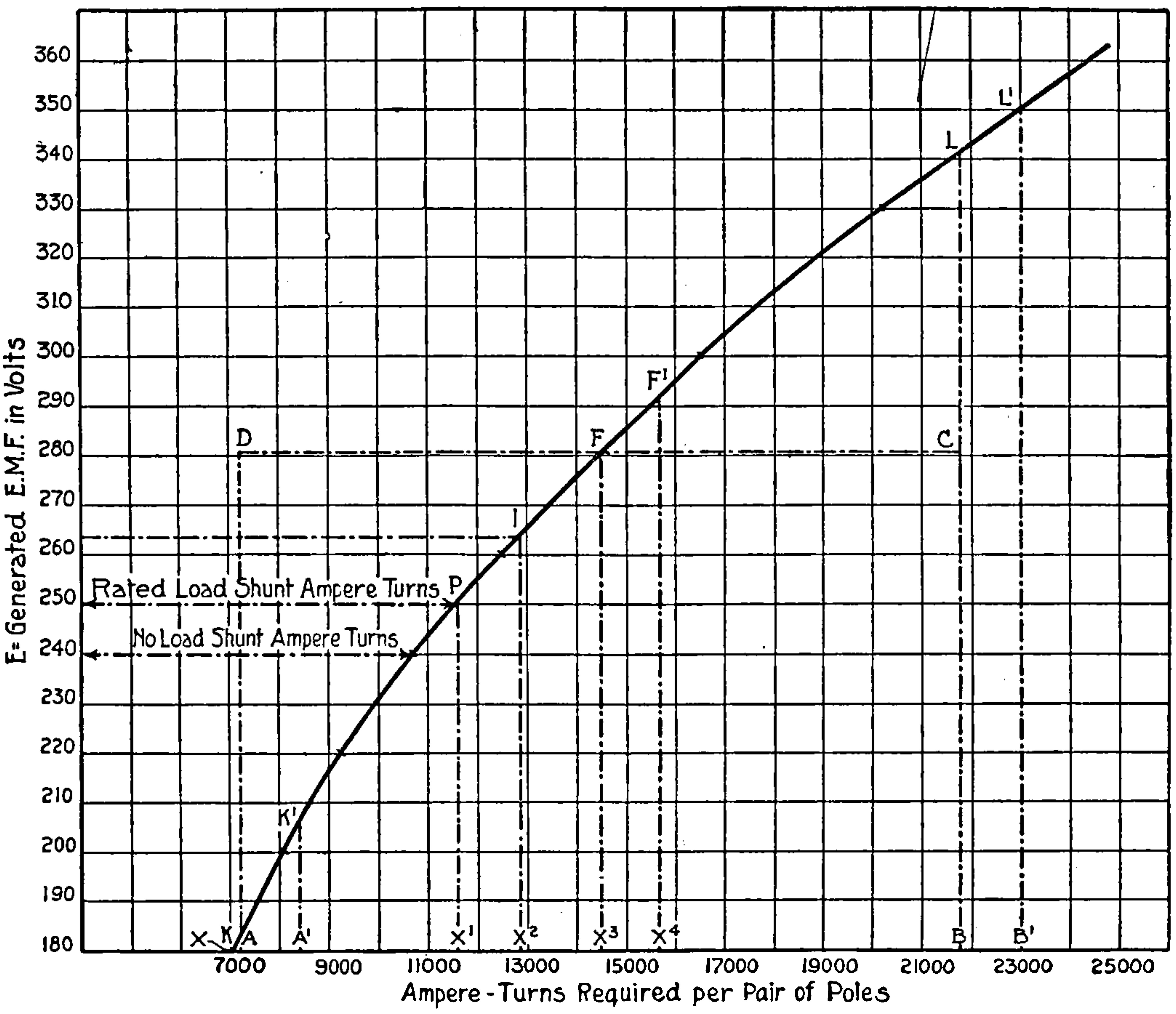



Fig. 260. Magnetization Curve of 150-K'w. 250-Volt Generator, 225 R.P.M.

Adding these to $X_2$, we find $X_3 = 14,461$, assuming, for the moment, that there is no drop in pressure due to diminished permeability of the teeth at the forward pole-horn. For this latter we must allow, as explained on pages 141-144.

We have the distorting ampere-turns per pair of poles $= \frac{464 \times 75 \times 0.828}{4} = 7,203$. Therefore, set off 7,203 ampere-turns on each side of the point $X_3$ upon the scale of abscissæ, and thus obtain the points $A$ and $B$, which represent the hindward and forward pole-horns, respectively. If the distortion of the main flux were absent, the latter would be proportional to the area $ABCD$; but as it is not so, it is proportional to the smaller area $ABLK$. In order to make this area equal to that of the rectangle, we must shift the point $F$ higher up the curve to some such position as $F'$, so that area $A'B'L'K'$ = area $ABCD$. In this manner we obtain the point $X_4$ = 15,700 as the necessary number of ampere-turns per pair of poles at rated load.

**Shunt Field=Winding.** From Fig. 260 we see that 10,700 ampere-turns are needed when the terminal voltage of the generator is 240

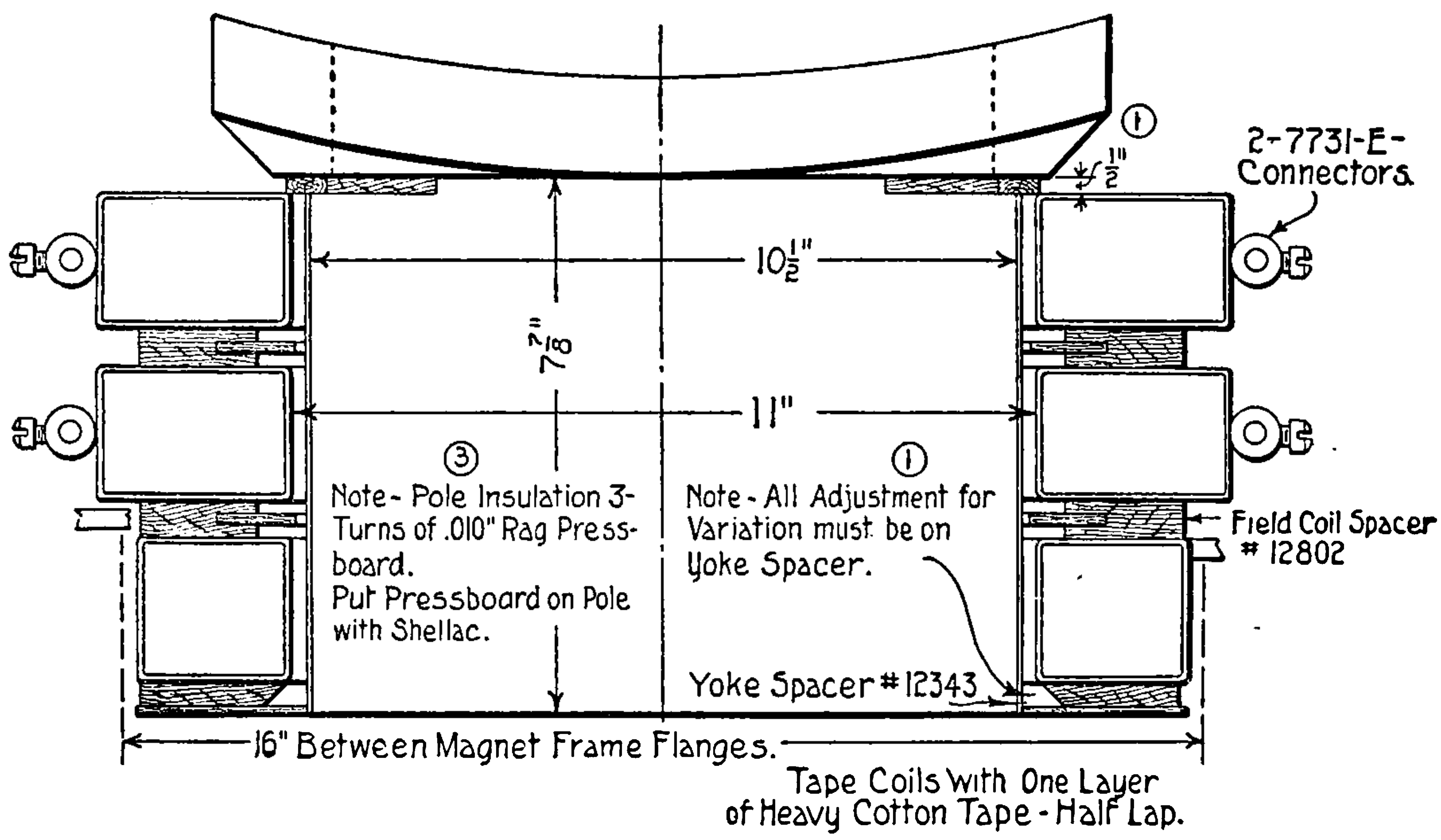



Fig. 261. Make-Up of Field-Coils of Generator Whose Construction is Described in Text

volts, that is, when no external current is being drawn. Hence, we shall require 5,350 ampere-turns per pole.

Assuming a depth of winding of about 1½ inches, we get the length of a mean turn as 3. 54 feet. Then, from formula on page 81, we get No. 10 wire as the most suitable size to use. Planning to have 72.5 per cent of the available 250 volts, that is, 181.5 volts, as the terminals of the field spools when hot (the remainder being consumed in the field rheostat), we require $\frac{181.5 \div 8}{2.9} = 7.82$ amperes per spool. Hence, the turns per shunt spool will be $\frac{5,570}{7.82} = 712.$

The length of 712 turns will be 2,830 feet, giving a resistance of very nearly 2.9 ohms per shunt spool. They will be arranged in 25 layers of 32 turns each, 2 coils per pole, Fig. 261. A table for make-up of field-coles is shown in Fig. 262.

**Series Field-Winding.** This winding is required to supply 2,280 ampere-turns at a rated load of 607 amperes. Planning to divert 31.6 per cent of this current through a rheostat in parallel with the winding, we find $0.684 \times 607 = 415$ amperes available for series excitation. Hence, each series coil should consist of $\frac{2{,}280}{415} = 5.5$ turns. The mean length of one turn is found to be 3.4 feet, so that 5.5 turns have a length of 18.7 feet.

The series winding per spool consists of 5.5 turns, made up of 5 strips of sheet copper 1.5 inches by $\frac{1}{16}$-inch section = 0.465 square inch. At 20° C. the resistance will, therefore, be

**Cumulative Compound Dynamo.**

| Case | Dimension of Strip. | | No. in ∥ in one Coil | No. of Leads. | Depth of Spacers. | Length of Shunt Coil Form. |
|---|---|---|---|---|---|---|
| A | $1\frac{1}{4} \times .015$ | | 1 - | 1 | $\frac{3}{8}$ | $2\frac{1}{8}$ |
| B | $1\frac{1}{4} \times \frac{1}{16}$ | | 1 - 3 | 1 | " | $2\frac{1}{8}$ |
| C | $1\frac{1}{4} \times \frac{1}{16}$ | | 4 - 8 | 2 | " | $2\frac{1}{8}$ |
| D | $1\frac{1}{2} \times .015$ | | J - 8 | 1 | " | 2 |
| E | $1\frac{1}{2} \times \frac{1}{16}$ | | 1 - 3 | 1 | " | 2 |
| F | $1\frac{1}{2} \times \frac{1}{16}$ | | 4 - 8 | 2 | " | 2 |
| G | $1\frac{3}{4} \times .015$ | | 1 - 8 | 1 | " | $1\frac{7}{8}$ |
| H | $1\frac{3}{4} \times \frac{1}{16}$ | | 1 - 3 | 1 | " | $1\frac{7}{8}$ |
| I | $1\frac{3}{4} \times \frac{1}{16}$ | | 4 - 8 | 2 | " | $1\frac{7}{8}$ |
| J | $1 \times .015$ | | 1 - 8 | 1 | " | $1\frac{3}{4}$ |
| K | $2 \times \frac{1}{16}$ | | 1 - 3 | 1 | " | $1\frac{3}{4}$ |
| L | $2 \times \frac{1}{16}$ | | 4 - 8 | 2 | $\frac{3}{8}$ | $1\frac{3}{4}$ |

Length of Coil 2"

Fig. 262. Table for Make-Up of Field-Coils

$$\frac{0.00000814 \times 18.7}{0.465} = 0.000327 \text{ ohm}$$

**Losses.** *Armature.* For the armature copper loss we have

$$607^2 \times 0.0172 = 6{,}350 \text{ watts}$$

To compute the armature iron loss, we have

$$\text{Volume of teeth} = \frac{0.560 + 0.505}{2} \times 1 \times 10.72 \times 116 = 663 \text{ cu. in.}$$

$$\text{Volume of core} = \frac{\pi}{4}\left(43^2 - 34.5^2\right) \times 10.72 = 5{,}555 \text{ cu. in.}$$

Hence, from formulas on page 22, we have

Hysteresis loss in core $= 0.83 \times 0.004 \times 15 \times 83{,}000^{1.6} \times 5{,}555 \times 10^{-7} = 1{,}970$ watts

Hysteresis loss in teeth $= 0.83 \times 0.004 \times 15 \times 126{,}000^{1.6} \times 663 \times 10^{-7} = 477$ "

Eddy-current loss in core $= 40.6 \times 0.022^2 \times 15^2 \times 83{,}000^2 \times 5{,}555 \times 10^{-12} = 169$ "

Eddy-current loss in teeth $= 40.6 \times 0.022^2 \times 15^2 \times 126{,}000^2 \times 663 \times 10^{-12} = 46$ "

Total iron losses at rated load = 2,662 watts

The total loss in series field-winding and resistance, therefore, = 490 + 227 = 717 watts, giving a drop at rated load of 1.18 volts.

*Commutator.* Twenty-four brushes are pressed upon the commutator, each having an area of contact of 1.125 square inches. The total area of all the brushes will, therefore, be 27 square inches. Hence, by formula on bottom of page 125, assuming a brush tension of 1.25 pounds per square inch, the brush-friction loss = 27 × 1.25 × 0.3 × 1,650 × 746 ÷ 33,000 = 378 watts.

The total brush-contact drop is 1.6 volts. Hence, the loss at brush contact = 607 × 1.6 = 971 watts. This makes the total commutator loss = 971 + 378 = 1,249 watts.

*Bearing Friction and Windage.* Owing to this being a direct-driven (slow-speed) machine, we may assume the losses due to bear-

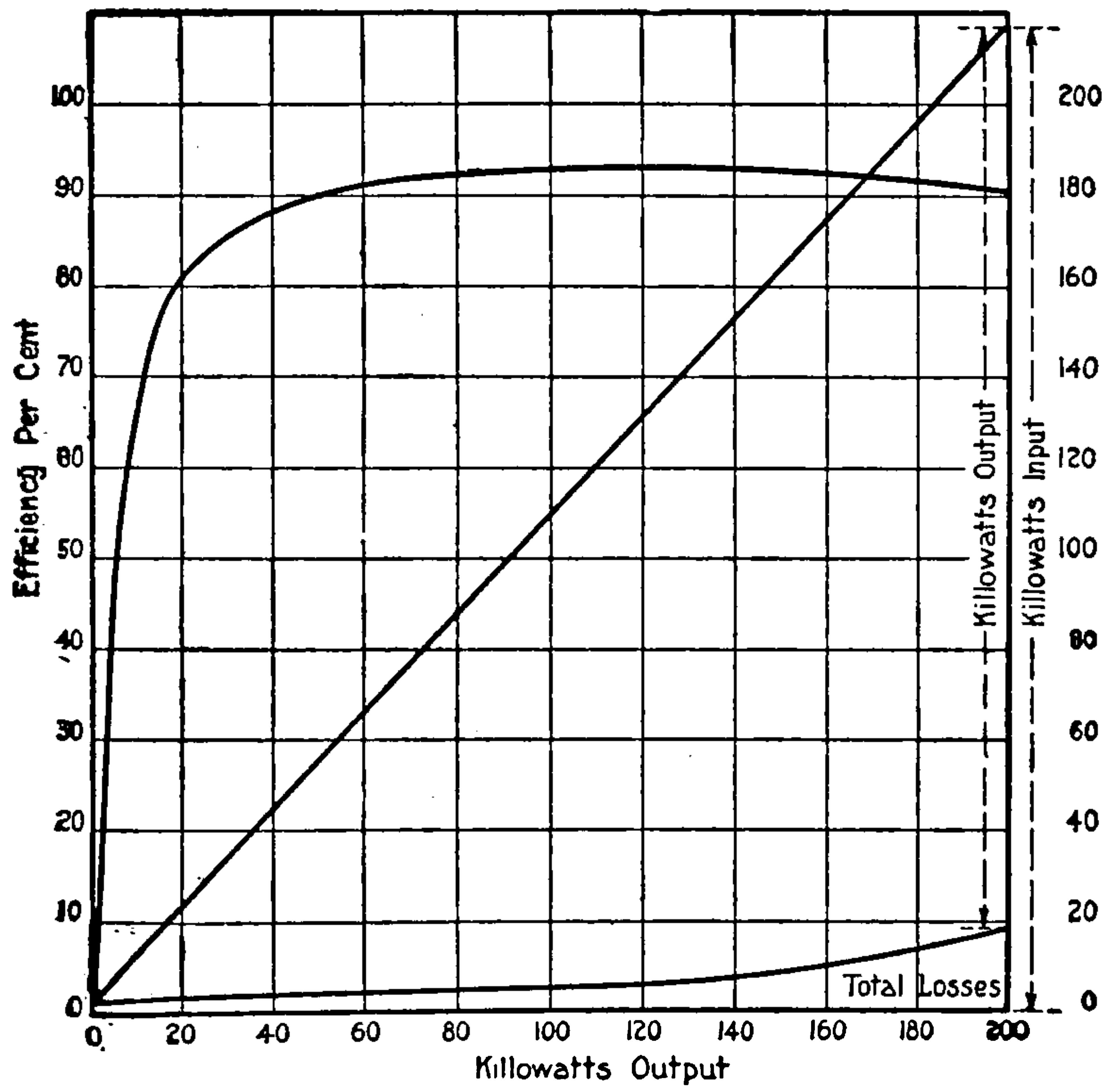
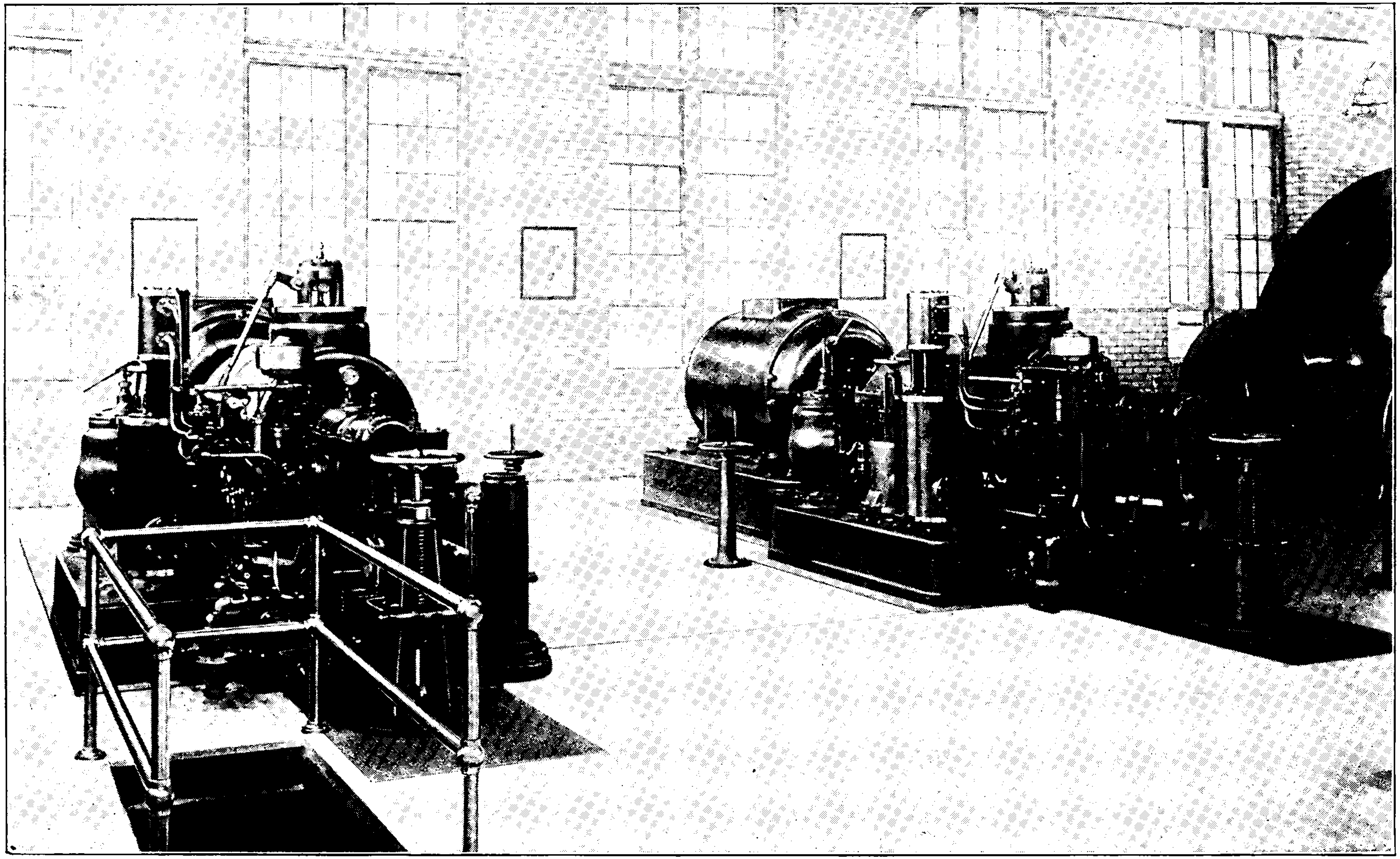



Fig. 264. Efficiency Curve of 140 D Generator, 250 V., 150 Kw., 225 R.P.M.

ing friction and windage as $\frac{2}{3}$ of 1 per cent of the output, that is, equal to 1,000 watts.

*Efficiency.* The total rated-load losses are

| | | | |
|---|---|---|---|
| Armature loss | 9,012 watts | = | 5.50 per cent |
| Excitation loss | 2,672 " | = | 1.63 per cent |
| Commutator loss | 1,249 " | = | 0.76 per cent |
| Bearing Friction and Windage | 1,000 " | = | 0.61 per cent |
| Total losses | 13,933 " | | 8.5 per cent |



INSTALLATION OF TWO-500-KILOWATT GENERATORS DRIVEN BY ALLIS-CHALMERS LOW PRESSURE STEAM TURBINE, FOR JOHNSON AND JOHNSON COMPANY, NEW BRUNSWICK, NEW JERSEY

*Courtesy of Allis-Chalmers Manufacturing Company*

# DETAIL SHEET

## GENERATOR DESIGN

*Name*............................ *Date submitted*....................

### Specification

| | | |
|---|---|---|
| 1 | Kilowatts | 150 |
| 2 | Terminal volts, rated load | 250 |
| 3 | Kilowatts no load | 240 |
| 4 | Amperes, rated load | 600 |
| 5 | Revolutions per minute | 225 |
| 6 | Number of poles | 8 |
| 7 | Frequency in cycles per second | 15 |
| 8 | Peripheral speed of armature, feet per minute | 2,650 |

### Materials

| | | |
|---|---|---|
| 9 | Armature core | Sheet Steel |
| 10 | Armature spider | Cast Iron |
| 11 | Armature binding wire | No. 16 Phosphor Bronze |
| 12 | Conductors | Copper |
| 13 | Commutator segments | Copper |
| 14 | Commutator leads | Copper |
| 15 | Commutator spider | Cast Iron |
| 16 | Pole-pieces | Cast Iron |
| 17 | Magnet-cores | Cast Steel |
| 18 | Magnet-yoke | Cast Iron |
| 19 | Brushes | Carbon |
| 20 | Shaft | Steel (0.35% C.) |
| 21 | Bearings | |

### Dimensions

*Armature—*

| | | |
|---|---|---|
| 22 | Diameter over all | 45 in. |
| 23 | Diameter at bottom of slots | 43 in. |
| 24 | Internal diameter of core | 34.5 in. |
| 25 | Length over conductors | 27 in. |
| 26 | Length of core over laminations | 13 in. |
| 27 | Insulation between sheets % | 9.8% |
| 28 | Number of ventilating ducts | 2 |
| 29 | Width of each ventilating duct | 0.375 in. |
| 30 | Effective length, magnetic iron | 10.72 in. |

| | | |
|---|---|---|
| 31 | Effective length of core ÷ total length | 82.5% |
| 32 | Thickness of sheets | 0.022 in. and $\frac{3}{64}$ in. at ends |
| 33 | Number of sheets | 479 of 0.022 in. and 4 of $\frac{3}{64}$ in.* |
| 34 | Number of slots | 116 |
| 35 | Depth of slot | 1 in. |
| 36 | Width of slot at root | 0.66 in. |
| 37 | Width of slot at surface | 0.66 in. |
| 38 | Width of tooth at root | 0.505 in. |
| 39 | Width of tooth at armature face | 0.560 in. |
| 40 | Size of conductor, Diam | Depth 0.35 in.<br>Width 0.08 in. |
| 41 | Size of conductor insulated | 0.14 in. by 0.41 in. |
| 42 | Pitch of winding, No. of teeth | 13 |
| 43 | Total number of face wires or bars | 928 |
| 44 | Arrang. of wires or bars per slot | 4–0.08 in. wide; 2–0.35 in. deep |
| 45 | Number in parallel per slot | 0 |
| 46 | Number in series per slot | 8 |
| 47 | Copper section ÷ slot section | 0.34 |
| 48 | Total insulation between cond. and core | 0.079 in. on sides of slots<br>0.127 in. on bottom of slots |
| 49 | Thickness insulation between conds | 0.060 in. vertically<br>0.110 in. between layers |

*Gap—*

| | | |
|---|---|---|
| 50 | Length in center | $\frac{5}{16}$ in. |
| 51 | Length maximum | $\frac{5}{16}$ in. |
| 52 | Bore of field | $45\frac{5}{8}$ in. |

*Pole-Piece—*

| | | |
|---|---|---|
| 53 | Length parallel to shaft | 13 in. |
| 54 | Length of arc, max | 13.48 in. |
| 55 | Length of arc, min | 11.57 in. |
| 56 | Thickness at edge of core | $1\frac{3}{8}$ in. |

*Magnet-Core—*

| | | |
|---|---|---|
| 57 | Length of magnet-core, radial | $7\frac{7}{8}$ in. |
| 58 | Diameter of magnet-core | $10\frac{1}{2}$ in. |
| 59 | Length parallel to shaft | $10\frac{1}{2}$ in. |
| 60 | Distance between magnet-cores | 9 in. |

*Magnet-Coils—*

| | | |
|---|---|---|
| 61 | Length over all winding space | $7\frac{7}{8}$ in. |
| 62 | Thickness of insulation on flanges | |
| 63 | Thickness of insulation on body | $\frac{1}{16}$ in. |
| 64 | Length of main winding space, ex. insuln. (shunt) | Each coil = 2 in. |
| 65 | Length of compound winding space, ex. insuln | $1\frac{1}{2}$ in. |
| 66 | Depth of winding space, ex. insuln | |

*4 sections per sheet.

67 Total section of field copper..........................9.12 sq. in.

68 Size of shunt conductor..........................No. 10 B. and S. G.

69 Turns in series per pole..........................2 coils, each 400 turns

70 Size of compound conductor..........5 strips, 1½ in. by $\frac{1}{16}$ in., in parallel

71 Turns in series per pole..........................5½

*Yoke—*

72 Outside diameter..........................77¼ in.

73 Inside diameter..........................66 in.

74 Thickness..........................5⅝ in.

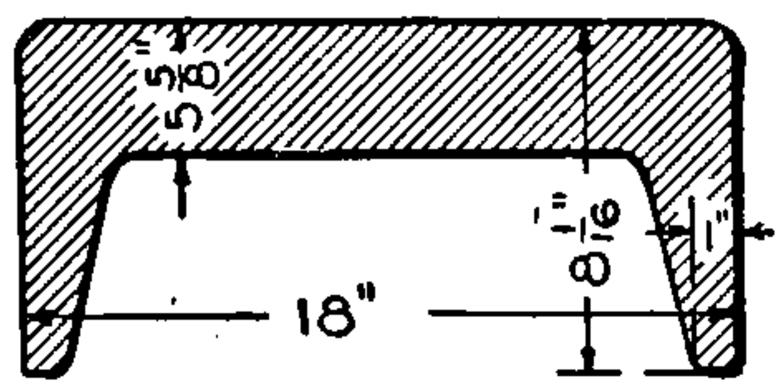


Fig. 265. Section of Yoke

75 Diameter over ribs..........................

76 Thickness of ribs..........................1 in.

77 Length along armature..........................18 in.

*Commutator and Brushes—*

78 Diameter..........................28 in.

79 Number of segments..........................464

80 Number of segments per slot..........................4

81 Width of segment at commutator face..........................0.158 in.

82 Width of segment at root..........................0.138 in.

83 Useful depth of segment..........................1.25 in.

84 Thickness of mica insulation..........................0.035 in.

85 Available length surface of segment..........................8.25 in.

86 Cross-section commutator leads..........................0.0468 sq. in.

87 Total length of commutator..........................12.5 in.

88 Peripheral speed..........................2,650 ft. per min.

89 Number of sets of brushes..........................8

90 Number in one set..........................3

91 Length..........................3 in.

92 Width..........................2.25 in.

93 Thickness..........................0.50 in.

94 Area of contact, one brush..........................1.125 sq. in.

95 Area of contact, one set..........................3.375 sq. in.

96 Type of brush..........................Radial Carbon

ARMATURE

97 No-load voltage..........................240 volts

98 Type of winding..........Simplex, Singly Re-entrant, Lap-Wound Drum

99 Number of circuits..........................8

100 Mean length, one armature turn..........................87.5 in

101 Total armature turns..........................464

102 Turns in series between brushes..........................58

103 Length between brushes..........................423 ft.

104 Cross-section one arm. conductor..........................0.028 sq. in.

105 Amperes per square inch in armature conductor..........................2,714

106 Resistances between brushes at 20° C..........................0.123 ohm

107 Resistances between brushes at 50° C..........................0.138 ohm

108 Total resistance of armature at.......................... { 20° C. 0.0154 ohm<br>50° C. 0.0172 ohm

148 Amperes, rated load ........ 415
149 Amperes per square inch, rated load ........ 892
150 Resistance of rheostat in parallel with series field ........ 0.00644 ohm

MAGNETIC

151 Megalines entering armature per pole, no load ........ 6.9
152 Megalines, entering armature per pole, rated load ........ 7.6
153 Coefficient of magnetic leakage, actual ........ 1.09
154 Megalines in field, no load ........ 7.5
155 Megalines in field, rated load ........ 8.3
156 Armature, section ........ 45.6 sq. in.
157 Length, magnetic ........ 10 in.
158 Density no load ........ 75,600
159 Density rated load ........ 83,000
160 Ampere-turns per inch length, no load ........ 10.8
161 Ampere-turns per inch length, rated load ........ 18.0
162 Ampere-turns, no load ........ 108 } per pair of poles
163 Ampere-turns, rated load ........ 180 }
164 Teeth transmitting flux from one pole-piece ........ $\frac{32°}{360°} \times 116 = 10.3$
165 Allowances for spread of flux ........ .07
166 Section of roots ........ 59.5 sq. in.
167 Length ........ $2 \times 1 = 2$ in.
168 Apparent density, no load ........ 116,000
169 Apparent density, rated load ........ 127,800
170 Corrected density, no load ........ 114,000
171 Corrected density, rated load ........ 123,000
172 Ampere-turns per inch length, no load ........ 287
173 Ampere-turns per inch length, rated load ........ 565
174 Ampere-turns, no load ........ 574 } per pair of poles
175 Ampere-turns, rated load ........ 1,130 }
176 Gap, section at pole-face ........ 163 sq. in.
177 Length gap ........ $2 \times \frac{5}{16}$ in. $= 0.625$ in.
178 Density at pole-face, no load ........ 42,400
179 Density at pole-face, rated load ........ 46,000
180 Ampere-turns, no load ........ 8,280 } per pair of poles
181 Ampere-turns, rated load ........ 9,090 }
182 Magnet-Core, section ........ 86.5 sq. in.
183 Length (magnetic) ........ $2 \times 7.875 = 15.75$ in.
184 Density, no load ........ 86,900
185 Density, rated load ........ 96,000
186 Ampere-turns per inch length, no load ........ 25.4
187 Ampere-turns per inch length, rated load ........ 42
188 Ampere-turns, no load ........ 400 } per pair of poles
189 Ampere-turns, rated load ........ 661 }
190 Magnetic Yoke, section ........ 100 sq. in.
191 Length per pole ........ 29 in.
192 Density, no load ........ 37,600
193 Density, rated load ........ 41,500
194 Ampere-turns per inch length, no load ........ 46

195 Ampere-turns per inch length, rated load........................61

196 Ampere-turns, no load........................1,332 } per pair of poles

197 Ampere-turns, rated load........................1,769 } per pair of poles

### Ampere-Turns per Pole

| | | No Load and 240 Volts. | Rated Load and 263.5 Internal Volts |
|---|---|---|---|
| 198 | Armature core | 54 | 90 |
| 199 | Armature teeth | 287 | 565 |
| 200 | Gap | 4,140 | 4,545 |
| 201, 202 | Magnet-pole, Magnet-core | 200 | 330 |
| 203 | Magnet-yoke | 666 | 884 |
| | | 5,347 | 6,414 |

204 Demagnetizing ampere-turns per pole, at rated load................748

205 Allowance for increase in density through distortion................315

206 Total ampere-turns at rated load and 250 terminal volts..........7,850

207 If the rheostat in the shunt circuit is adjusted to give 5,347 ampere-turns at 240 volts, then, when the terminal voltage is 250, the shunt excitation will amount to $\frac{250}{240} \times 5{,}347 = 5{,}570$ ampere-turns. $7{,}850 - 5{,}570 = 2{,}280$ ampere-turns must be supplied by the series winding.

### Calculation of Spool Winding

*Shunt*—

208 Mean length of one shunt turn =............................42.6 in.

209 Ampere-turns per shunt spool at rated load.....................5,570

210 Ampere feet...............................................19,800

211 Total radiating surface of two shunt field-spools + series field-spool.............................................294 sq. in.

212 Proportion available for shunt = —— × = ...............217 sq. in.

213 Permit .40 watt per square inch at 20° C............................

214 ∴ $217 \times .40 = 87$ watts per shunt spool at 20° C......................

215 And 98 watts per shunt spool at 50° C...............................

216 Plan to have 72.5 per cent of the available 250 volts (*i.e.*, 181.5) at the terminals of the field-spools when hot, the remainder being consumed in the field rheostat. This is 181.5 volts at 20° C., or 22.7 volts per spool. Hence require $\frac{22.7}{2.9} = 7.82$ amperes per spool

217 Turns per shunt spool $= \frac{5.570}{7.82} =$ ...........................712

218 Length of 712 turns.......................................2,830 ft.

219 Pounds per 1,000 ft...............................40 "calculated"

220 No. 10 B. and S. has 31.5 lbs. per 1,000 ft., $2.83 \times 31.5 = 89$ lbs. "used" per pole.

221 Bare diameter.............................................0.102 in.

222 S. C. C. diameter.........................................0.108 in.

223 Cross-section of copper.................................0.00815 sq. in.

224 Amperes per square inch......................................855

225 Length of the portion of winding space available for shunt winding .4 in.
226 Winding consists of 25 layers of 32 turns each, of No. 10 B. and S.

### Series Winding

227 The series winding is required to supply 2,280 ampere-turns at rated load of 600 amperes.
228 Planning to divert 31.6 per cent through a rheostat in parallel with the series winding, we find we have $607 \times 0.684 = 415$ amperes available for the series excitation; hence each series coil should consist of $\frac{2,280}{415} = 5.5$ turns.
229 Mean length of series turn........................................40.8 in.
230 Total length of 5.5 turns........................................18.7 ft.
231 Radiating surface available for series coil....................77 sq. in.
232 Permit .40 watt per square inch in series winding at 20° C.
233 Watts lost per series spool at 20° C. = $.40 \times 77$ =....................31
234 Hence resistance per spool at 20° C. $= \frac{31}{(415)^2} = 0.00018$ ohm.
235 Copper cross-section = 0.465 square inch, "calculated."
236 Series winding per spool consists of 5.5 turns made up of 5 strips of sheet copper 1.5 in. $\times \frac{1}{16}$ in.

### Thermal Calculations and Losses

Armature—

237 $I^2R$ loss, rated load, at 50° C..................................6,350 watts
238 Hysteresis loss, rated load.... { core..........................1,970 watts
teeth..........................477 watts }
239 Eddy-current loss, rated load. { core..........................169 watts
teeth..........................46 watts }
240 Total hys. and eddy-cur. losses, rated load....................2,662 watts
241 Total hys. and eddy-cur. losses, no load.......................2,300 watts
242 Total armature loss, rated load................................9,012 watts
243 Radiating surface of armature..................................4,510 sq. in.
244 Watts per square inch radiating surface..........................2
245 Assumed increase of temperature per watt per square inch of radiating surface as measured by increased resistance................ = 25° C.
246 Hence, estimated total increase temperature of armature at rated load.................................................. = 50° C.

Shunt or Main Field—

247 $I^2R$ total, no load 50° C........................................939 watts
248 $I^2R$ total, rated load 50° C.....................................1,240 watts
249 Radiating surface..............................................1,740 sq. in.
250 Watts per square inch, rated load................................0.715
251 Total increase in temperature, rated load.........................25° C.
252 I. E. rated load, field and rheostat.............................1,740 watts

Series or Compound Field—

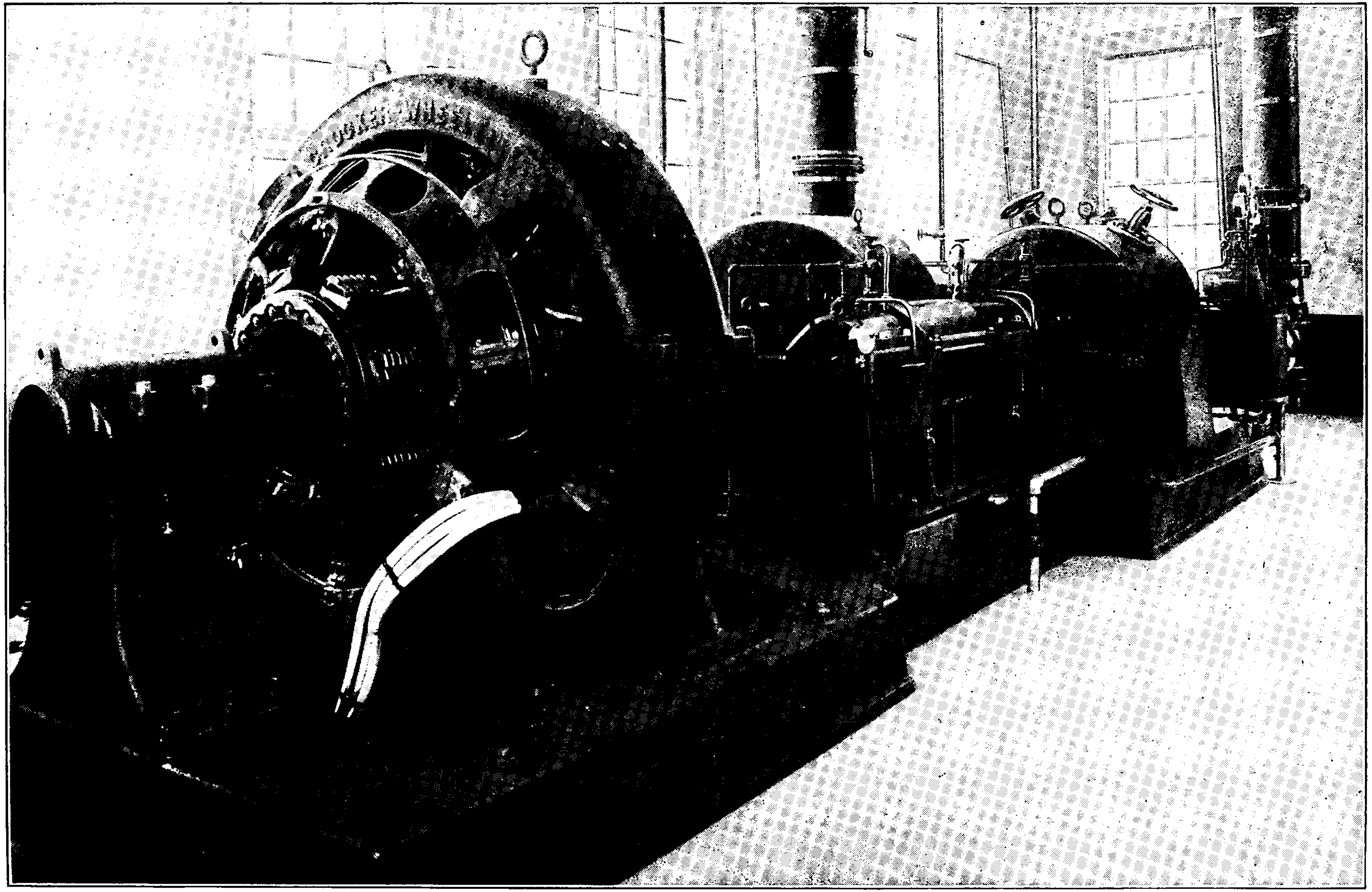
253 $I^2R$ total, rated load............................................490 watts
254 Radiating surface................................................615 sq. in.

297 Magnet-yoke........................................3,794 lbs.
298 Shunt coils........................................694 lbs.
299 Series coils........................................306 lbs.
300 Total spool copper........................................1,080 lbs.
301 Brush-gear........................................533 lbs.
302 Bed-plate and bearings........................................
303 Machine complete........................................12,400 net lbs.

DRAWINGS REQUIRED

304 Longitudinal cross-section.
305 End elevation.
306 Plan.
307 Diagram of armature winding.
308 Details of important features.
309 Efficiency curve.
310 Curve of regulation.
311 Curves for losses from no load to rated load.
312 $8 \times 10\frac{1}{2}$-in. paper required for description of method of calculation.

Drawings to be made with pencil on brown drawing paper, then traced and blue-printed.



**DE LAVAL MULTI-STAGE GEARED TURBINE, BACK PRESSURE TYPE**
*Courtesy of DeLaval Steam Turbine Company*

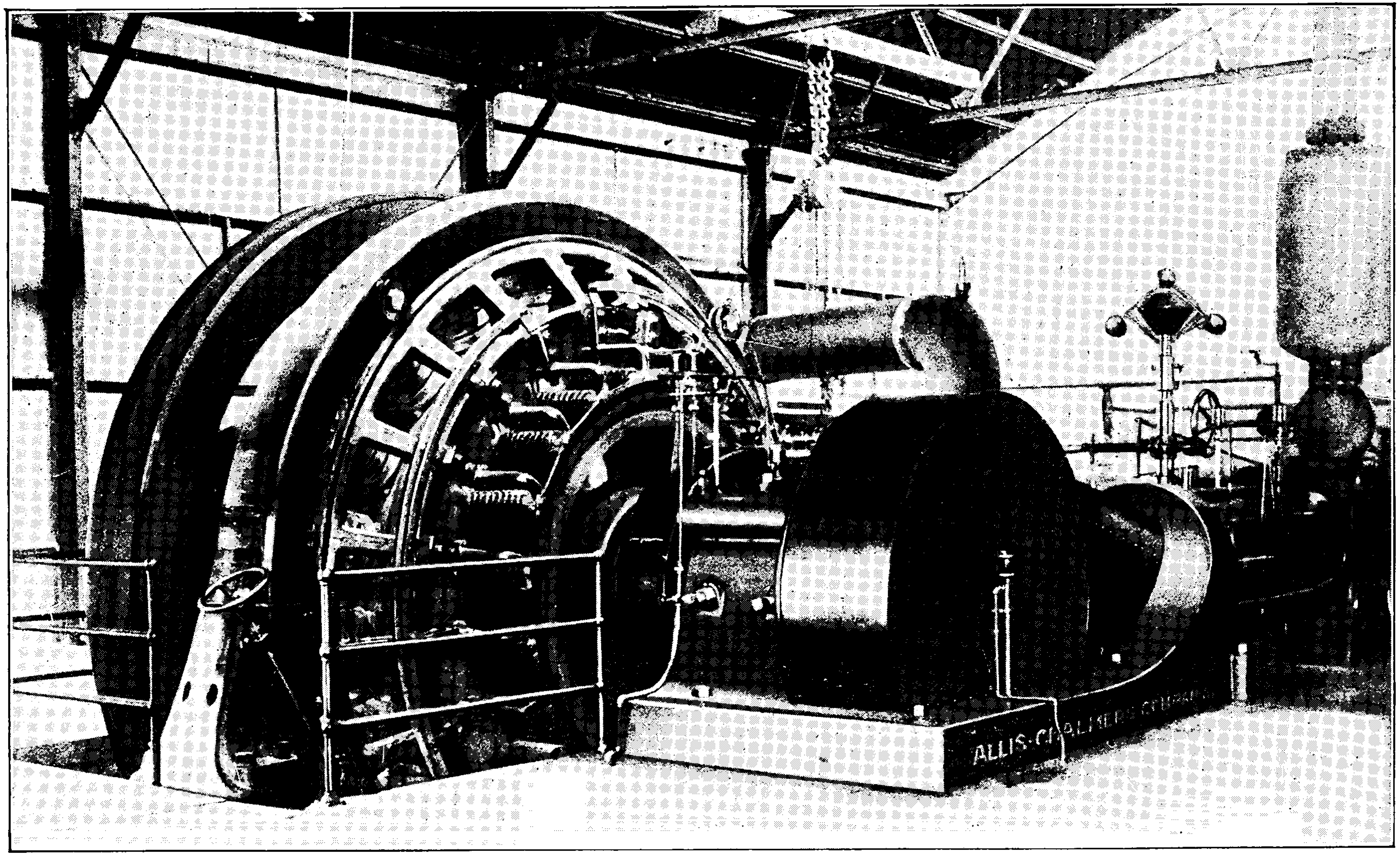



Fig. 1. Allis-Chalmers Type I Generator and Corliss Engine
*Courtesy of Allis-Chalmers Manufacturing Company*

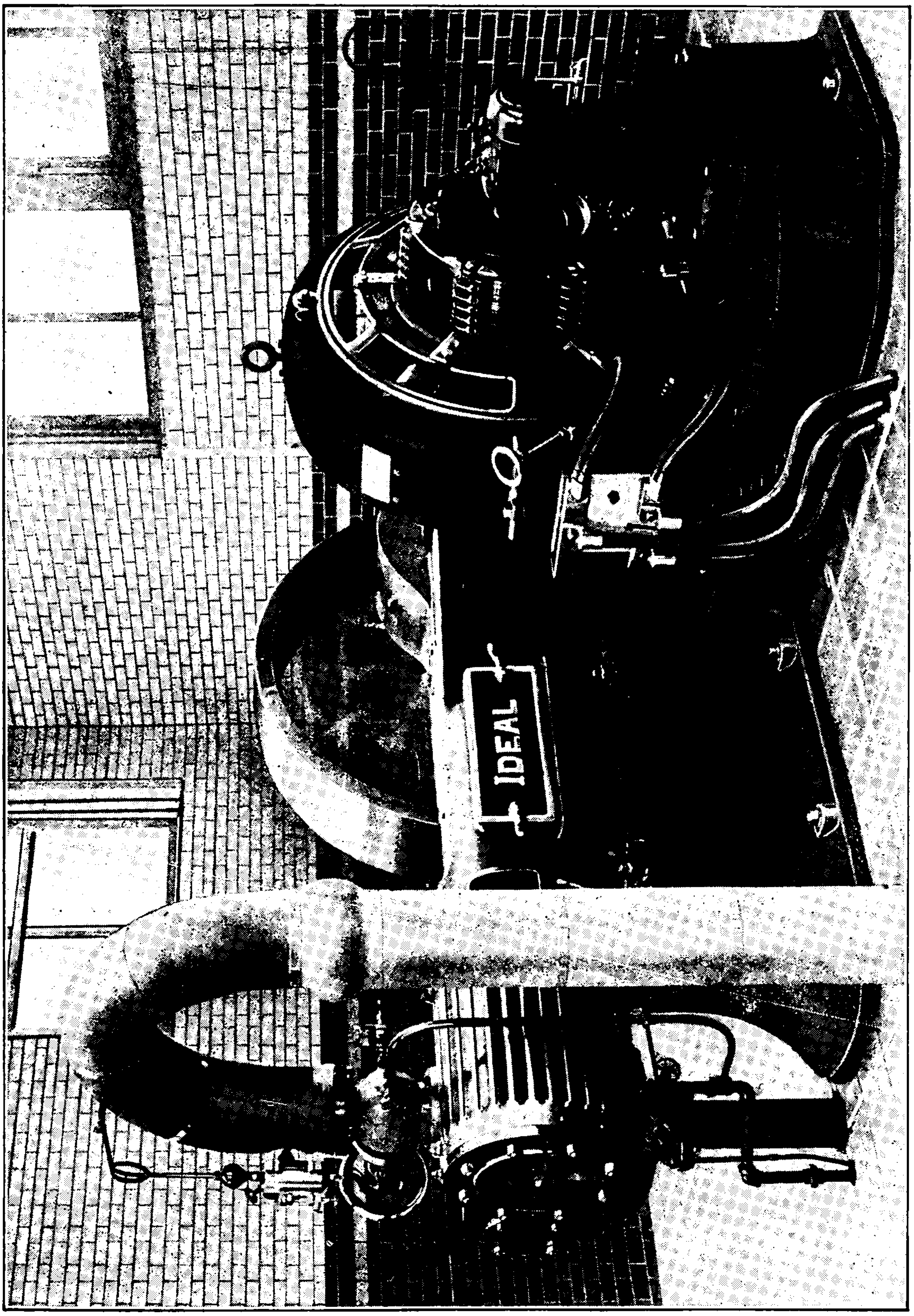



Fig. 2. Allis-Chalmers Generator Direct-Connected to "Ideal" Engines
*Courtesy of Allis-Chalmers Manufacturing Company*

*Steam-Turbine Driven.* Direct steam-turbine driven generators are similarly manufactured with either vertical or horizontal shafts. An example of the vertical type is the Curtis steam turbine unit manufactured by the General Electric Company and shown in Fig. 9. The generator of this type of unit is, however, as manufactured at present, always a three-phase alternator. Illustrations of horizontal-shaft steam-turbine units are given in Figs. 10 and 11.

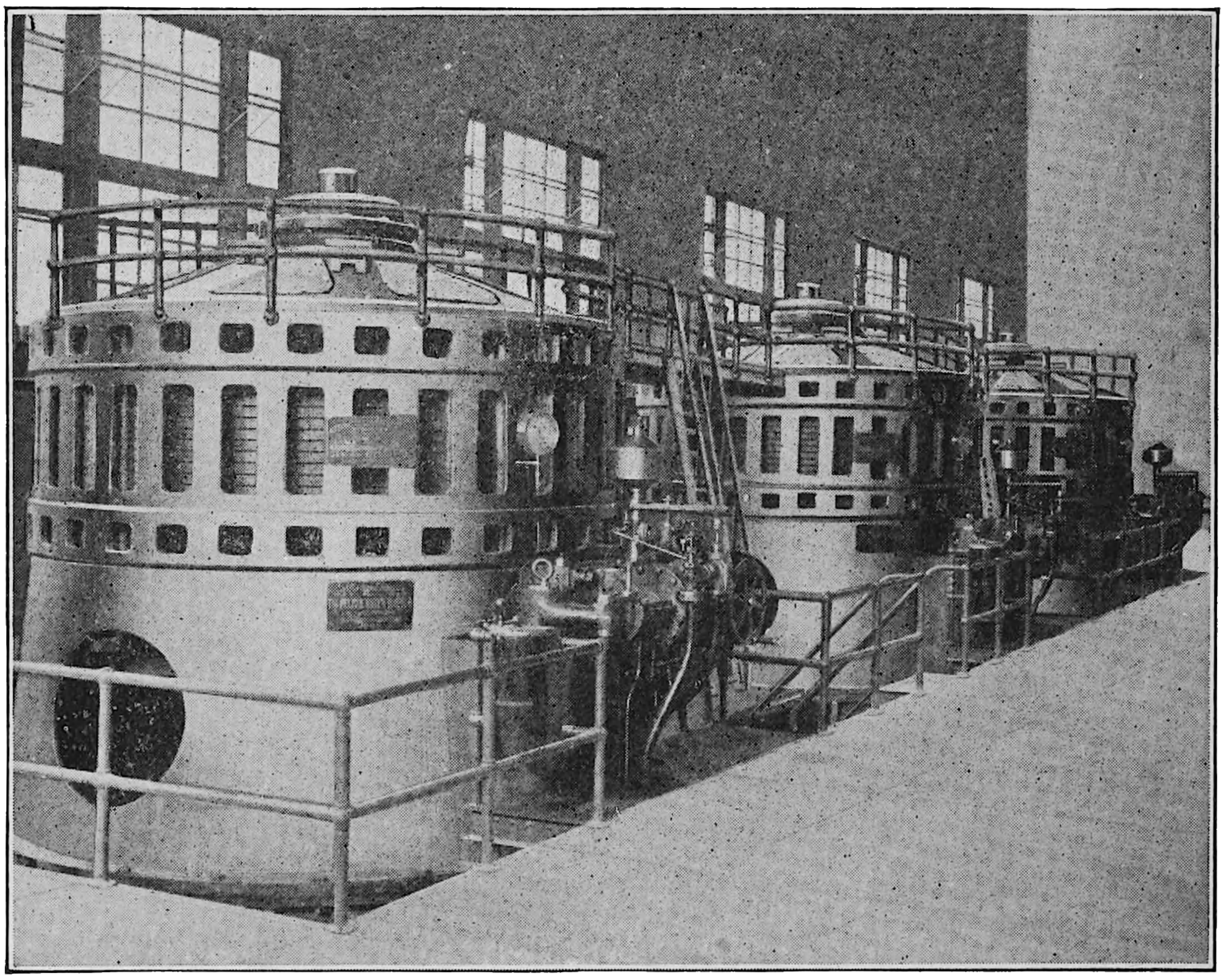


Fig. 5. Bank of Water-Wheel Driven Alternators
*Courtesy of General Electric Company*

**Belted Generators.** Generators that are not direct-connected to their prime movers are almost always driven by belt, or in rather special cases by some form of rope drive or silent chain drive. Belt-driven generators, up to 150-kw. capacity, usually carry a metal, wood, or paper pulley that merely overhangs the main bearings. If the generator is larger, or from 150- to 500-kw. capacity, a third bearing is provided to relieve the bending strain occasioned by the belt pull. The prime movers used in connection with belted generators are generally only steam engines, gas engines, and water wheels. In the smaller sizes in isolated plants, however, various internal

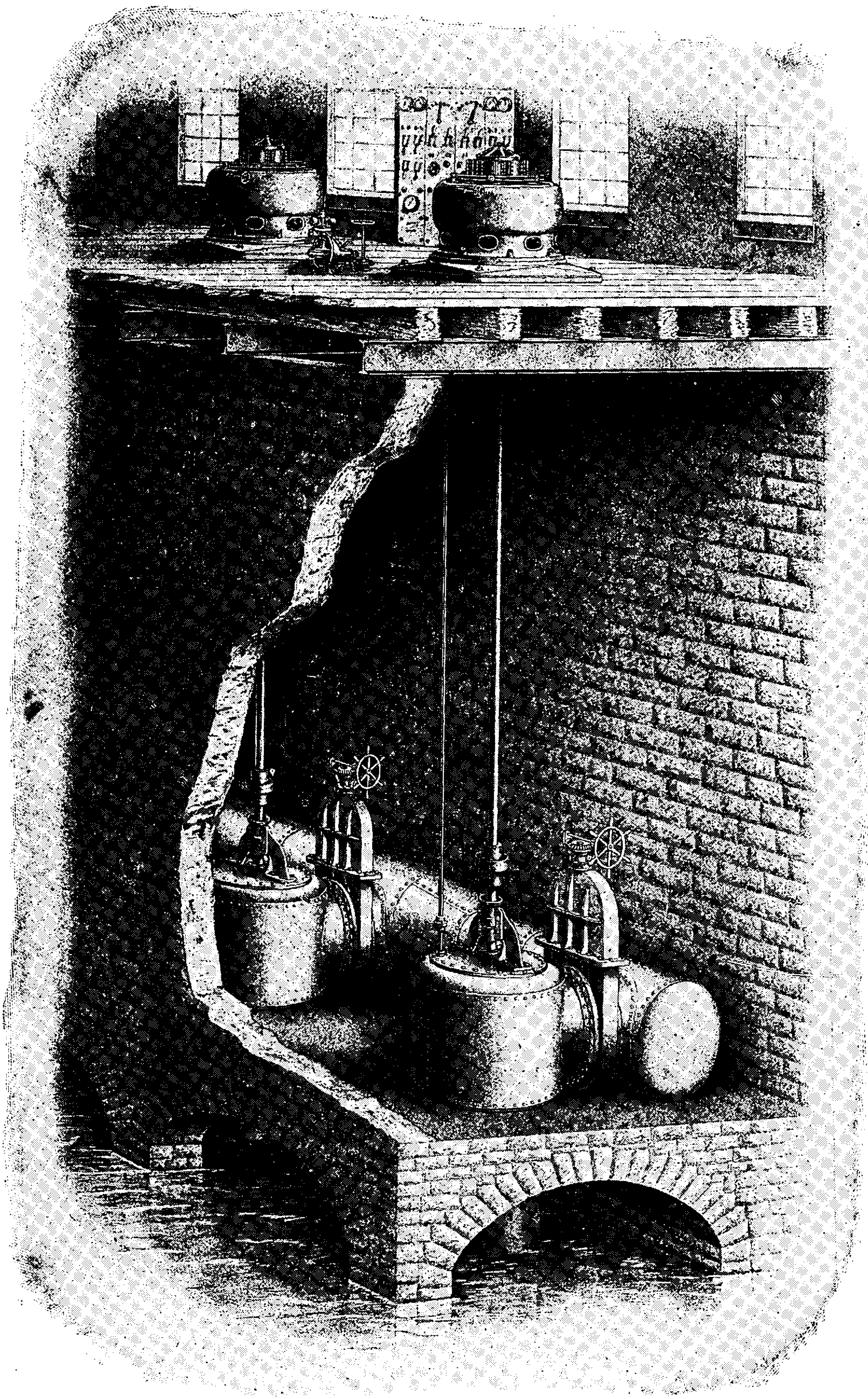


Fig. 6. Generators Connected Direct on Top of Turbine Shaft
*Courtesy of Trump Manufacturing Company*

combustion engines are found driving belted generators. The steam turbine is never belted to a generator, since in the smaller powers it rotates at very high speed, rendering the use of belting impracticable.

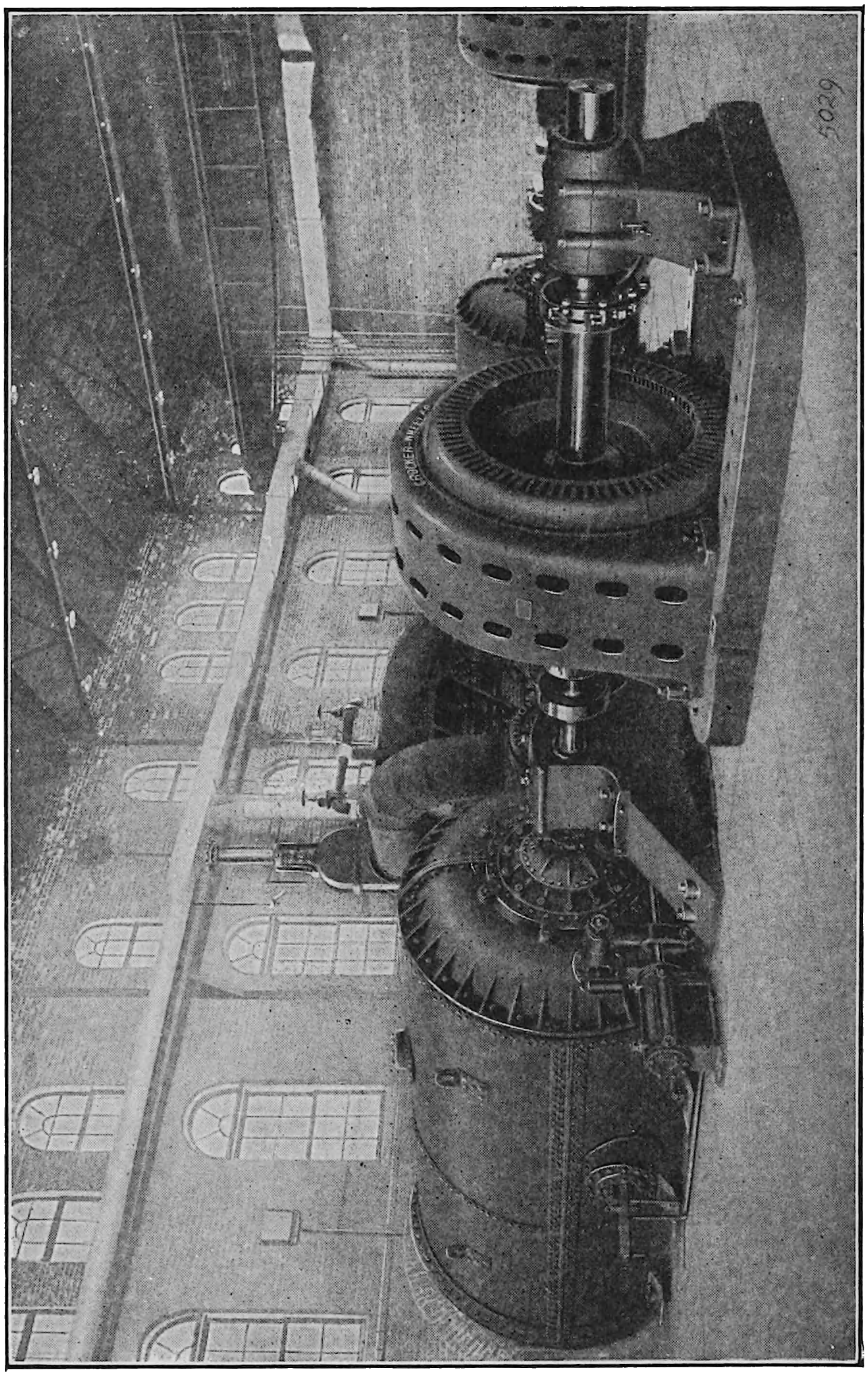


Fig. 7. Two 2400-Volt Generators Direct-Connected to Water Wheels
*Courtesy of Crocker-Wheeler Company*

**Geared Generators.** Gearing is only used for driving generators in the following cases: First, vertical-shaft water wheels and horizontal-shaft generators are often connected, in case of low heads, by means of bevel gearing, the generator shaft revolving at a higher speed than the turbine. Second, in smaller sizes, steam turbines

and generators are connected by means of gearing, the generator shaft revolving at a lower speed than the steam-turbine shaft. An example of this method of connection is given in Fig. 12. Third,

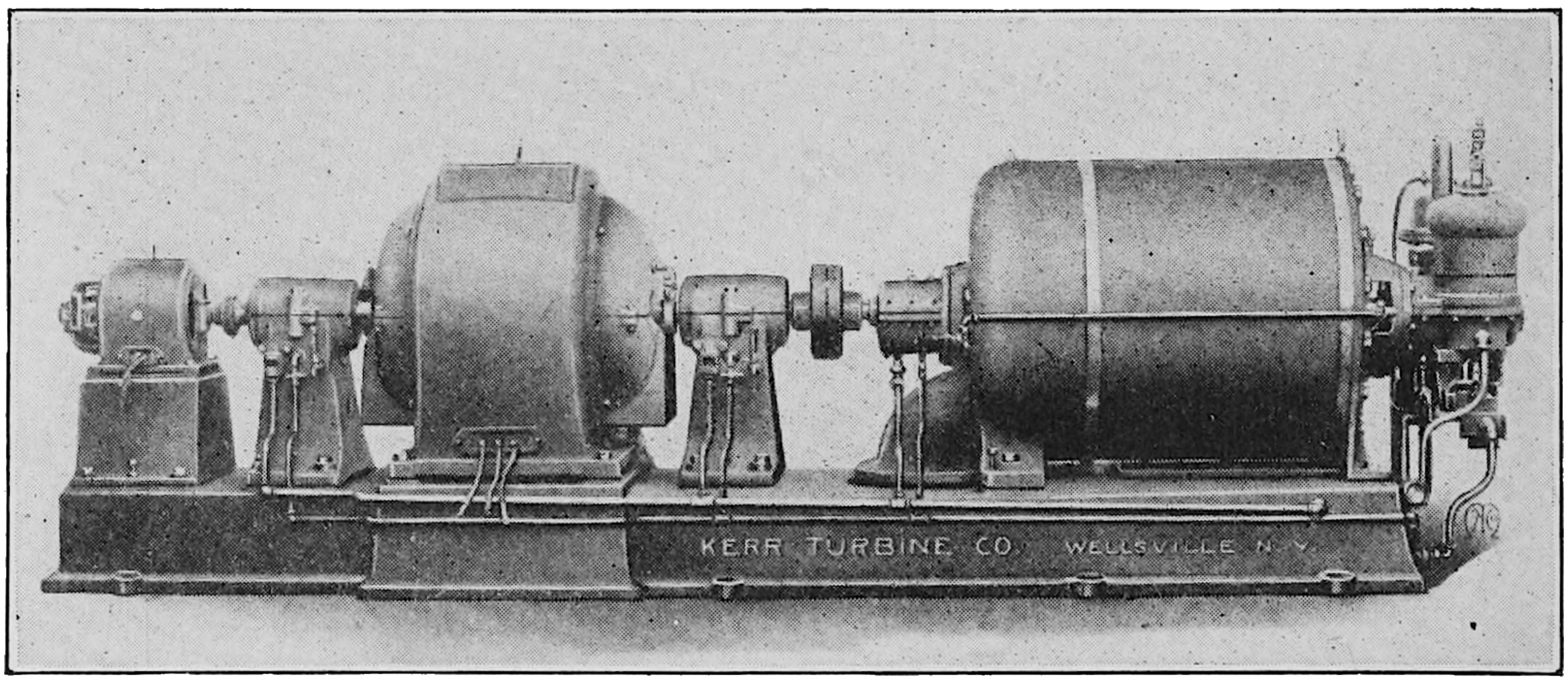



Fig. 10. Kerr Steam Turbine Generating Unit
*Courtesy of Kerr Turbine Company*

direct-current generators used as exciters for steam-turbine driven alternators are sometimes geared to the shaft of the unit.

**Selection of Type of Generator Drive.** At the present time, the best modern practice employs direct-driven generators whenever

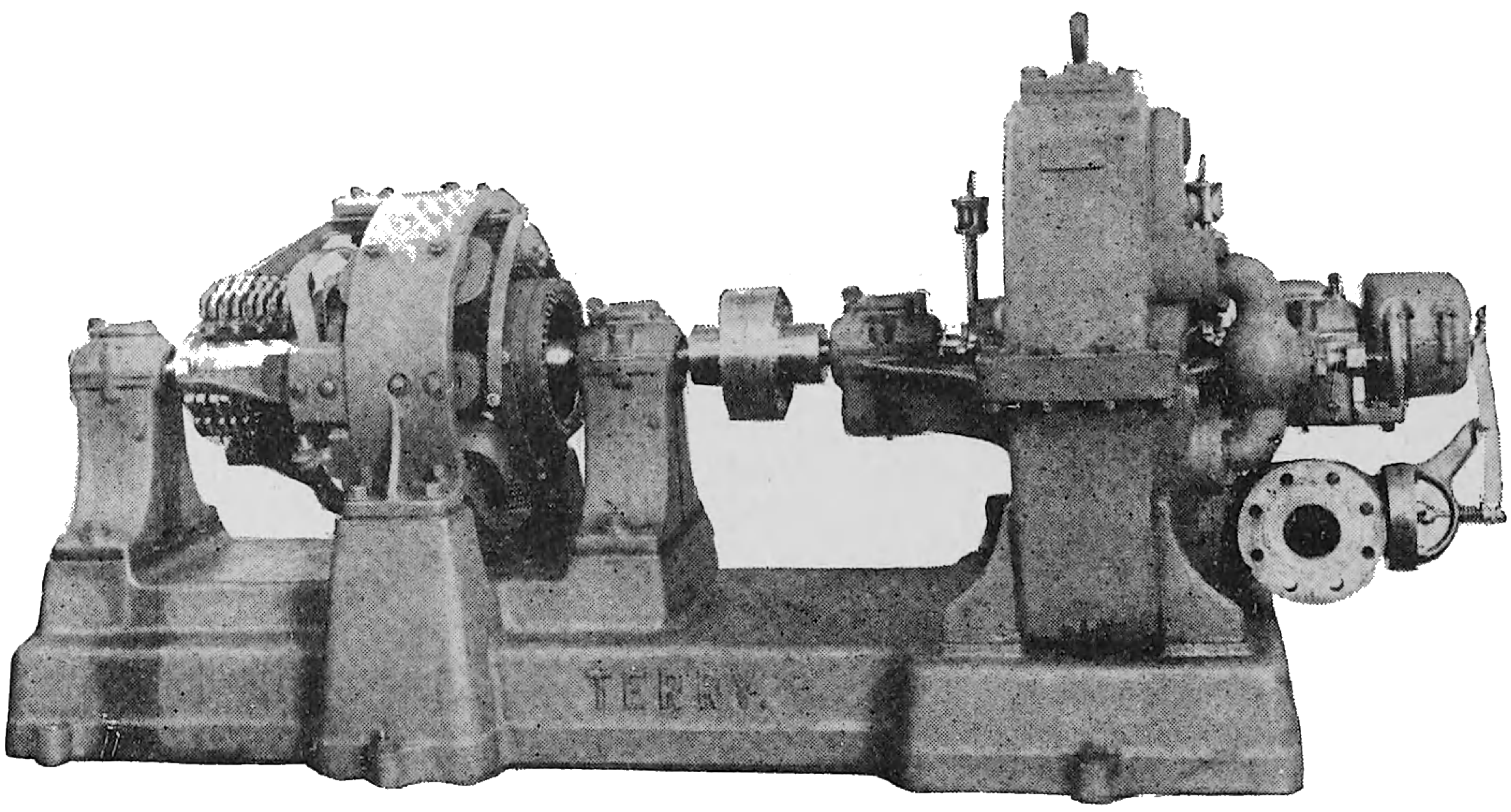



Fig. 11. Terry Steam Turbine Direct-Connected to Generator
*Courtesy of Terry Steam Turbine Company*

possible, and only the smaller units are ever belt-driven, since even the best system of belting is unsatisfactory for transmitting large amounts of power. Direct driving necessitates, in general, a larger, heavier, and, therefore, more expensive generator for the same

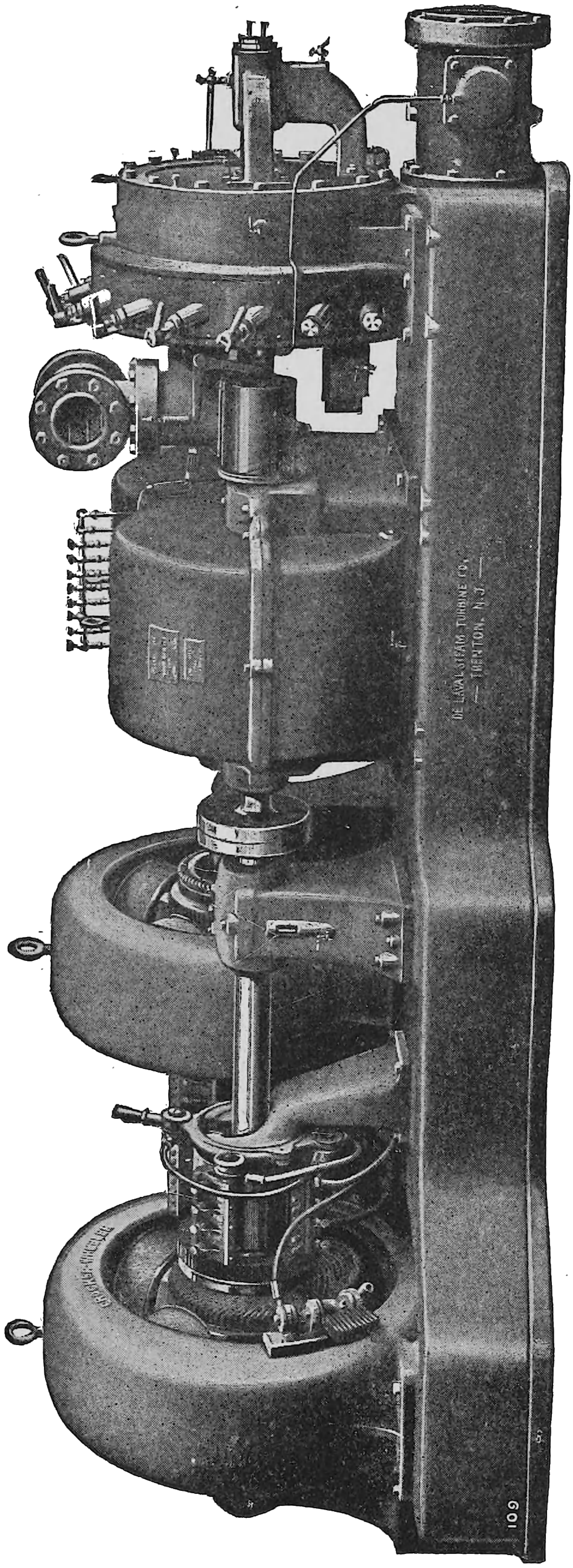



Fig. 12. De Laval Double-Geared Turbine Driving Two D. C. Generators
*Courtesy of De Laval Steam Turbine Company*

capacity; but the compactness, simplicity, positive action, and general advantages of direct driving are so great that in most cases they warrant the increased cost. An important advantage possessed by the direct-connected generator is the small floor space required. In some instances this advantage allows a saving in the cost of the building and in the real estate, and more than counterbalances the increased cost of the generating unit. In belt driving, the distance between the centers of the engine and generator shaft should be at least three times the diameter of the engine pulley to insure satis-

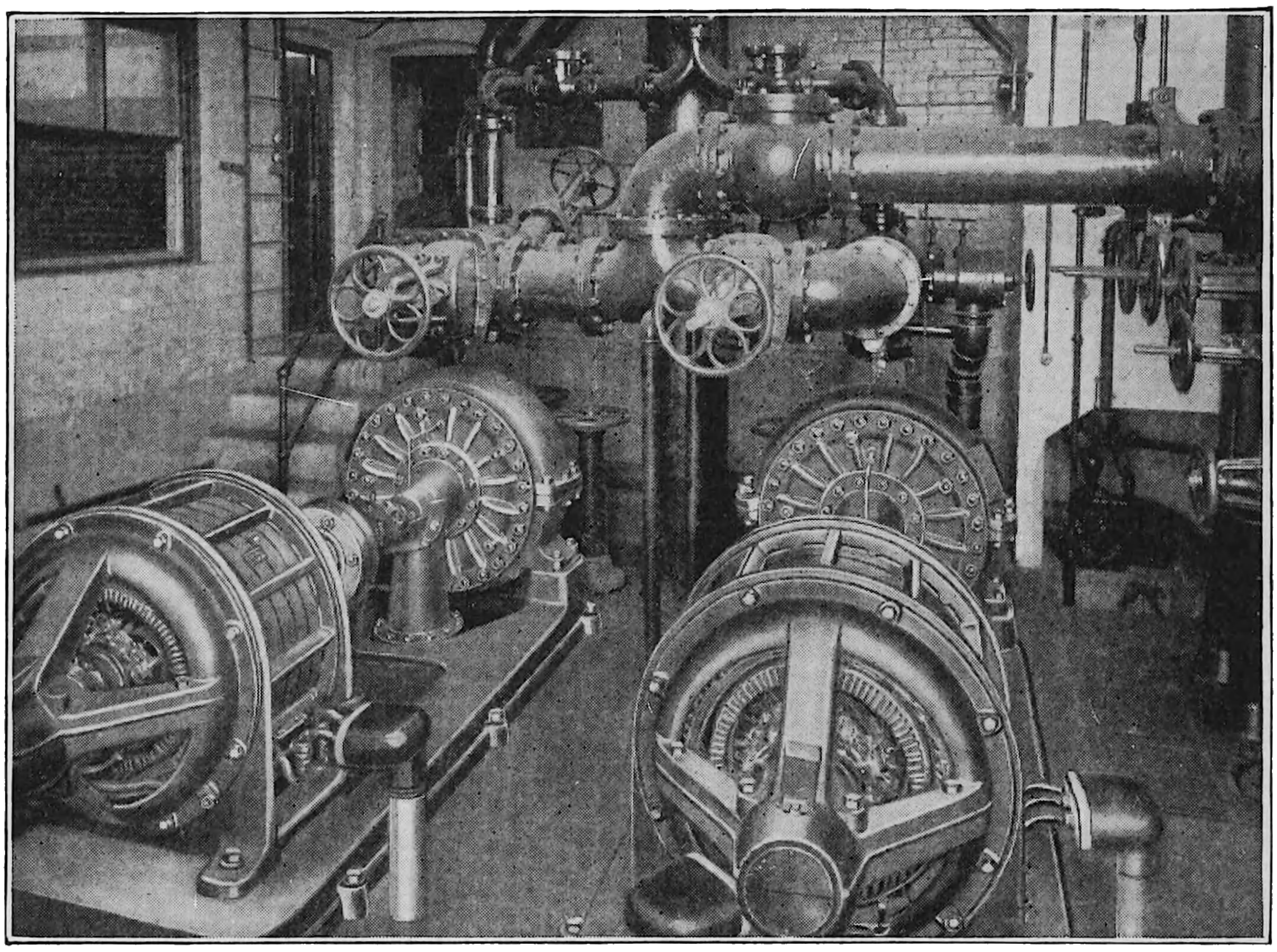


Fig. 13. Two Induction Motors Direct-Connected to Centrifugal Pumps
*Courtesy of General Electric Company*

factory working of the belt. In some cases, however, the belt-driven generator may be preferable, particularly in the smaller sizes, where only the cost of the units is to be considered, or on account of the ease with which the generator can be adjusted to an engine already in use.

## MOTORS

**Similarity to Generators.** The same methods as are employed for driving generators are also used in connecting motors to the work they perform. Direct connection is resorted to wherever feasi-

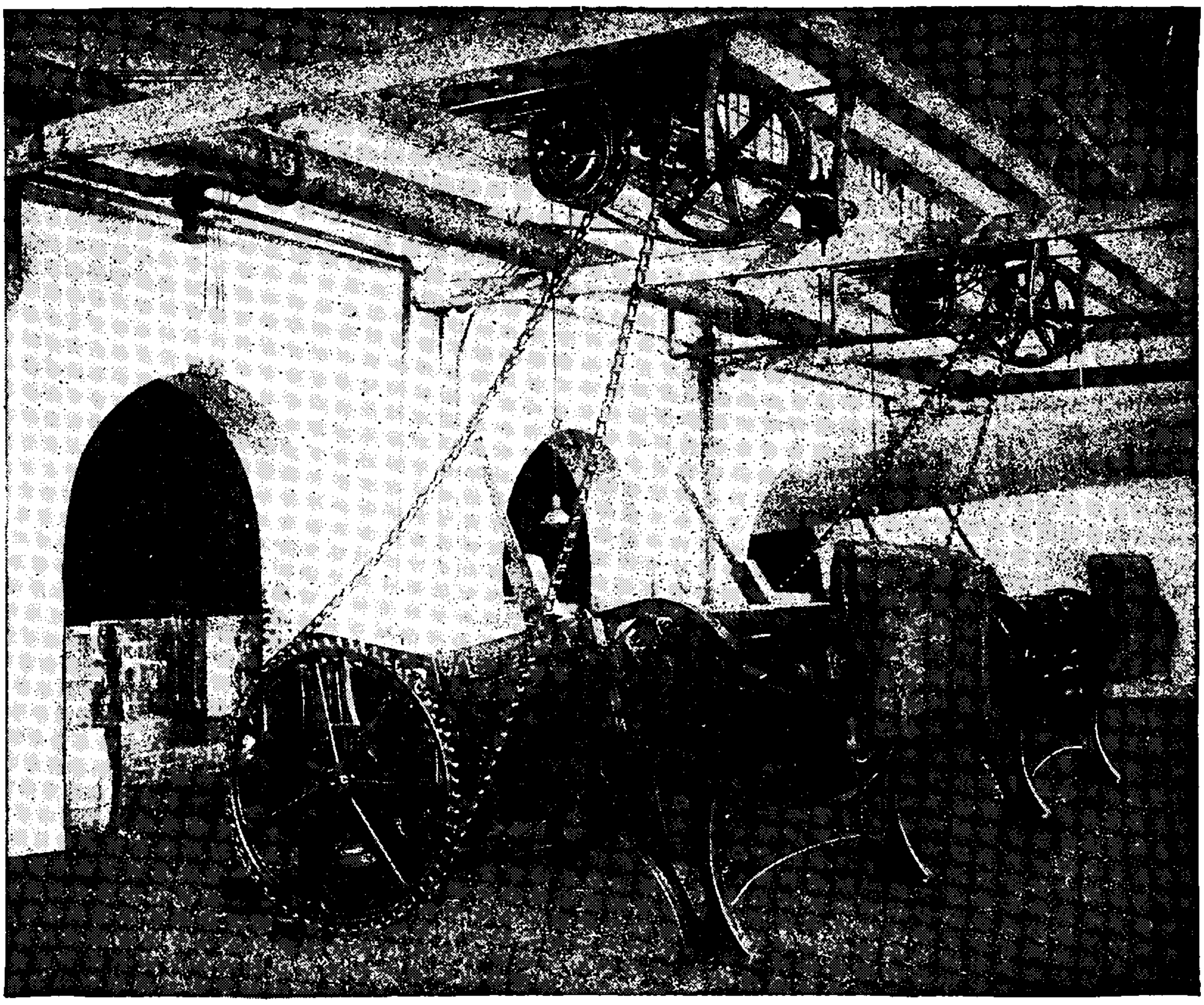


Fig. 15. Motors Driving Jack Shafts Through Silent Chain
*Courtesy of General Electric Company*

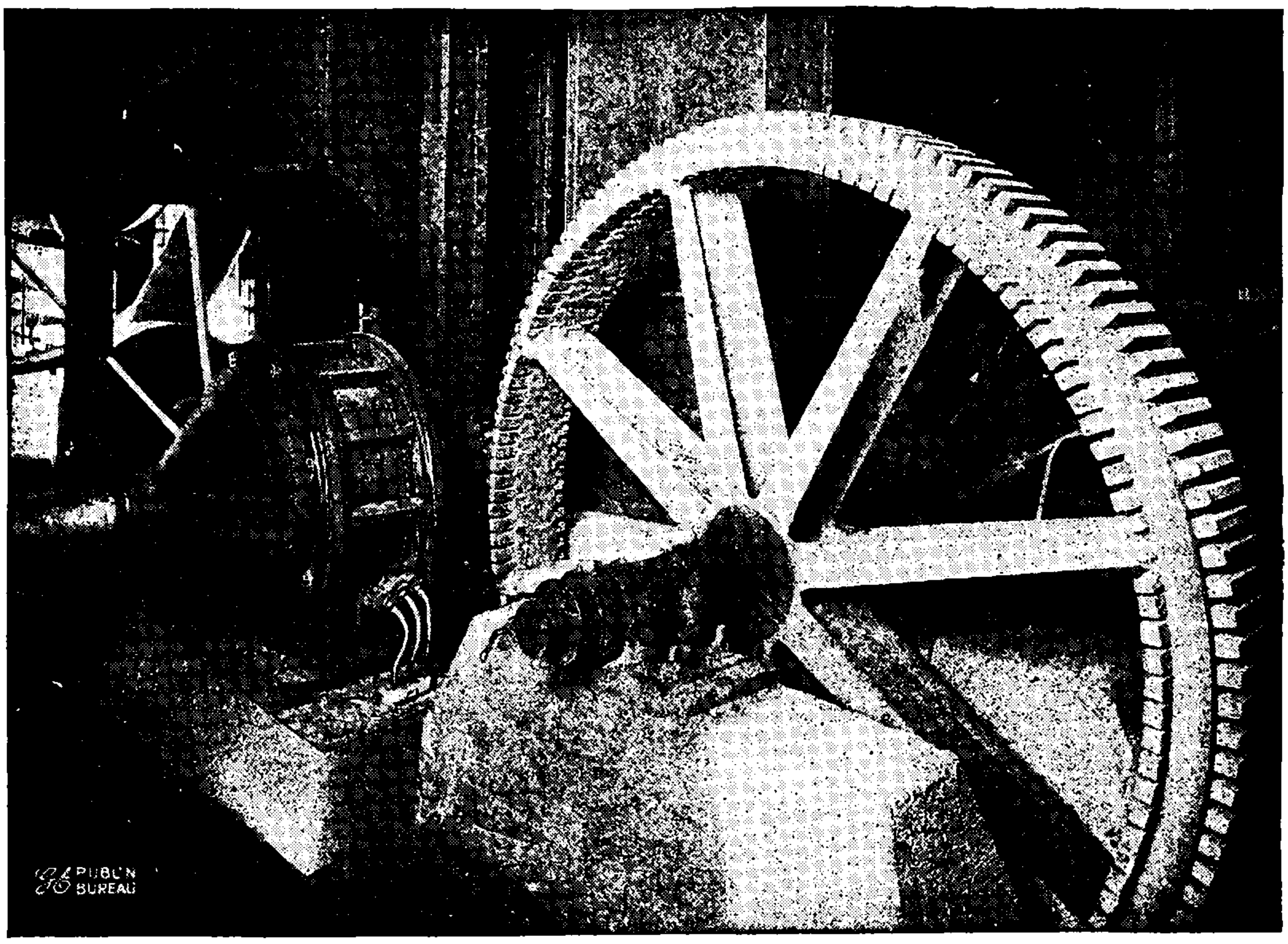


Fig. 16. Induction Motor Geared to Belt Conveyor
*Courtesy of General Electric Company*

# DIRECT-CURRENT TYPES

**General Classification.** The various types of dynamo-electric machinery fall naturally under the two main divisions of alternating-current and direct-current machines. Reserving the consideration of alternating-current machines for a later chapter and confining our attention for the present to the direct-current ones, we find that these latter can be further subdivided into generators, motors, dynamotors, motor generators, and boosters.

In order to present the modern direct-current types in some logical sequence, they will be taken up under these subdivisions, and any special construction, advantage, or feature will be pointed out. The machines described will be selected as illustrating the best standard practice, but it must be remembered that this treatment can not pretend to do more than introduce the reader to the subject.

## GENERATORS

**Capacities.** Direct-current generators are manufactured in standard sizes, varying in capacity from a fraction of a kilowatt to 2700 kilowatts. Sizes above 200 kw. are nearly always direct-driven, although belted generators are found up to 500 kw. Below 200 kw. either method is employed, depending upon the special conditions of the case.

**Speeds.** The speeds at which direct-current generators are driven, vary from 70 or 75 revolutions per minute in the largest sizes of engine type, up to 2000 in the belted and 3000 in the steam-turbine driven types. In general, the greater the kilowatt capacity the lower the speed, although even this general rule does not hold in comparing different lines. Belted generators are very seldom run below 300 to 400 revolutions per minute, while 325 is a rather high speed for a direct-driven generator, if we except the generating sets and marine sets run by vertical engines. These latter, in the very smallest sizes, reach a speed of 850 revolutions per minute.

**Number of Poles.** Modern direct-current generators are always multipolar as soon as their capacity is above 5 or even 3 kilowatts, the number of poles increasing with the size of the generator. Belted generators usually have 4, 6, or 8, and occasionally 10 poles. Direct-driven generators, since the speed is fixed by the prime mover, are designed to meet these conditions. Such machines seldom have less than 6 poles and in the larger sizes and slower speeds very often have from 24 to 36.

## CLASSIFICATION

Direct-current generators, according to their electrical design, may be divided into two main classes: those giving constant current, feeding series circuits; and those maintaining constant voltage, feeding parallel circuits.

**Constant Current Types.** Constant current generators are still found supplying current to series street arc-lighting circuits, and in the types used at present deliver approximately from 5 to 10 amperes, their voltage being variable, depending upon that needed by the circuit they are supplying. The manufacture of these series generators has been practically discontinued. New installations for street lighting employ alternating current or else direct current obtained by means of mercury arc rectifiers. The series machines still in use are of the Brush, Thomson-Houston, and Wood types. Of these, the Brush and the Thomson-Houston have open coil armatures, and the Wood has a closed coil armature. As these machines are rapidly becoming obsolete, no further description will be given of them.

**Constant Voltage Types.** Constant voltage generators may be further subdivided into those giving 5 to 12 volts, those giving about 125 volts, those giving about 250 volts, those giving 500 to 750 volts, and those giving 1200 volts. Generators designed to give from 5 to 12 volts are employed for electroplating and electrochemical purposes. Where a sufficient number of vats can be connected in series, however, regular standard 125-volt machines are preferably employed. Generators giving 125 volts are used for indoor arc and incandescent lighting, for the running of smaller motors, and in connection with the three-wire system. Machines giving 250 volts are used principally for power purposes, and, with auxiliary devices or parts, can supply a three-wire system. Machines giving 500 to 750 volts are employed as generators for power and railway circuits, while 1200-volt generators are the most recent development in higher voltage direct-current railway installations. All railway generators, although denoted as constant voltage, are generally designed so that, by means of their compound winding, they over-

lighting and power service that are built for standard full load pressures of 120, 240, and 525 volts. They are compound-wound, giving variation in voltage from no load to full load; the no-load voltages being 115, 230, and 500, respectively. By proper increase in speed, these machines also operate satisfactorily at 125, 240, and 550 volts, full load. They are made in a great variety of capacities and speeds, ranging from 10 to 1200 kw., and run at speeds from 90 to 470 revolutions per minute.

Fig. 17 shows a 200-kw. 240-volt 125-r. p. m. machine of this

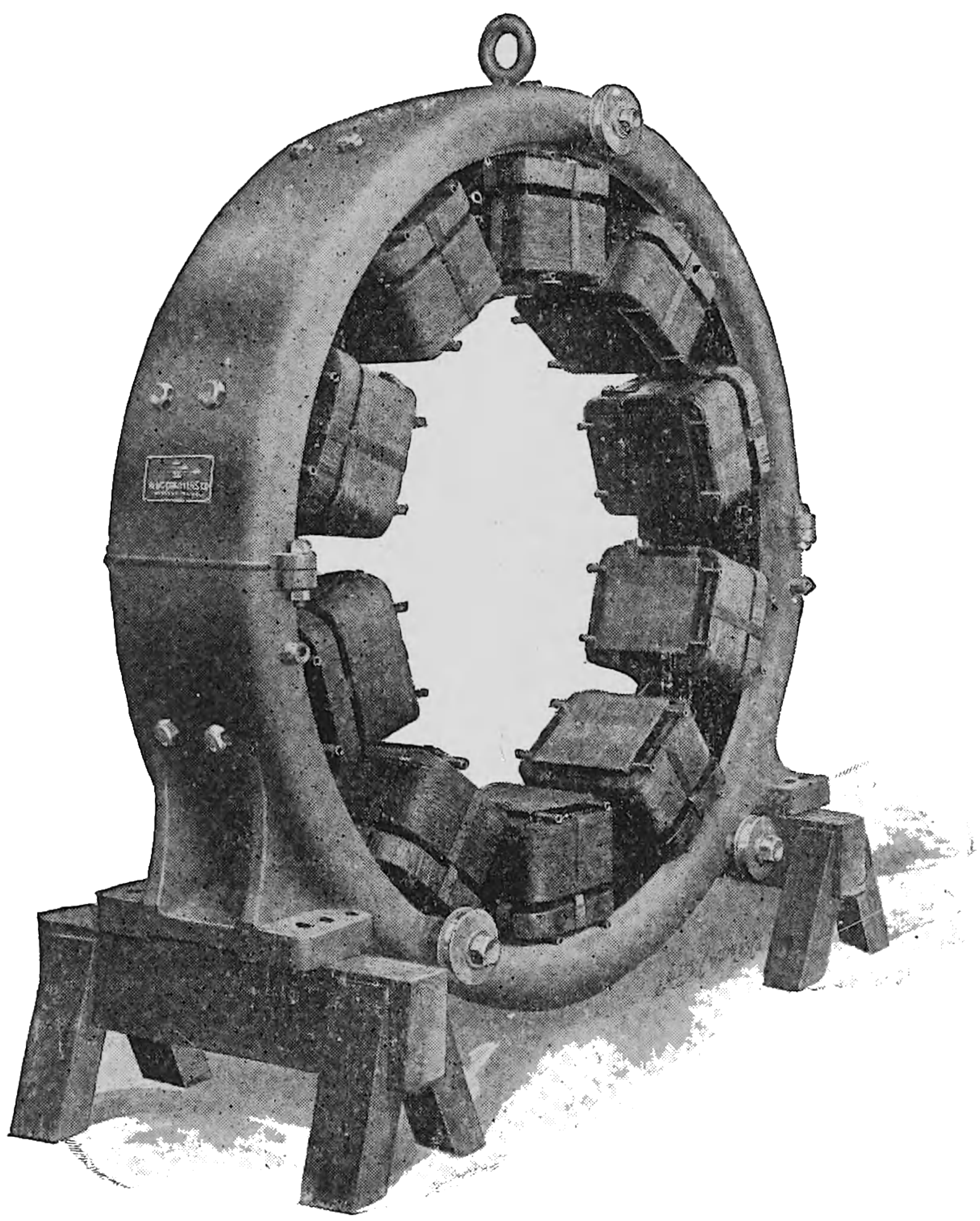


Fig. 18. Assembled Type I Field Yoke, Poles, and Coils
*Courtesy of Allis-Chalmers Manufacturing Company*

type. The cast-iron field frame is of circular form; the two parts of the yoke, divided horizontally, are bolted together, as shown. In the larger sizes the upper and lower halves are bolted together by cap screws having their heads set in pockets in the lower half of the yoke. The field poles are made of steel punchings riveted together, except in some of the larger frames where forced steel is used for round poles. The poles are bolted to the inside surface of the yoke. This method of construction enables accurate spacing to be obtained and, by removal of one or more poles, field coils can be changed, or minor armature repairs made, without dismantling the whole machine. The pole faces are carefully designed to give a well-graded flux distribution necessary for good commutation.

Fig. 18 is a view of assembled field yoke, poles, and coils. The field coils are ventilated by being built up in sections with air spaces between the pole and the coil and also between sections of the same coil. The coil is insulated from the pole by spacers and firmly held in place by fiber insulated pins driven into the pole sides. By the fan action of the armature air is forced through these spaces, rapidly dissipating the heat generated in the coils. This method of construction is shown by Fig. 19.

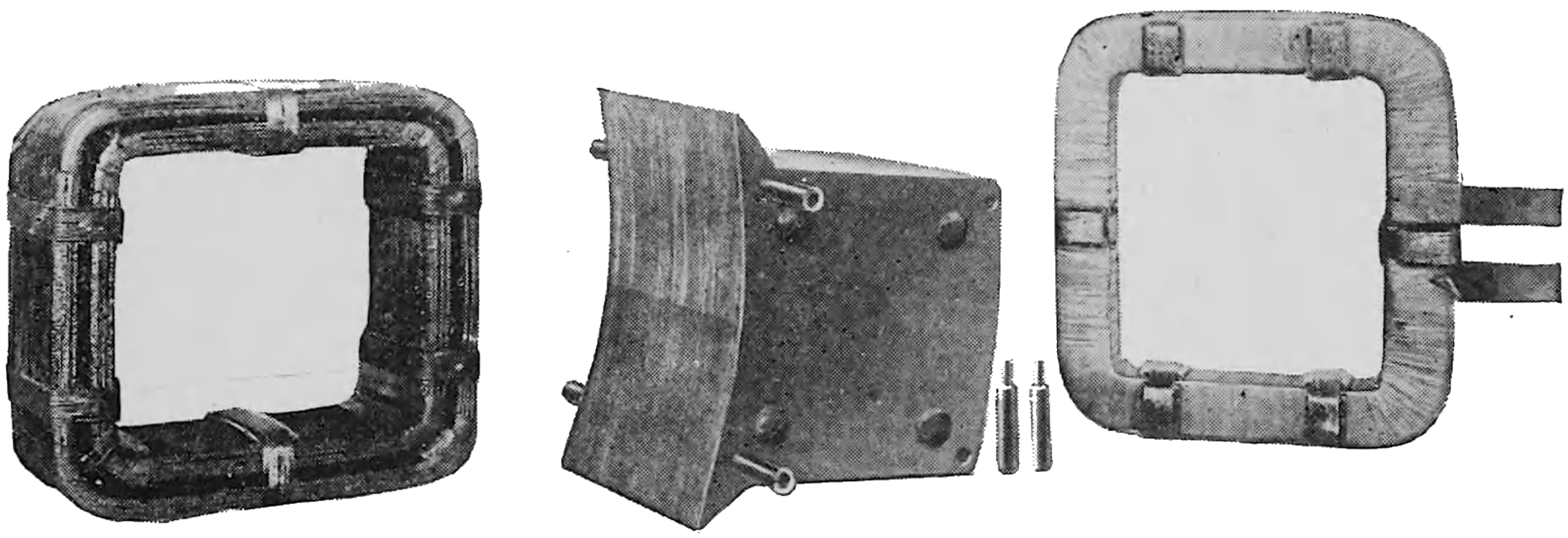


Fig. 19. Details of Type I Poles and Coils
*Courtesy of Allis-Chalmers Manufacturing Company*

The coils are impregnated at a high temperature with a compound rendering them moistureproof and oilproof. The armature is built up of high grade steel laminations, well japanned, containing ample radial ventilating ducts and mounted upon a spider of ample mechanical strength, so constructed as to assist in a free circulation of air about the machine. The armature coils are form-wound with ample clearance between the end connections to permit free air circulation. This feature of coil clearance is evident from Fig. 20. The armature coils are insulated with the highest grade of insulating material, then dipped and baked at a high temperature, and finally placed in a steam heated screw press and pressed into shape to fit the armature slot. This renders a coil practically unaffected by oil cr moisture. The coils are held in position in the armature slots by hardwood wedges fitted into grooves at the top of the slots. No band wires are used under the poles, but a steel wire band at each end of the armature serves to keep the ends of the coils in place. This type of armature, with conductors placed in deep slots, and not wound on the armature surface, is known as an *ironclad armature,* and is the standard form adopted by all manufacturers today.

This line of machines conforms to the standard practice of cross-connecting all multiple-wound armatures at points of equal potential to compensate for any inequality of the magnetic circuit. (See "General Electric Company", Fig. 48, showing equalizer rings.) The commutator is constructed of hard drawn copper bars separated

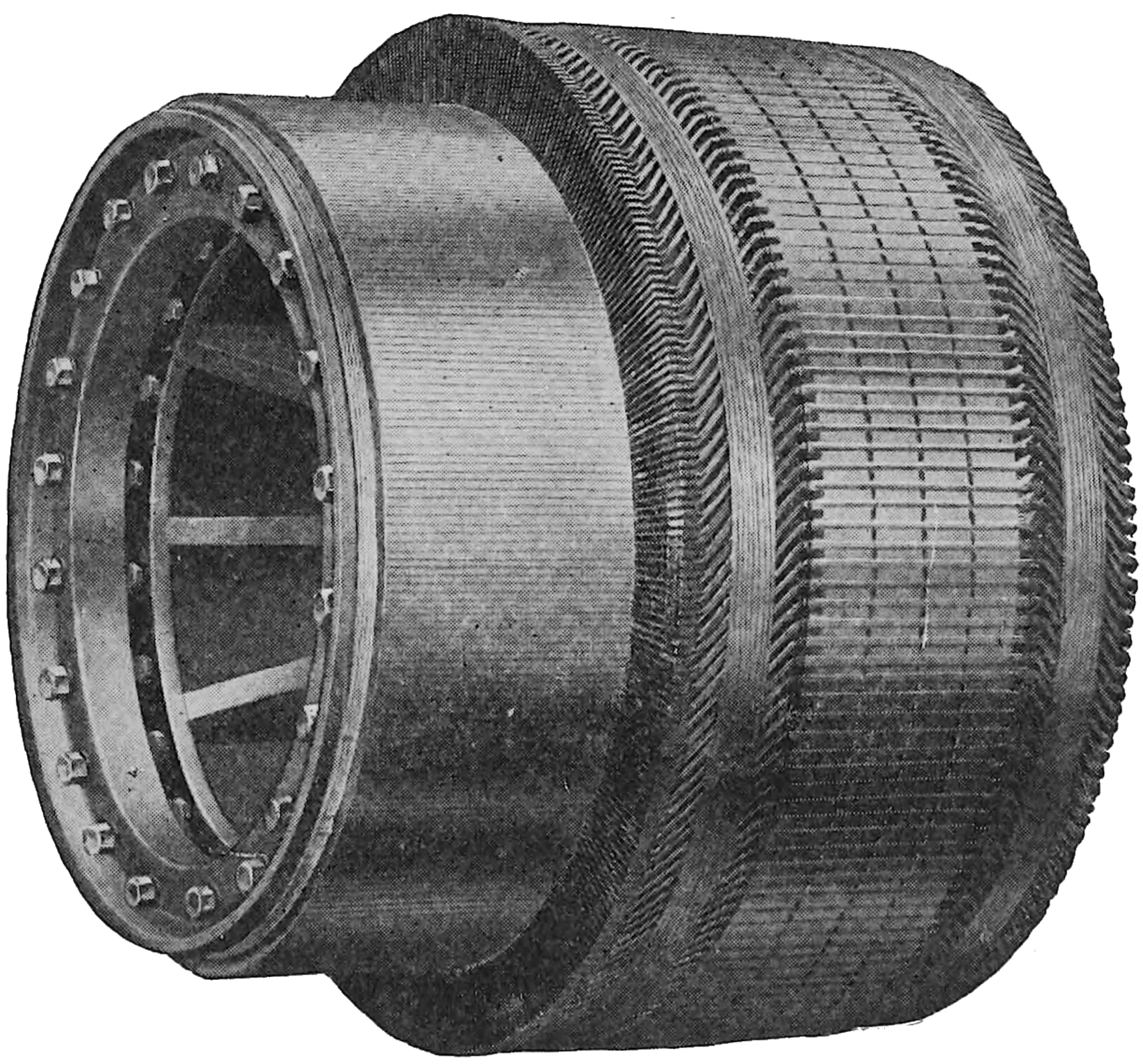
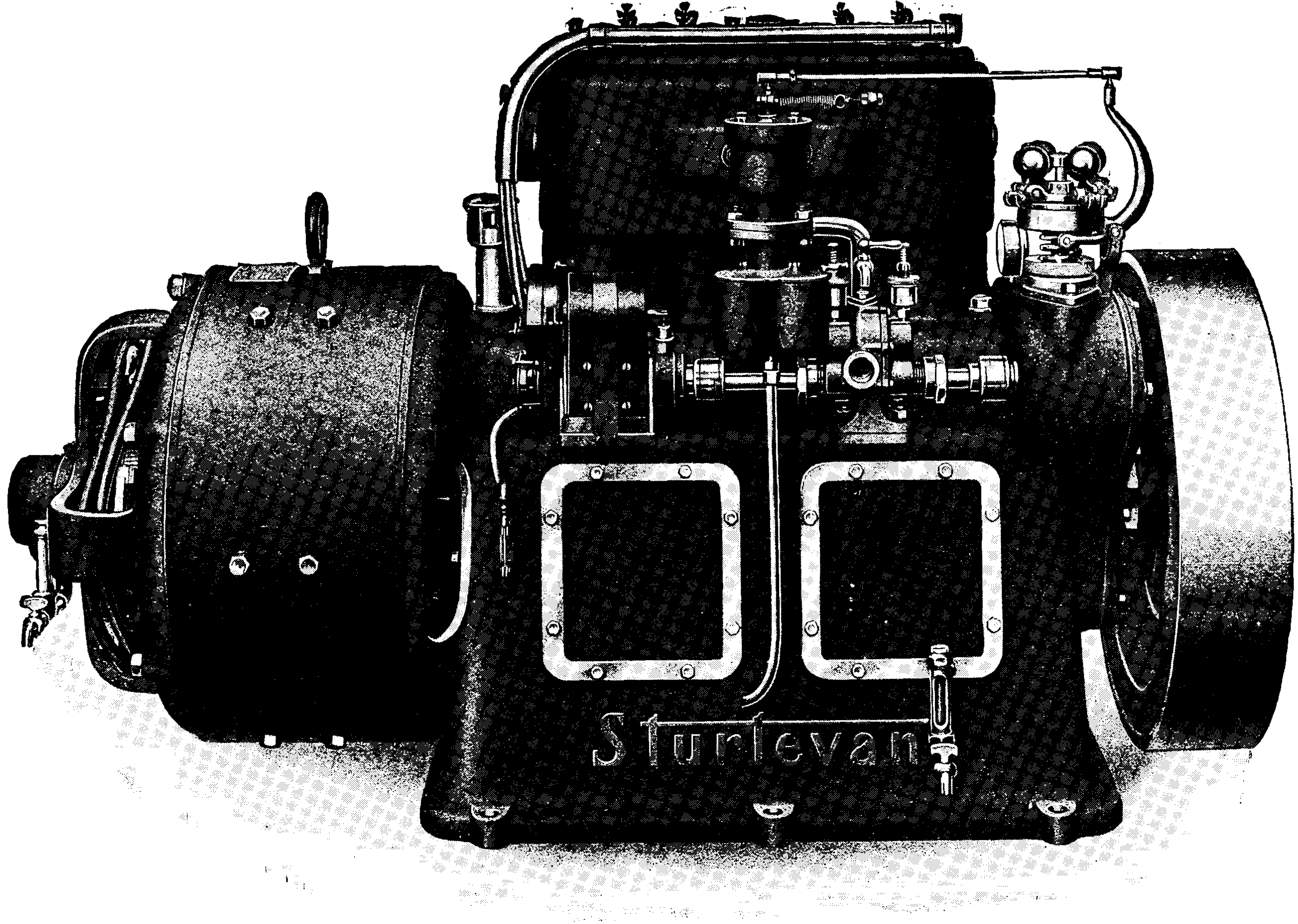


Fig. 20. Armature and Commutator of Allis-Chalmers Generator

by high grade mica of such hardness as to wear uniformly with the bars. The brush yoke, as seen from Figs. 17 and 18, is supported on the frame by three small rollers and is designed to secure a rigid structure and to leave the brushes and commutator easily accessible. The position of the brushes is adjusted by turning the handwheel.

*Standard Three-Wire Type.* The Allis-Chalmers Company builds a line of standard three-wire generators for output from 35 kw. to 250 kw., using their engine type frames for this purpose. These machines are wound for 240 volts between line wires and 120 volts between each line wire and the neutral. (See "Crocker-Wheeler




FIVE-KILOWATT GASOLINE ELECTRIC GENERATING SET
*Courtesy of B. F. Sturtevant Company*

Company" and "Westinghouse Electric and Manufacturing Company".)

*Belted Types.* The belted generators put upon the market by the Allis-Chalmers Company are intended to fulfill every requirement except those for the smallest capacities. The materials, methods, and processes employed are the same as for the engine type. The large sizes have a third or outboard bearing, this being accomplished like the construction shown in Fig. 45. For the

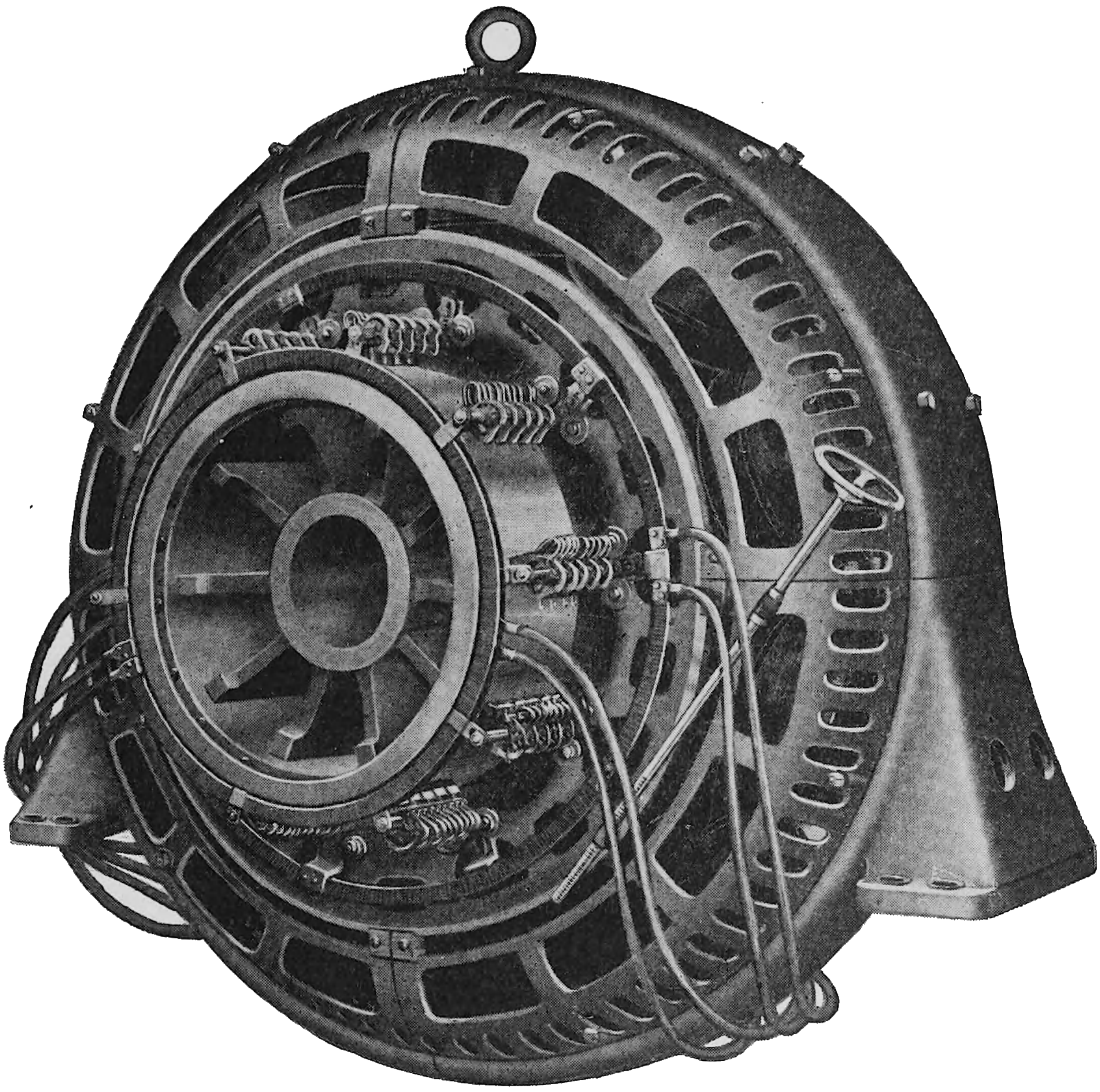


**Fig. 21.** C & C Type G Direct-Connected Generator
*Courtesy of C & C Electric & Manufacturing Company*

smaller belted sizes this company uses its type K machines. These latter have the same frames as the company's motors of this line, becoming compound generators by merely changing the shunt field winding and adding a series winding. These frames will be described in detail later, therefore, under "Motors".

**C & C Electric & Manufacturing Company.** *Direct-Connected.* The direct-connected type G machines of this company furnish a line of generators overcompounded 5 per cent and are wound for voltages of 125, 250, or 500. They are built in sizes from 25 to 500 kw. in both two- and three-wire types. A 250-volt 300-kw. machine is shown in Fig. 21. The magnet frame is circular and, together with the poles, is of soft cast steel of high permeability. It is divided horizontally. The poles are round, to give minimum field copper,

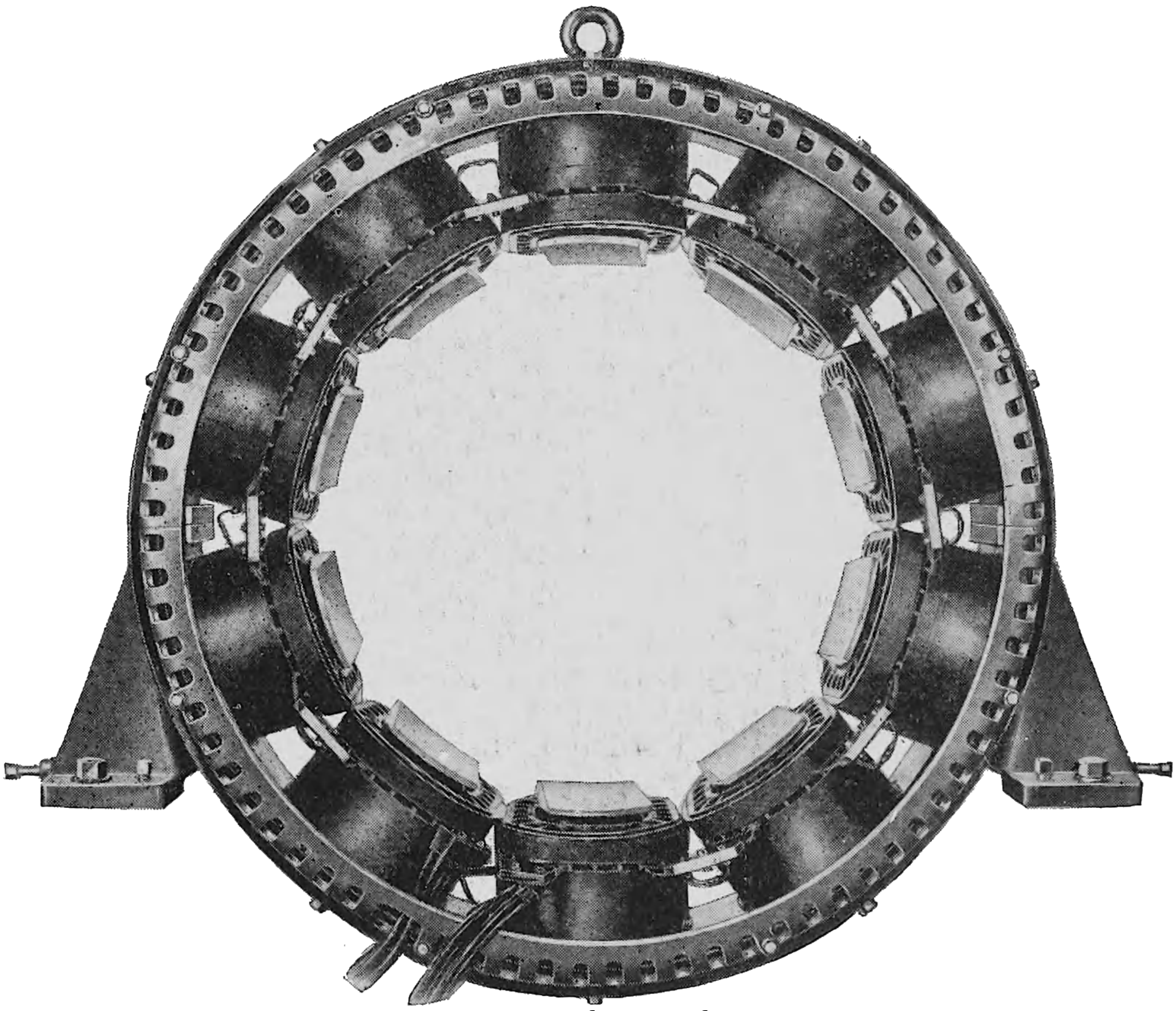


Fig. 22. 10-Pole Field Ring Showing Shunt and Series Coils
*Courtesy of C & C Electric & Manufacturing Company*

and are bolted to the yoke, thus being readily removed. They are specially slotted so as to divide them into sections, thereby having an air space through their center and parallel to the shaft. This increases the flux in the pole tips and materially decreases the armature reaction. The field coils are wound upon non-combustible insulated bobbins, the series and shunt coils being wound separately and carefully insulated. The series coils consist of a continuous laminated copper conductor joined only between the field spools by heavy screws. These details are illustrated in Fig. 22.

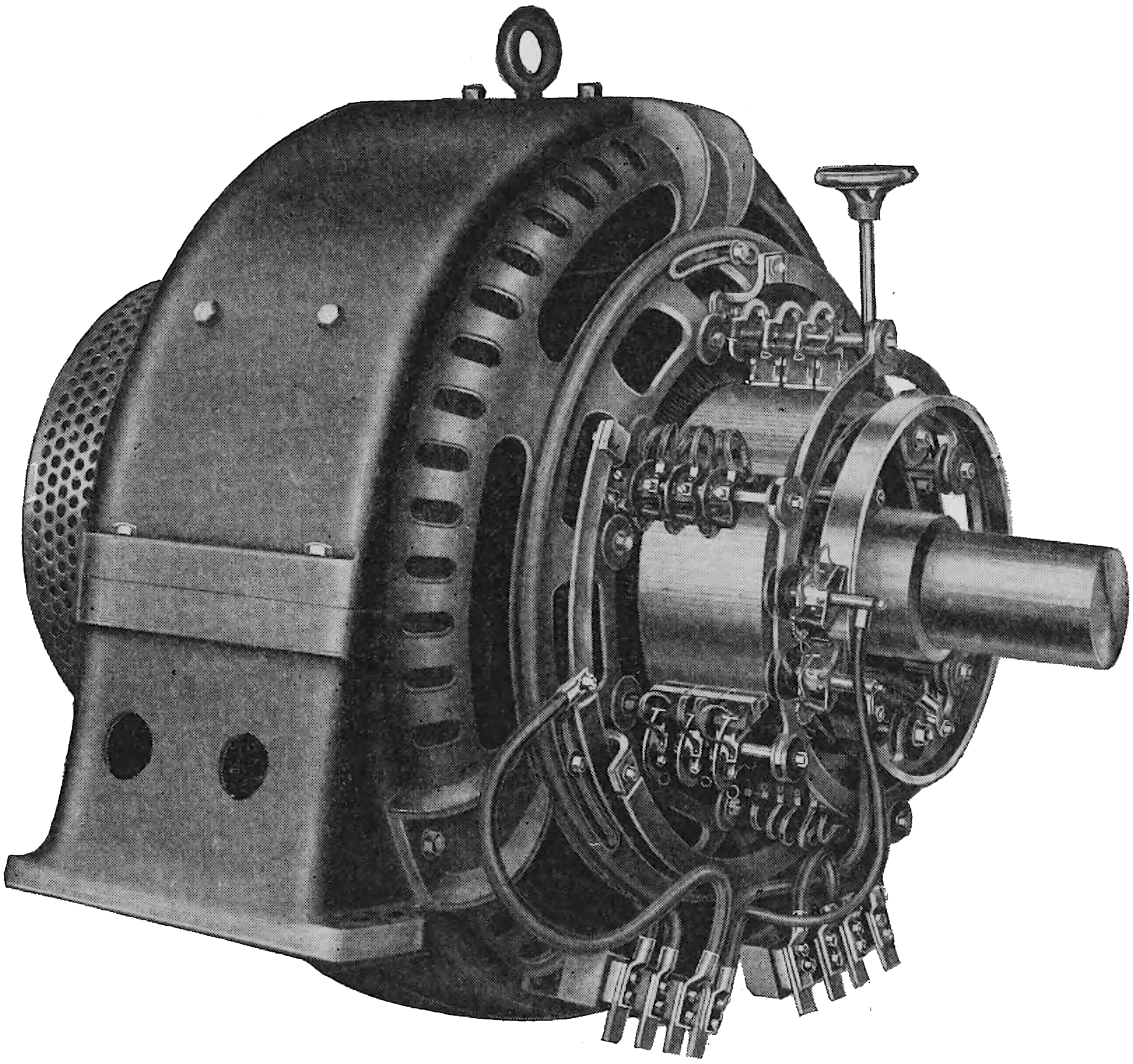


Fig. 25. C & C Type G Three-Wire Generator
*Courtesy of C & C Electric & Manufacturing Company*

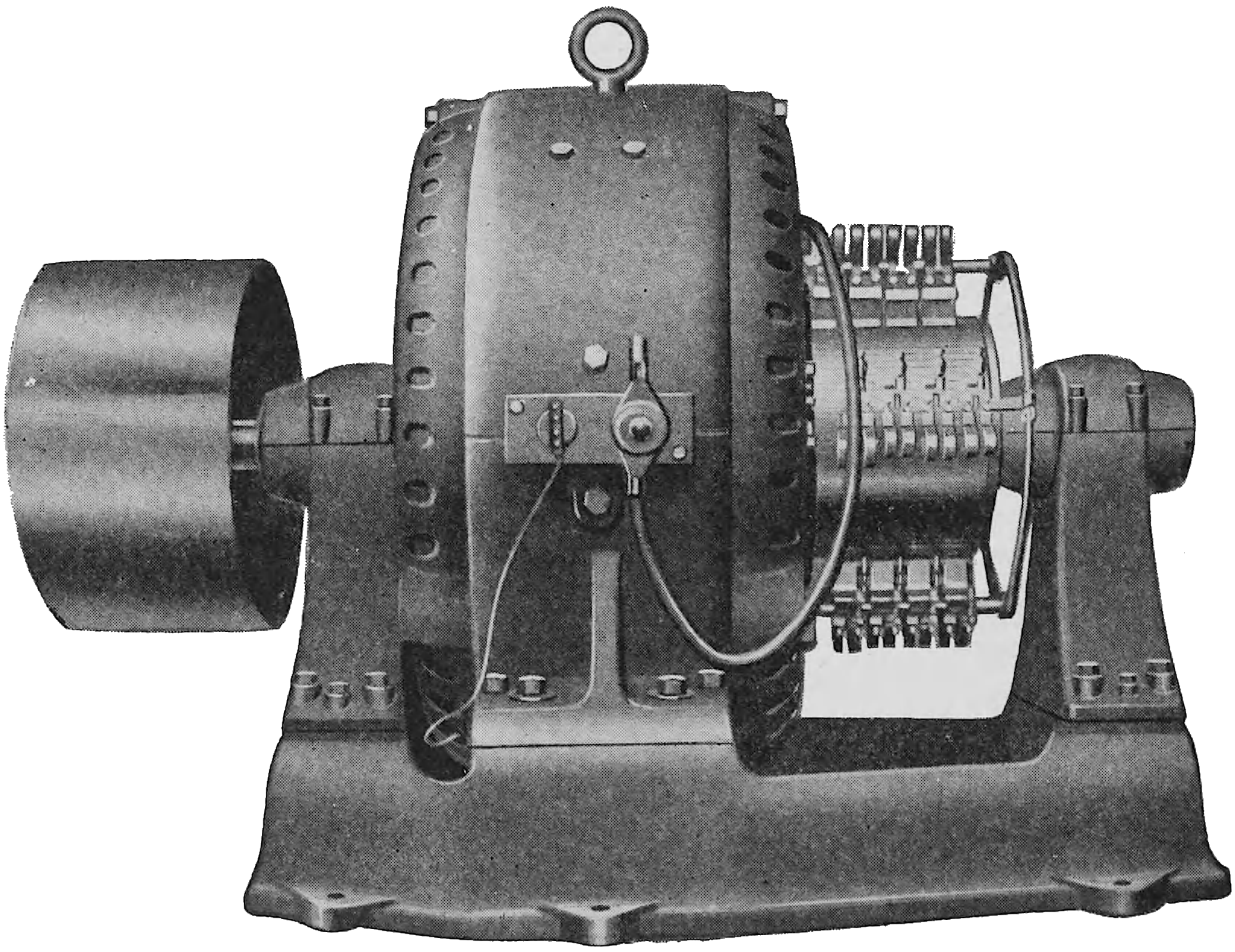


Fig. 26. C & C Type M P L Belted Generator
*Courtesy C & C Electric & Manufacturing Company*

grids with adjusting screws is employed for adjusting the compounding to any desired degree. Such a shunt is illustrated in Fig. 24.

*Three-Wire Types.* In C & C three-wire generators, well-ventilated auxiliary or balancing coils are attached to the armature spider on the side away from the commutator of a standard two-wire engine type generator. The ends of these coils are tapped into the armature winding, and the neutral point is taken from a single collector ring mounted on the commutator ring from which it is insulated. A ring at the end of the brush holder studs supports two additional studs for the brush making contact with the collector ring. Such a machine is shown in Fig. 25.

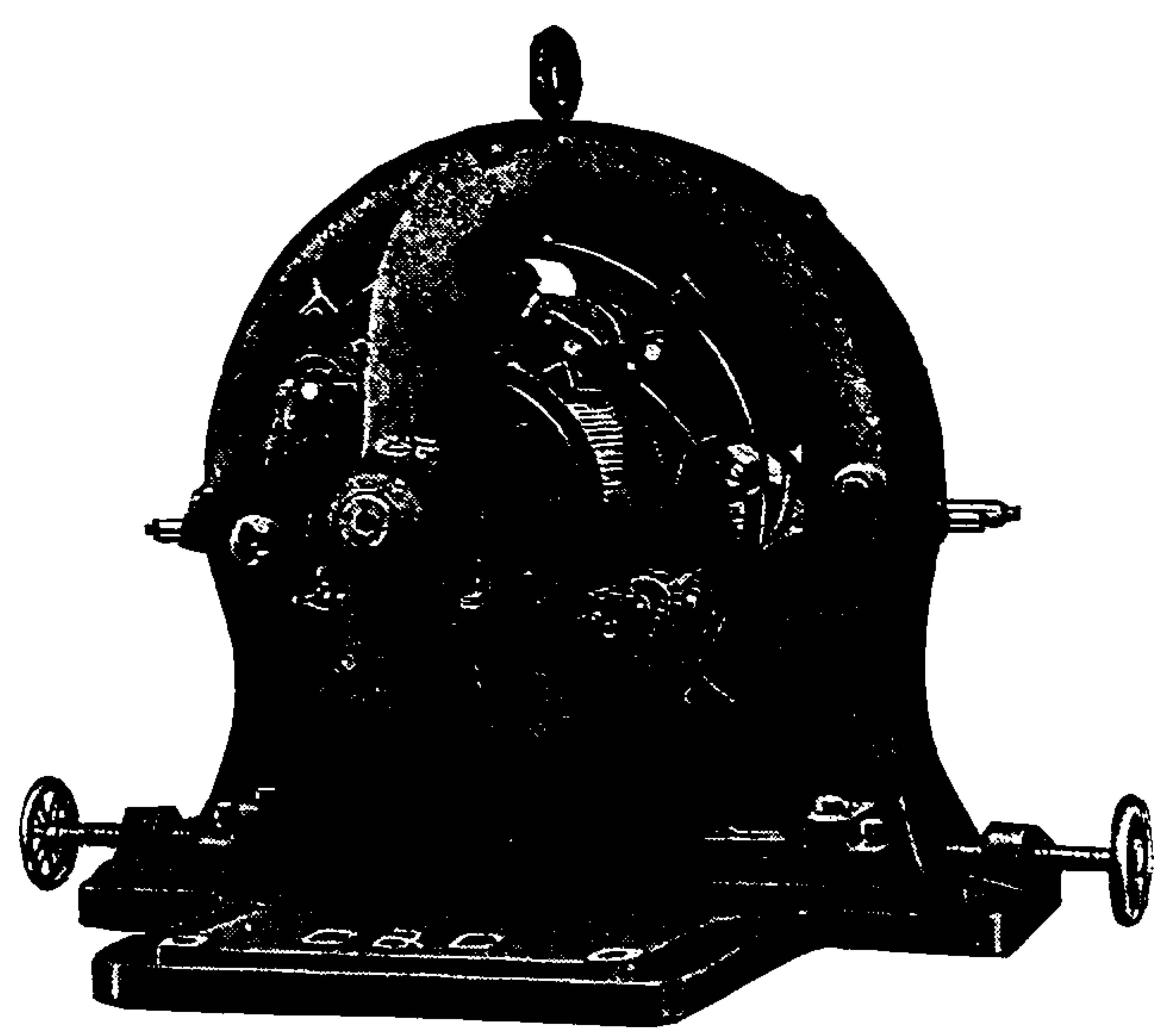


Fig. 27. C & C Type SL Belted Generator

*Belted Types.* A line of belted machines designated MPL is illustrated in Fig. 26. They embody the same features as the engine type and the same methods of manufacture are employed in their construction. In the larger sizes they are three-bearing.

Another line of belt-driven machines is illustrated in Fig. 27 These machines, designated type SL, are all of the 4-pole type. The magnet frame or yoke, the four poles, and the supporting feet are cast of the best soft steel in one piece. The protecting rings, which protect the field coils and support the brush rigging, are cast integrally with the bearing brackets. This piece is of cast iron and is attached to the magnet frame by dowel pins and cap screws. The field coils are carefully wound on easily removable sheet iron bobbins. All C & C machines employ special brush holders of the reaction type, carrying carbon brushes inclined at a slight angle from the radial line, and also use bearings of the self-oiling self-aligning type in which brass rings in the oil wells carry oil to the shaft. The generating sets put upon the market by this company are generators selected from the preceding lines, directly coupled to vertical high speed engines of various other manufacturers, an example of which is shown in Fig. 28.

**Crocker-Wheeler Company.** *Engine Types.* The line of engine type generators built by this company is in sizes from 200 to 1500 kw. rated at 125 or 250 volts, running at various speeds from 200 to 80 r. p. m., and having from 10 to 16 poles. For direct connection they also build a second line of 6- and 8-pole machines in sizes from 25 to 250 kw., whose speeds range from 325 to 150. One of the larger sizes is shown in Fig. 29. In these generators the magnet frame is of cast iron proportioned to insure ample stiffness in the

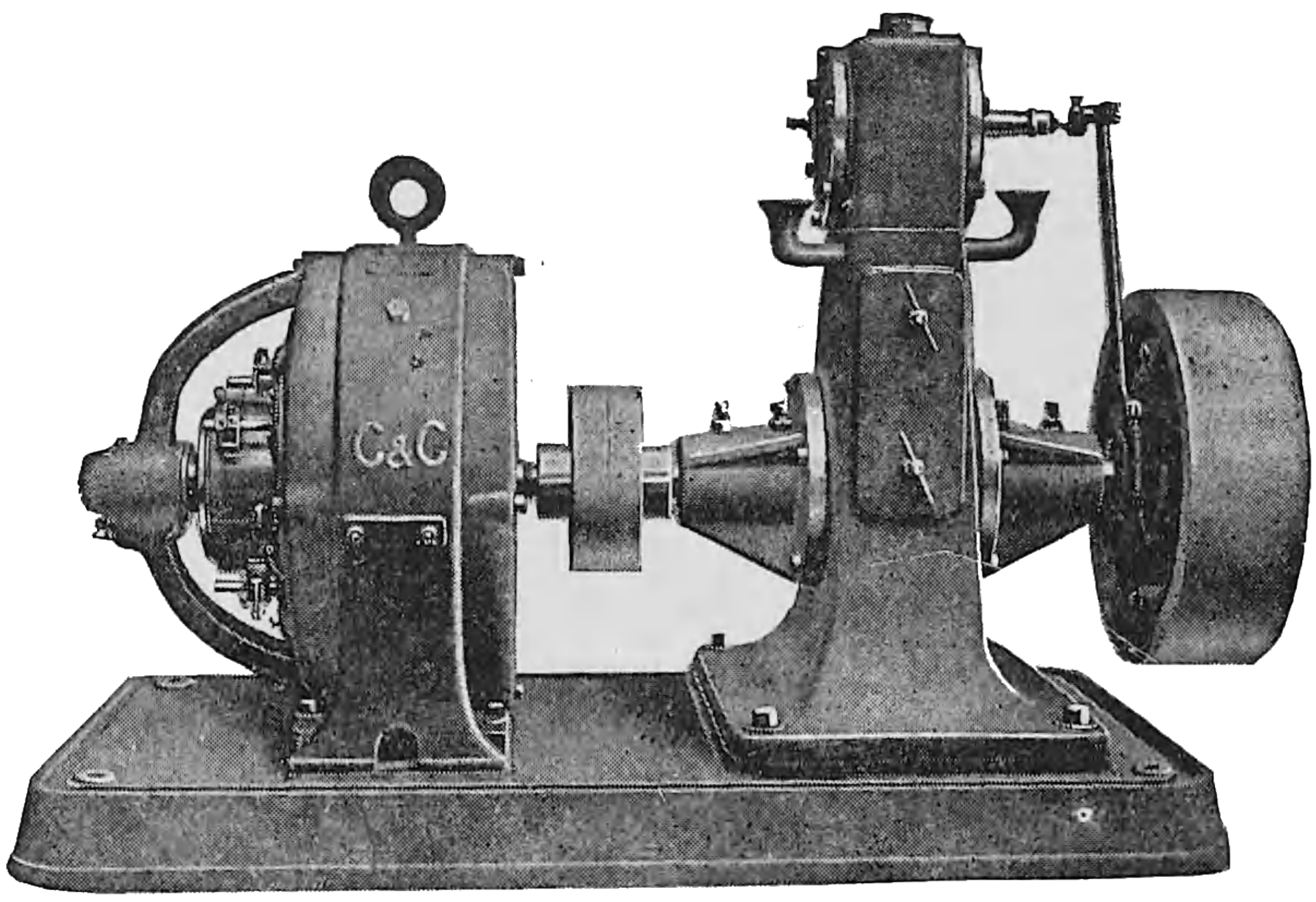



Fig. 28. C & C Type S L Generator Direct-Connected to High Speed Engine

smaller line, while in the larger it is stiffened by internally projecting flanges. The frame is split horizontally, the two halves being accurately aligned by dowel pins and bolted together. The lower half of the frame is provided with feet bolted down to the supporting base and supplied with leveling screws for accurately adjusting the position of the magnet frame. The poles are of steel securely bolted to the frame or, in the smaller line, cast welded into the frame. This is accomplished by constructing the poles first and placing them in position in the mould in which the magnet frame is to be cast. In casting the magnet frame, the molten metal flows around the ends of the poles so that, on cooling, one solid mass results. If the cast welded joint is perfectly made, it results in a better magnetic

tation. (See "Electro-Dynamic Company", page 68.) The air gap or clearance between the armature and the pole face is relatively large. This is a good feature, as it tends to reduce the bad effects occasioned when the armature is slightly out of center. The field coils on each pole are divided into sections separated from each other and from the pole core by spacers so as to provide increased ventila-

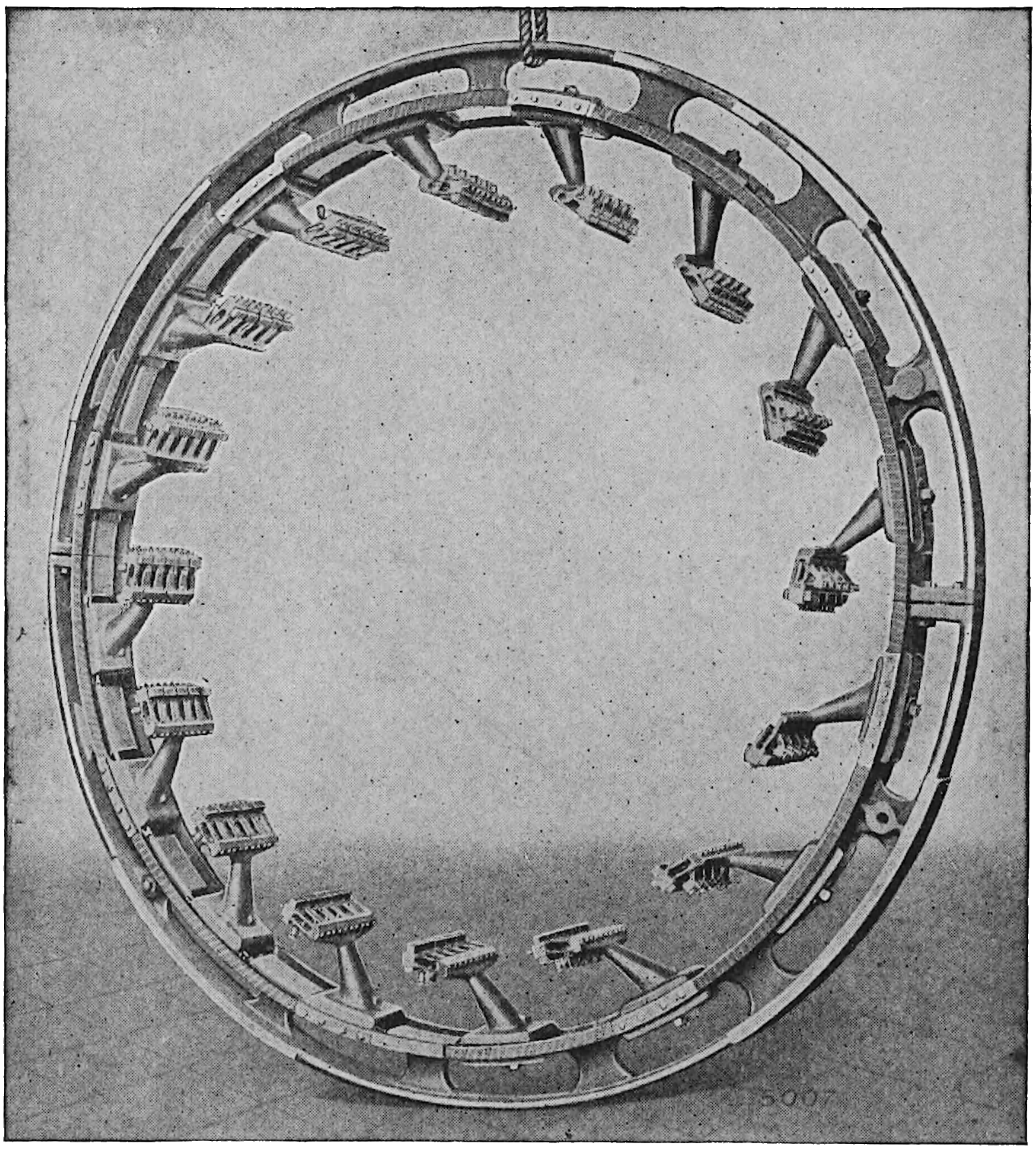


Fig. 30. Brush Rigging for 600-K. W. Generator
*Courtesy of Crocker-Wheeler Company*

tion. The windings of the series coils and also the commutating pole windings are of strip copper wound on edge. The connections of these windings between the various coils are made by interleaving the multiple strips, thus securing the best mechanical and electrical contact. The armature spider, consisting of a hub with projecting arms, supports the toothed laminations of the armature core. The armature conductors consist of flat or round copper wire without joints of any kind. They are thoroughly insulated and are retained in the slots by wedges or band wires. The commutator spider is mounted on an extension of the armature spider, thus being independent of the shaft.

The cast-iron rocker ring carrying the brush rigging is rigidly supported from the magnet frame and has means for shifting simultaneously the position of all the brushes. All the positive sets of brushes are connected to a copper brush ring mounted on one side

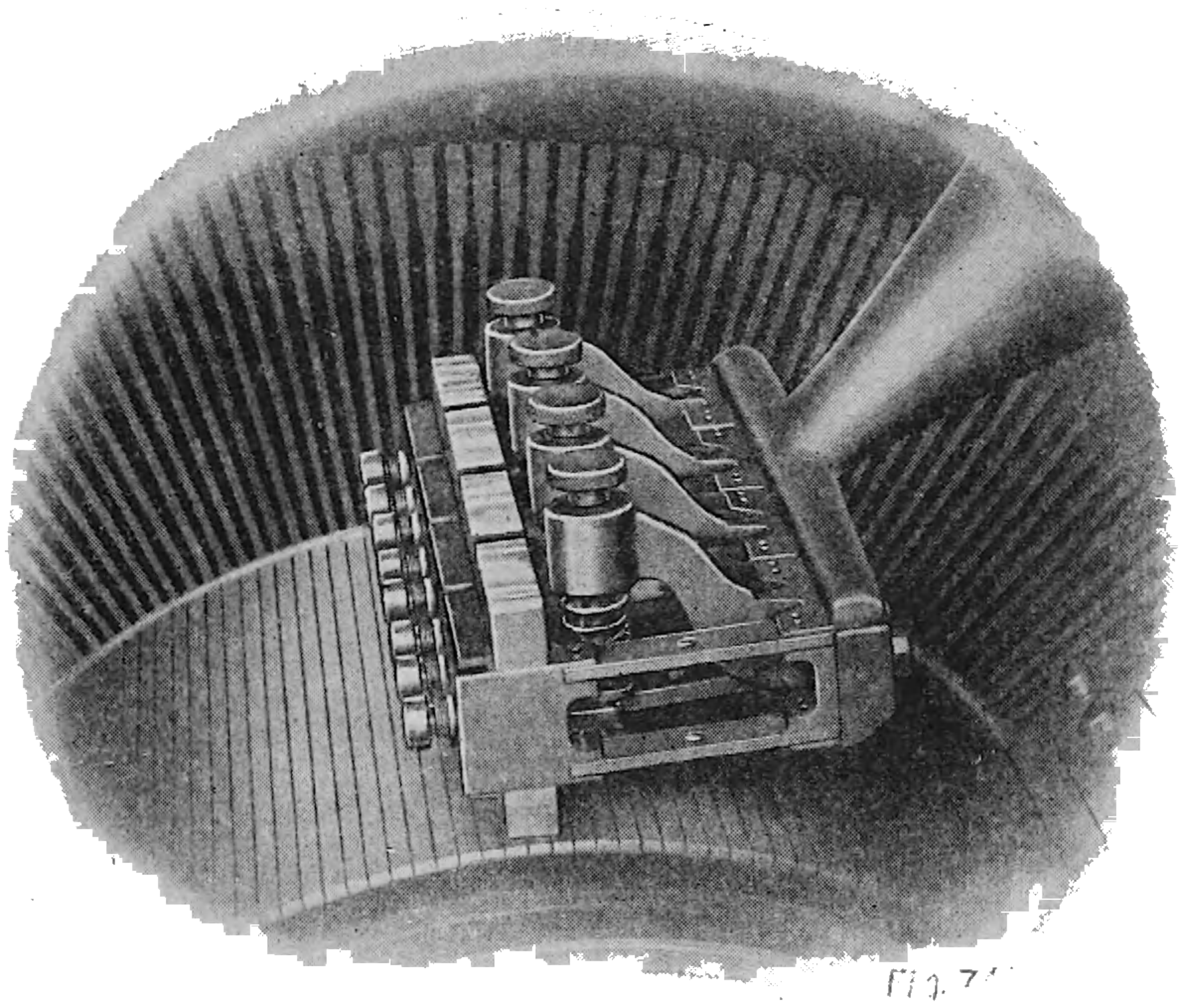


Fig. 31. Crocker-Wheeler Parallel Movement Brush Holder

of the rocker ring, and all the negative brushes to another ring similarly mounted on the other side of the rocker ring. A positive low resistance connection is provided between each brush and its brush holder bracket. The brushes are held by parallel movement holders that are individually adjustable and will not allow the position of the brush to change as it wears away. These features are shown in Figs. 30 and 31. The Crocker-Wheeler Company also manufactures a line of 550-volt engine type railway generators embodying the preceding features, in sizes from 150 to 1500 kw., with 8 to 16 poles, and running at 275 to 80 r. p. m.

*Belted Types.* Crocker-Wheeler belted generators are built in two separate lines, their form H and their form I machines. Form H generators, furnishing the sizes above 45 kw., employ the same

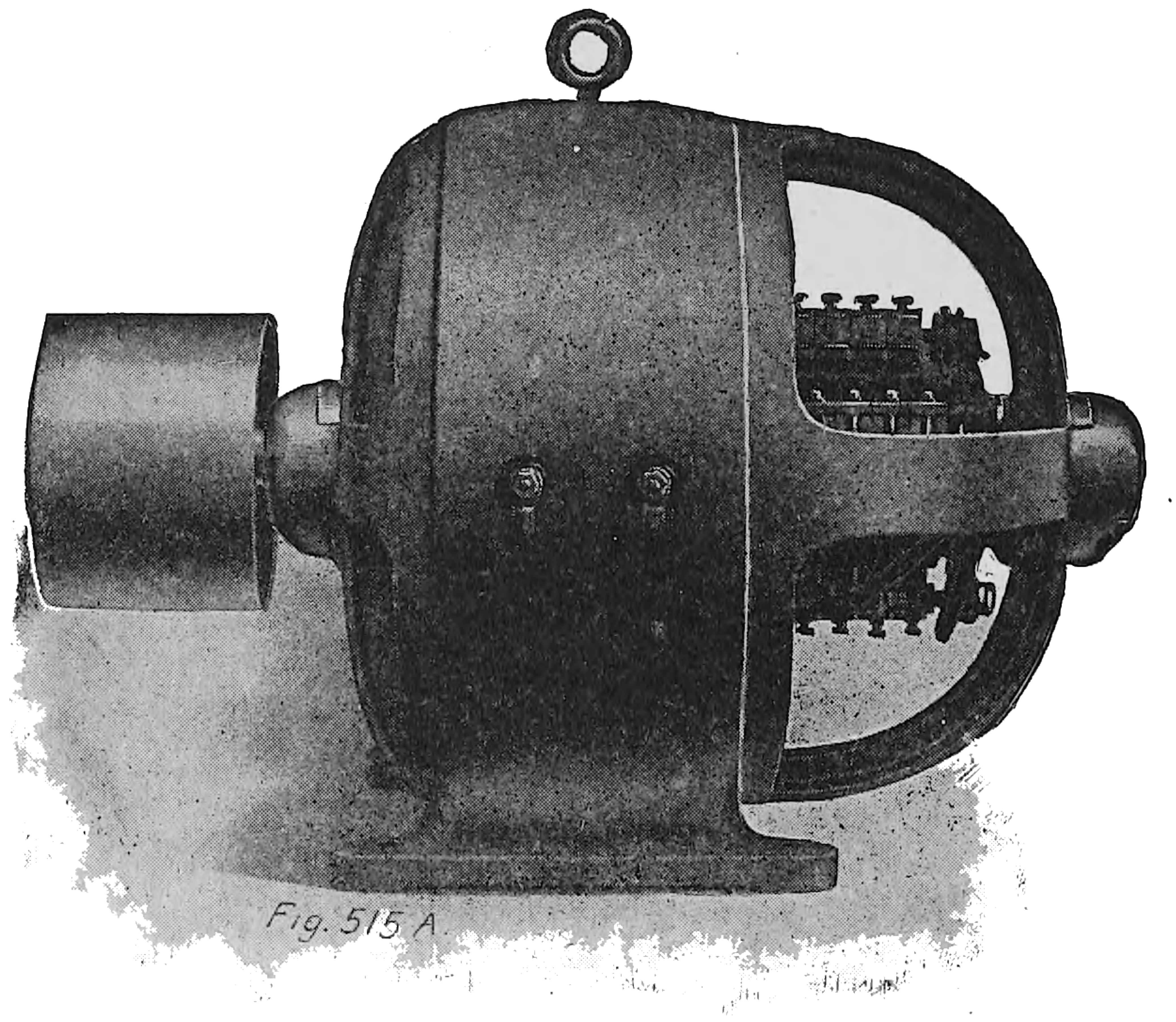



Fig. 32. Crocker-Wheeler Form I Generator

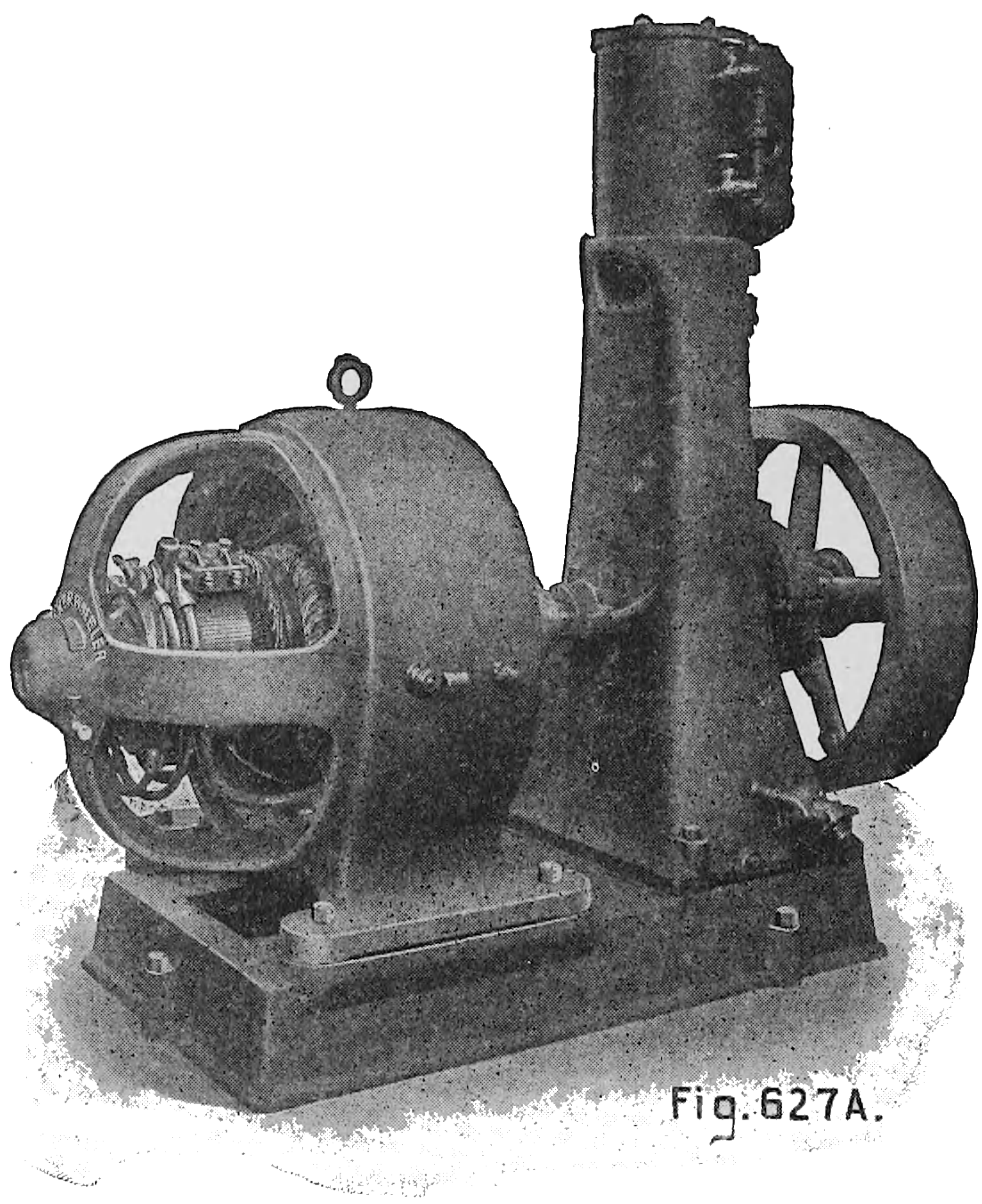



Fig. 33. Crocker-Wheeler Generator Direct-Connected to American Blower Company Engine
*Courtesy of Crocker-Wheeler Company*

with their standard two-wire machines. One of them is shown in Fig. 34.

The series field windings are divided into two equal sections. The windings on the positive poles are connected to one side of the armature circuit, and the windings on the negative poles to the other side. The armature slots are cut deeper than ordinarily, to provide room for auxiliary windings in the bottom of the slots. The type of auxiliary winding shown diagrammatically in Fig. 35 is known as the polyphase winding and consists of several windings, usually more than three, similarly connected to the armature with the neutral

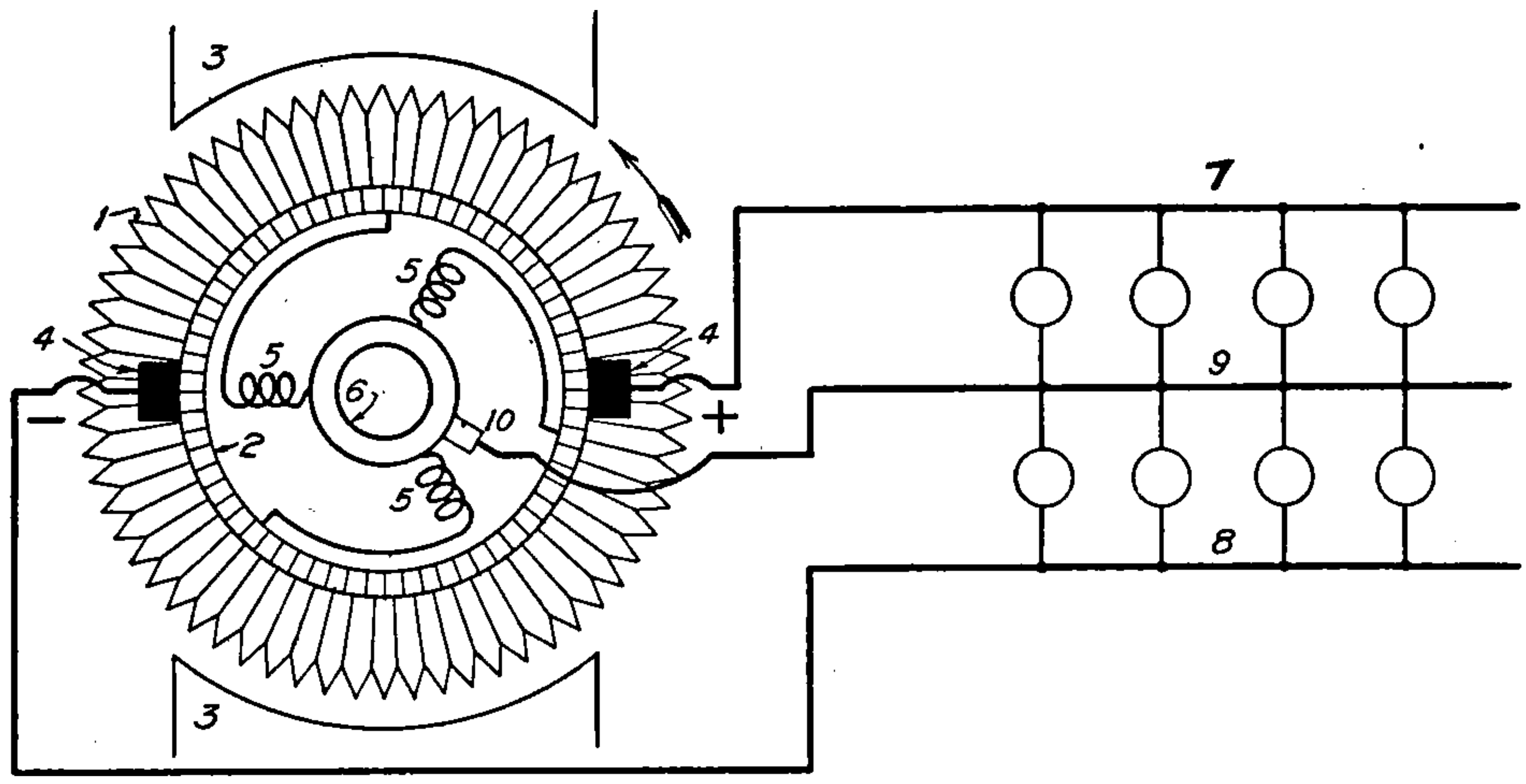



Fig. 35. Diagram of Auxiliary Windings of Crocker-Wheeler Armature. 1, Armature Winding; 2, Commutator; 3, Poles; 4, Brushes; 5, Auxiliary Winding; 6, Slip Ring; 7, Positive Wire; 8, Negative Wire; 9, Neutral Wire

point connected to the slip or collector ring. The polyphase winding is so distributed over the face of the armature that the average field in which it moves is uniform at all times. Any tendency to flicker is thereby entirely overcome. The collector ring is mounted at the outer end of the commutator and supported from the commutator spider.

**Fairbanks, Morse & Company.** *Engine Types.* The engine type generators manufactured by this company are illustrated in Fig. 36, showing a 200-kw. 250-volt machine. They are made in sizes from 50 to 300 kw., with speeds from 275 to 100 r. p. m. The frame or magnet yoke is made of special dynamo iron of high permeability. The pole cores are of extra quality re-hammered wrought iron, circular in cross section and bolted to the frame. The pole shoes are of laminated sheet steel, so shaped as to give the correct

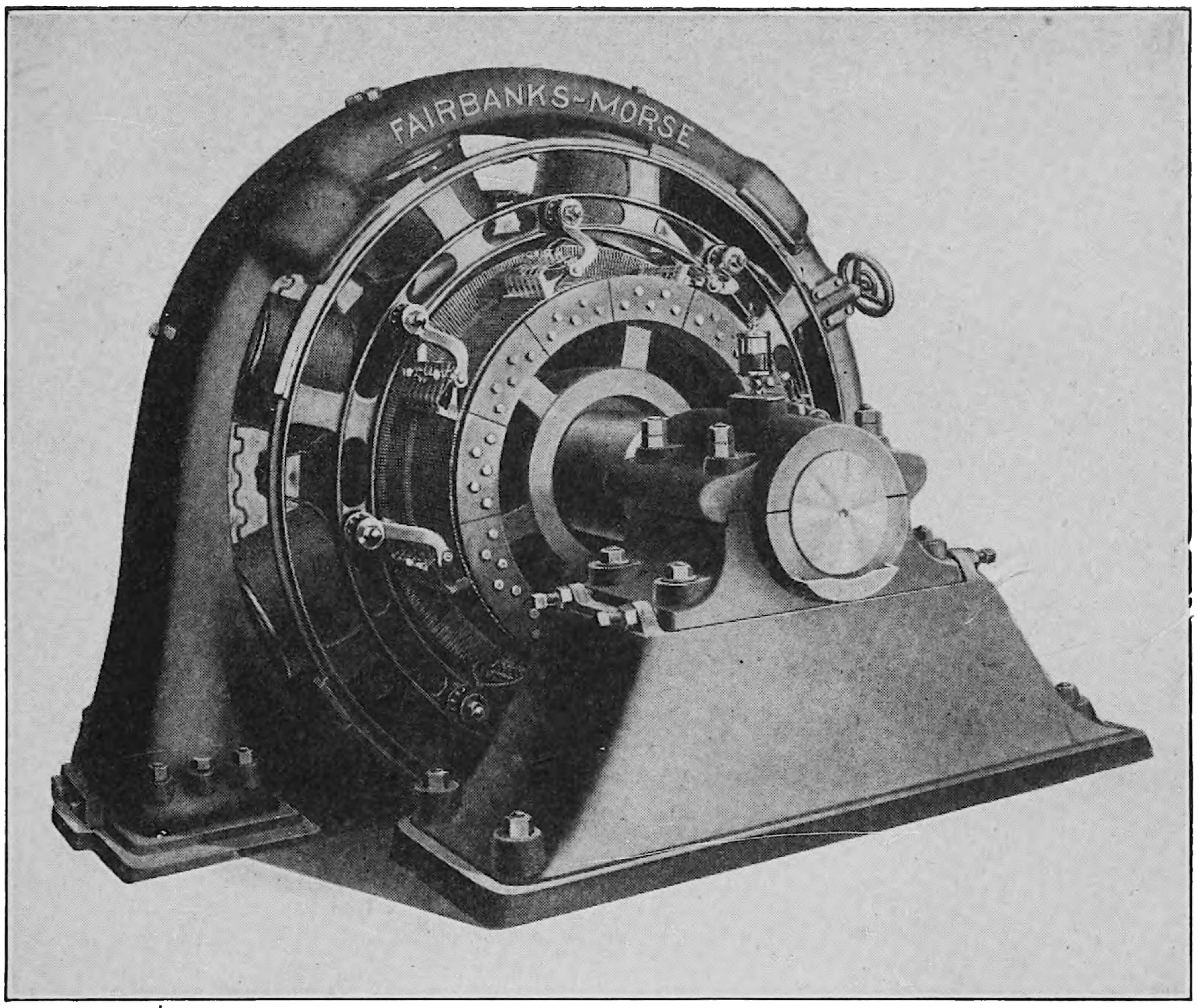



Fig. 36. Fairbanks-Morse Engine Type Generator

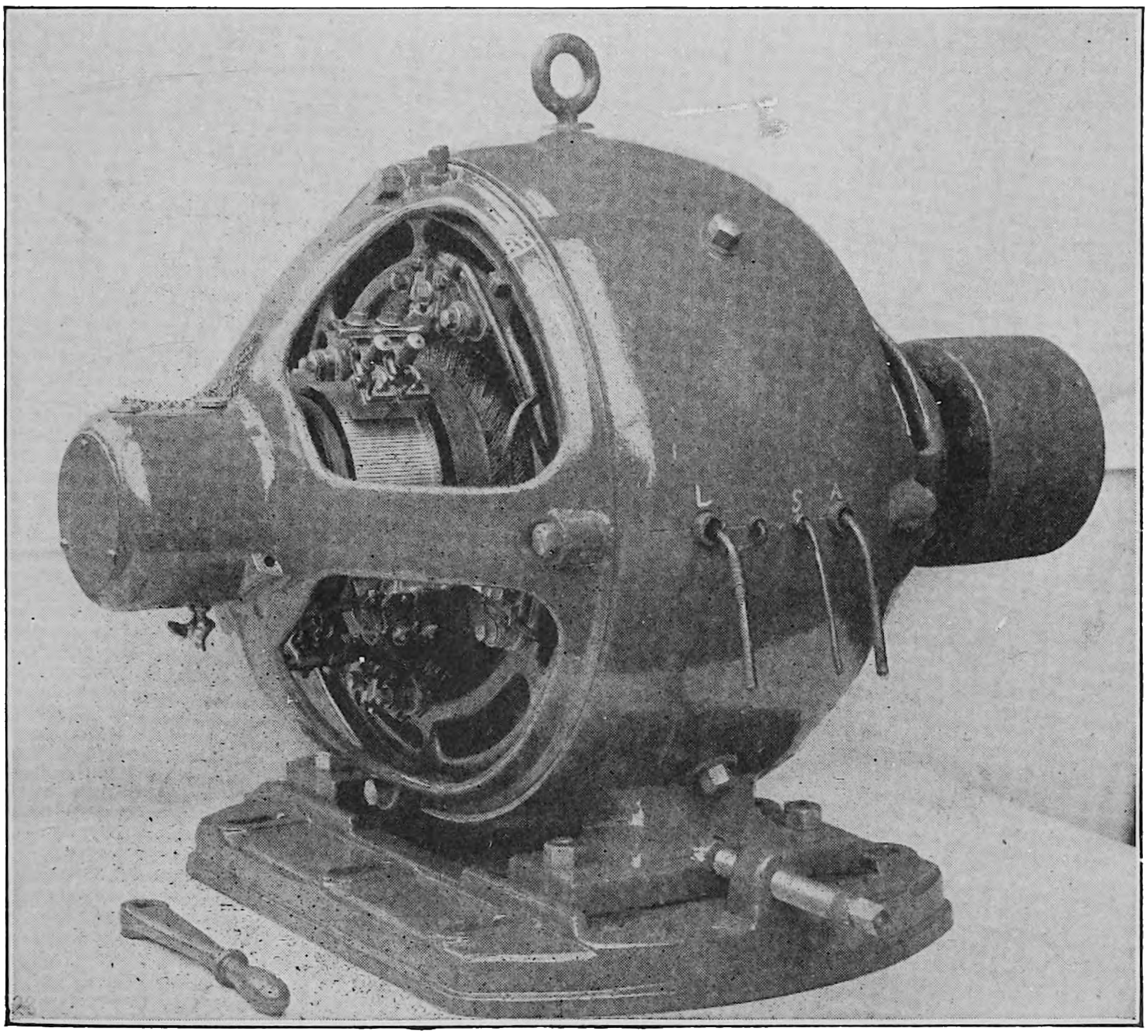


Fig. 37. Fairbanks-Morse Belted Generator

flux distribution and avoid eddy currents. The field coils are wound on metallic spools, the series and shunt coils being in separate com-

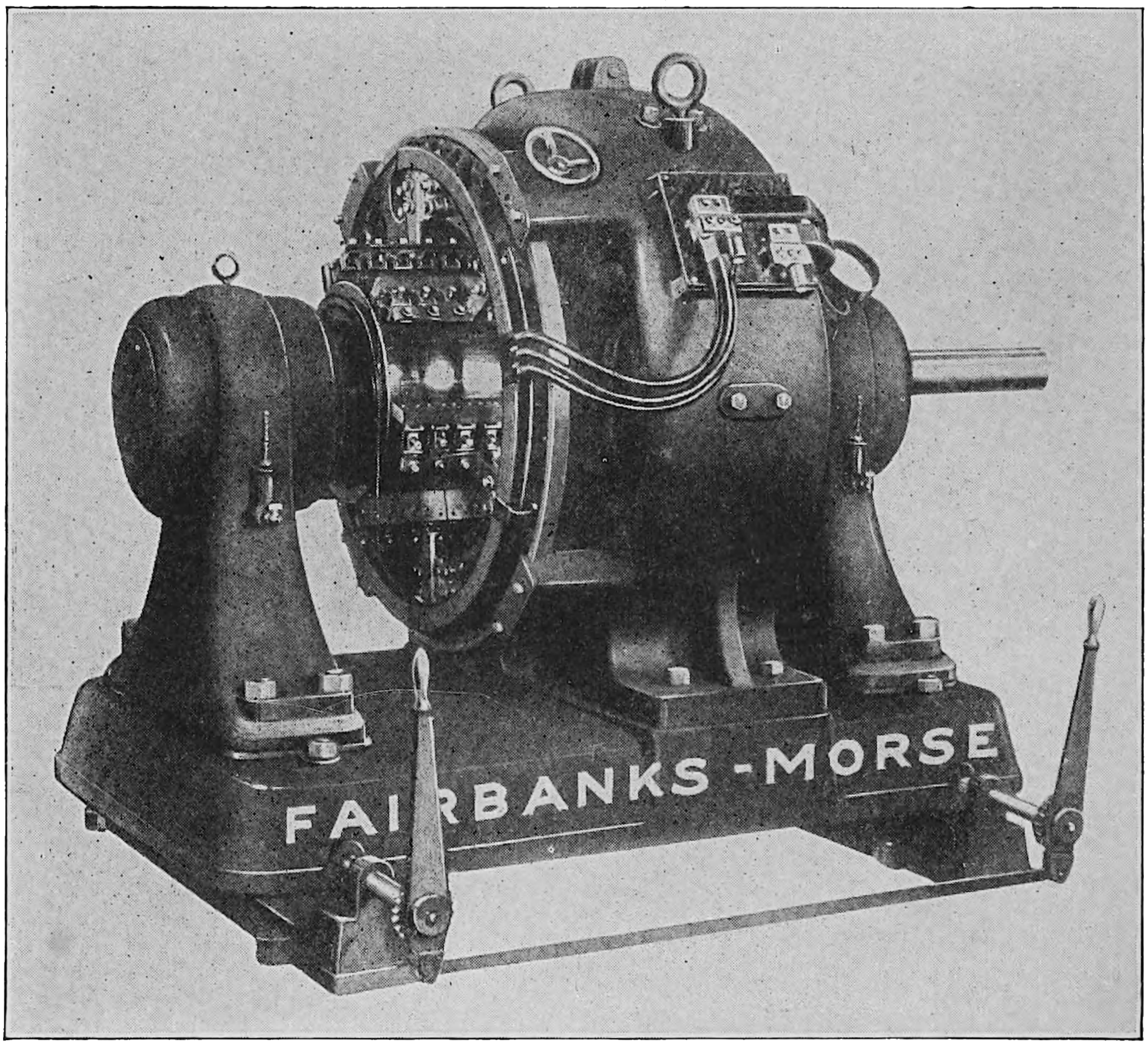



Fig. 38. Large Type of Fairbanks-Morse Belted Generator

partments. The armatures are ironclad, bar-wound with one piece coil, and well-ventilated.

*Belted Types.* This company also manufactures several lines of

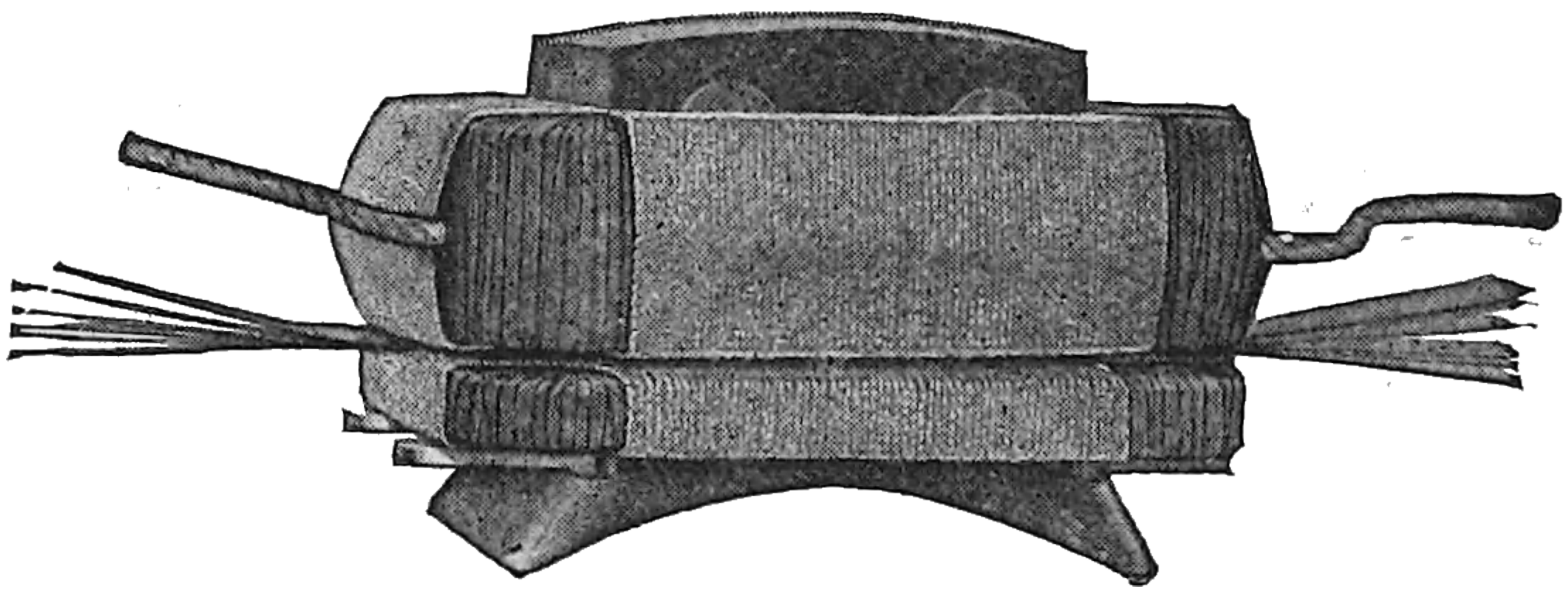


Fig. 39. Fairbanks-Morse Field Coils and Pole Piece

moderate and slow speed belted generators. Their moderate speed machines range from 2 to 125 kw., running 1850 to 675 r. p. m.

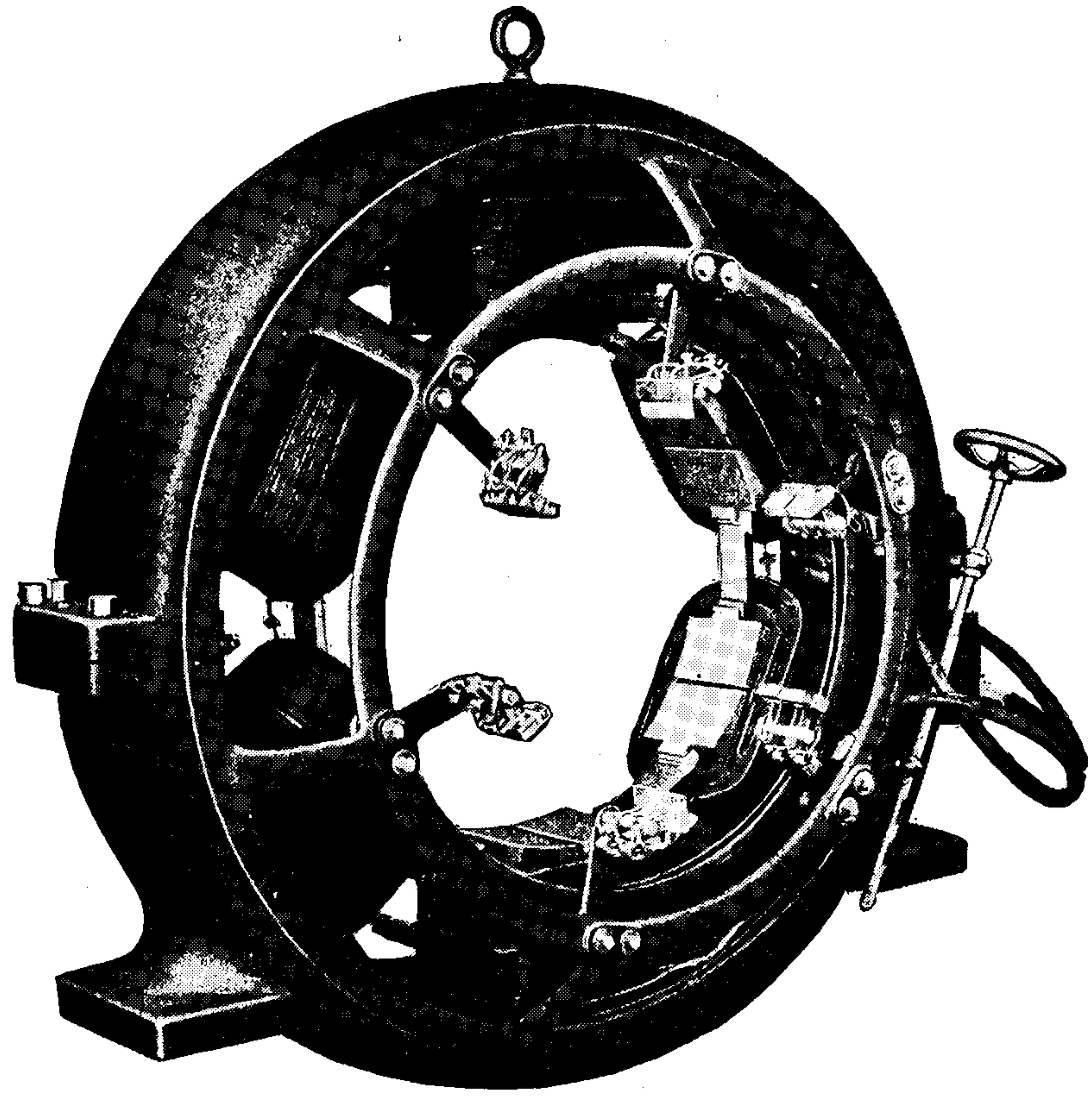


Fig. 42. Horizontally Split Frame with Armature Removed
*Courtesy of Fort Wayne Electric Works*

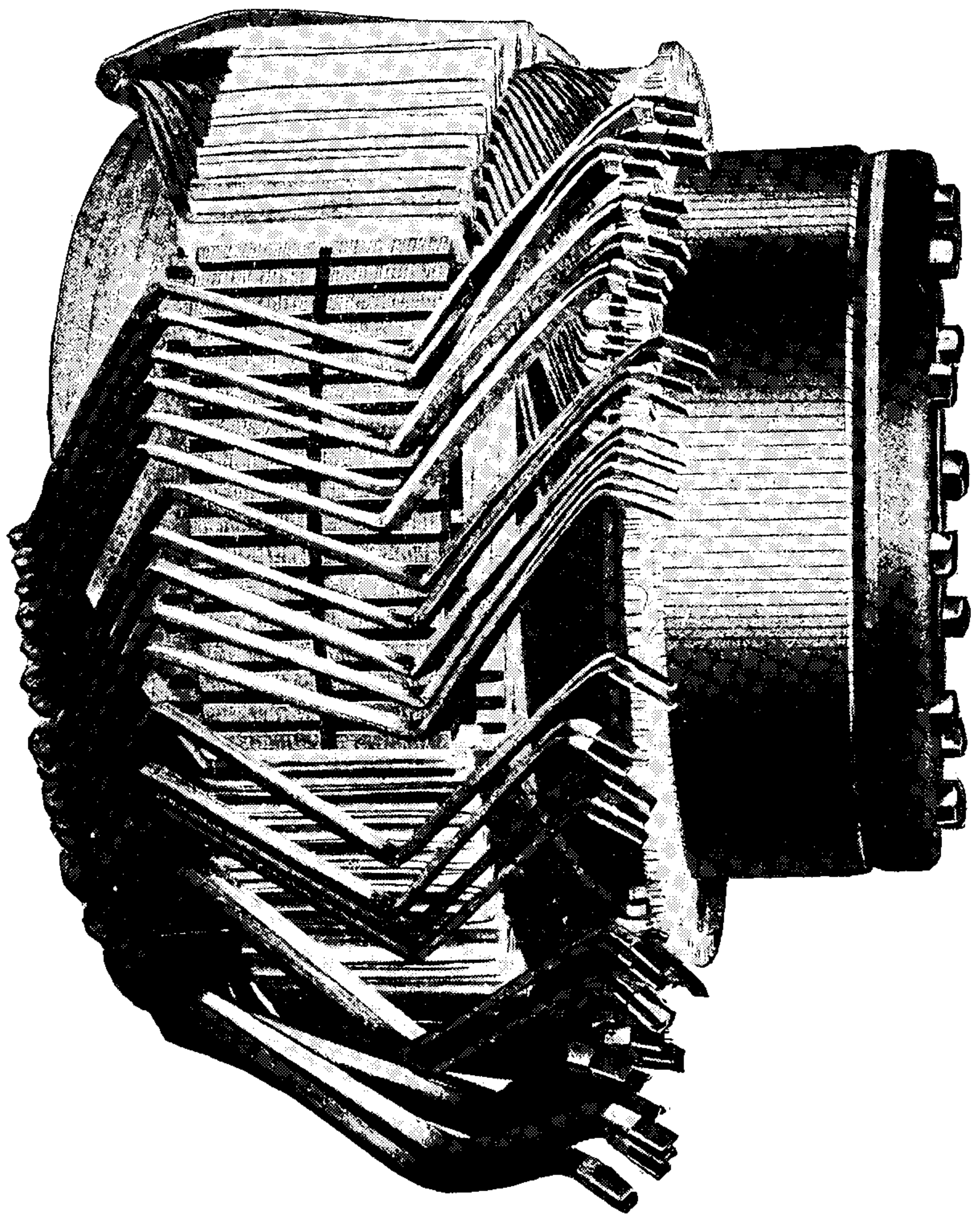


Fig. 43. Fort Wayne Armature Partly Wound

and *c*, Fig. 40. These are riveted together, slotted to about one-half their length, as shown at *n*, and provided with grooves *m* for holding them securely in the frame. After being cast welded into the frame, they are machined and, in the larger sizes, fitted with pole shoes. The field coils are wound on insulated metal forms, as shown in Fig. 41, providing good ventilation. Fig. 42 shows a horizontally split frame with armature removed and clearly illustrates

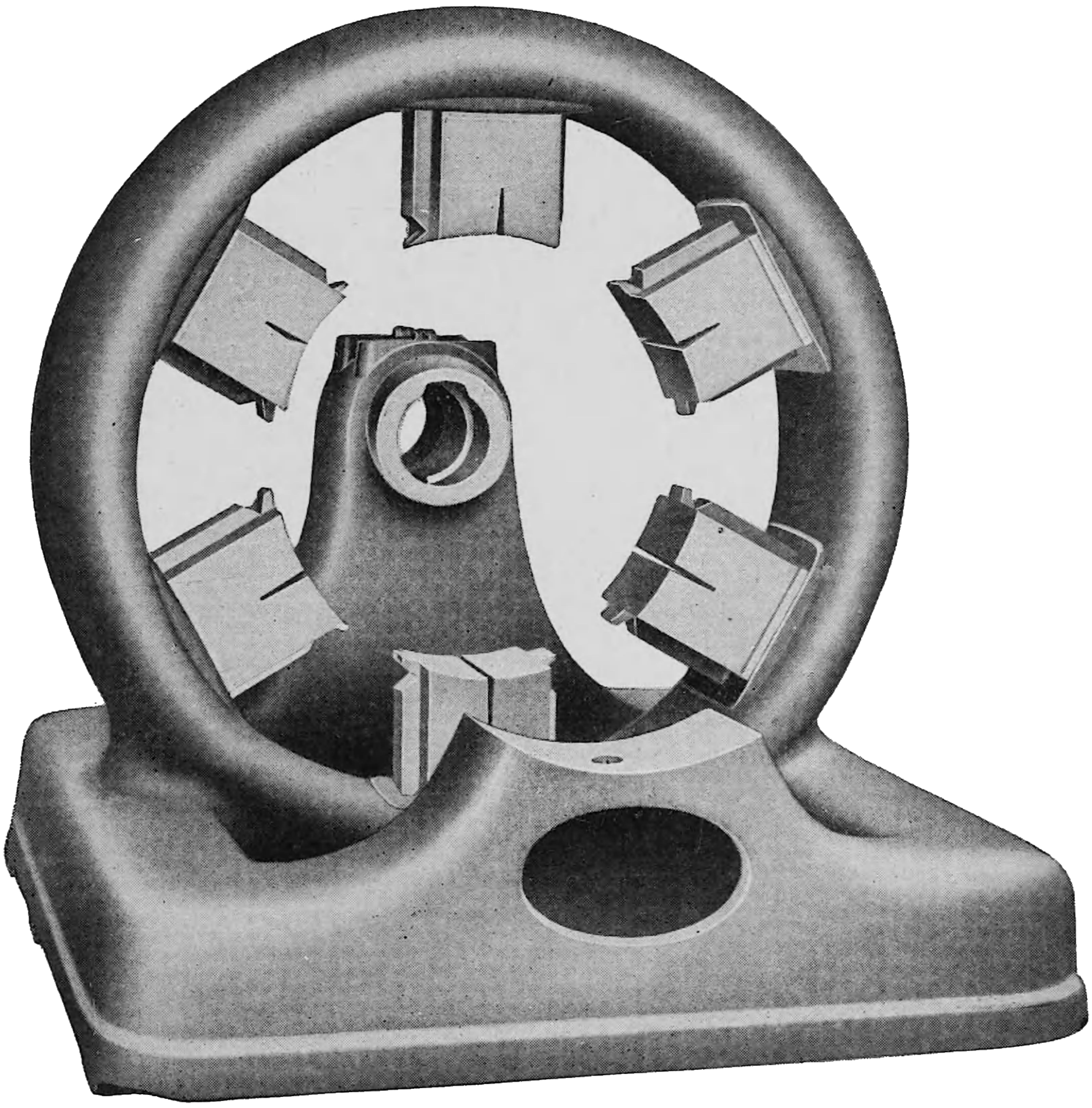


Fig. 44. One-Piece Frame of Type L F Generator
*Courtesy of Fort Wayne Electric Works*

these details, including the method of shifting the brush yoke. The armature is of the usual ironclad, one-piece coil, well-ventilated type. A partly wound armature is shown in Fig. 43.

*Belt-Driven Types.* Fort Wayne belt-driven types are manufactured in sizes from $\frac{3}{4}$ to 400 kw. They embody the same charac-

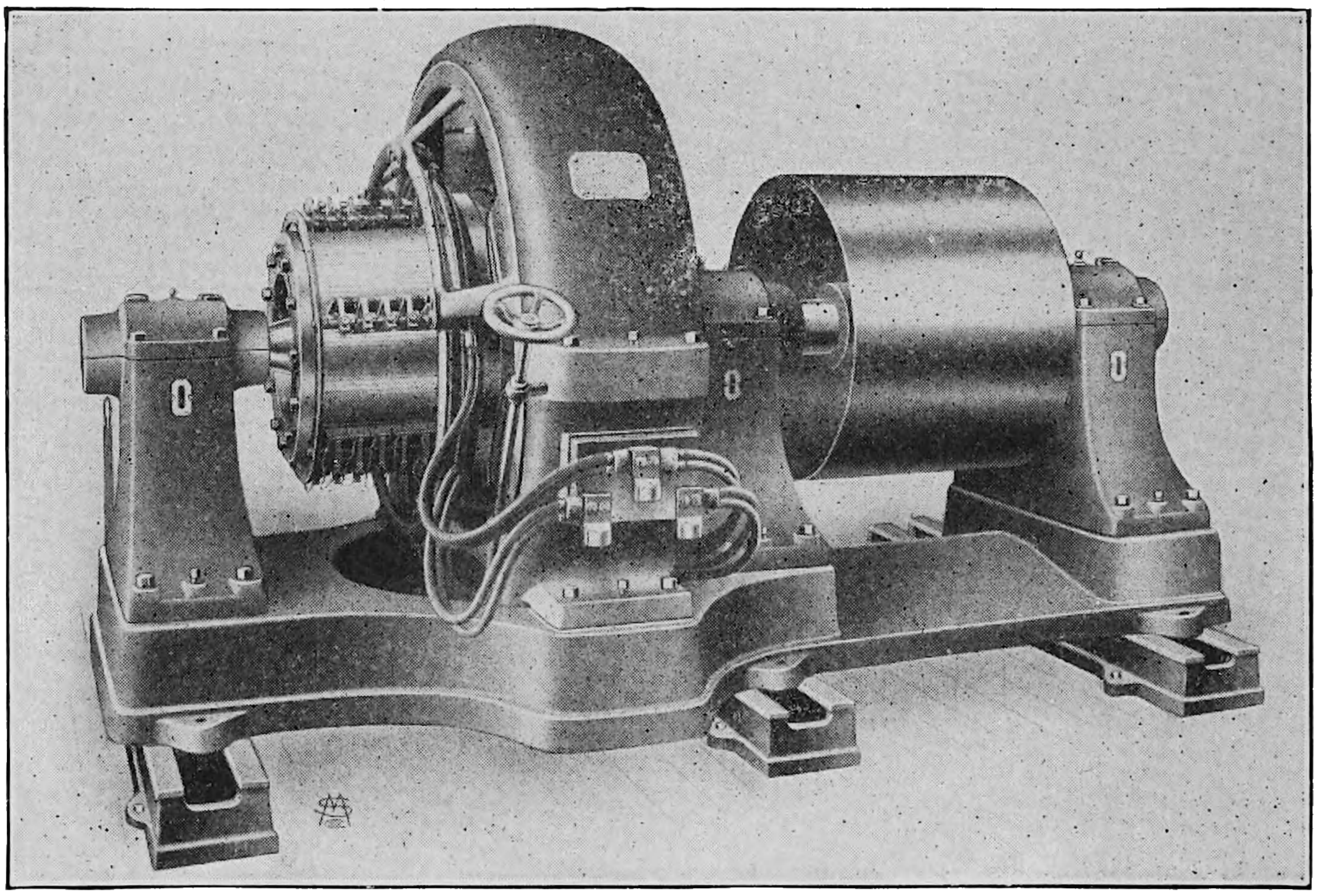


Fig. 45. Fort Wayne 3-Bearing Belted Generator

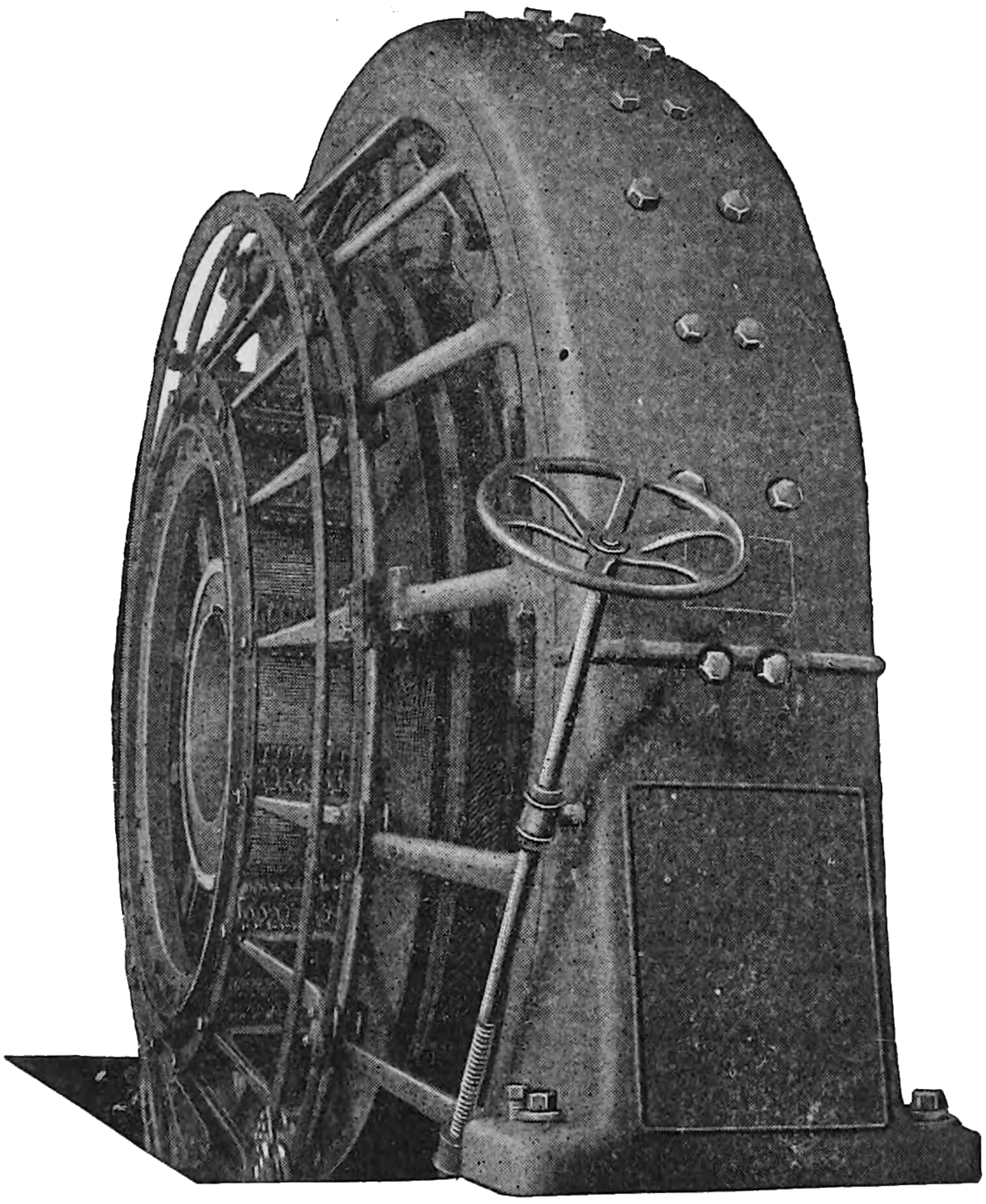


Fig. 46. General Electric Railway Generator

trated in Fig. 49, are inserted. These are made of steel strips set on edge and interlocked with the laminations, thus forming ventilating

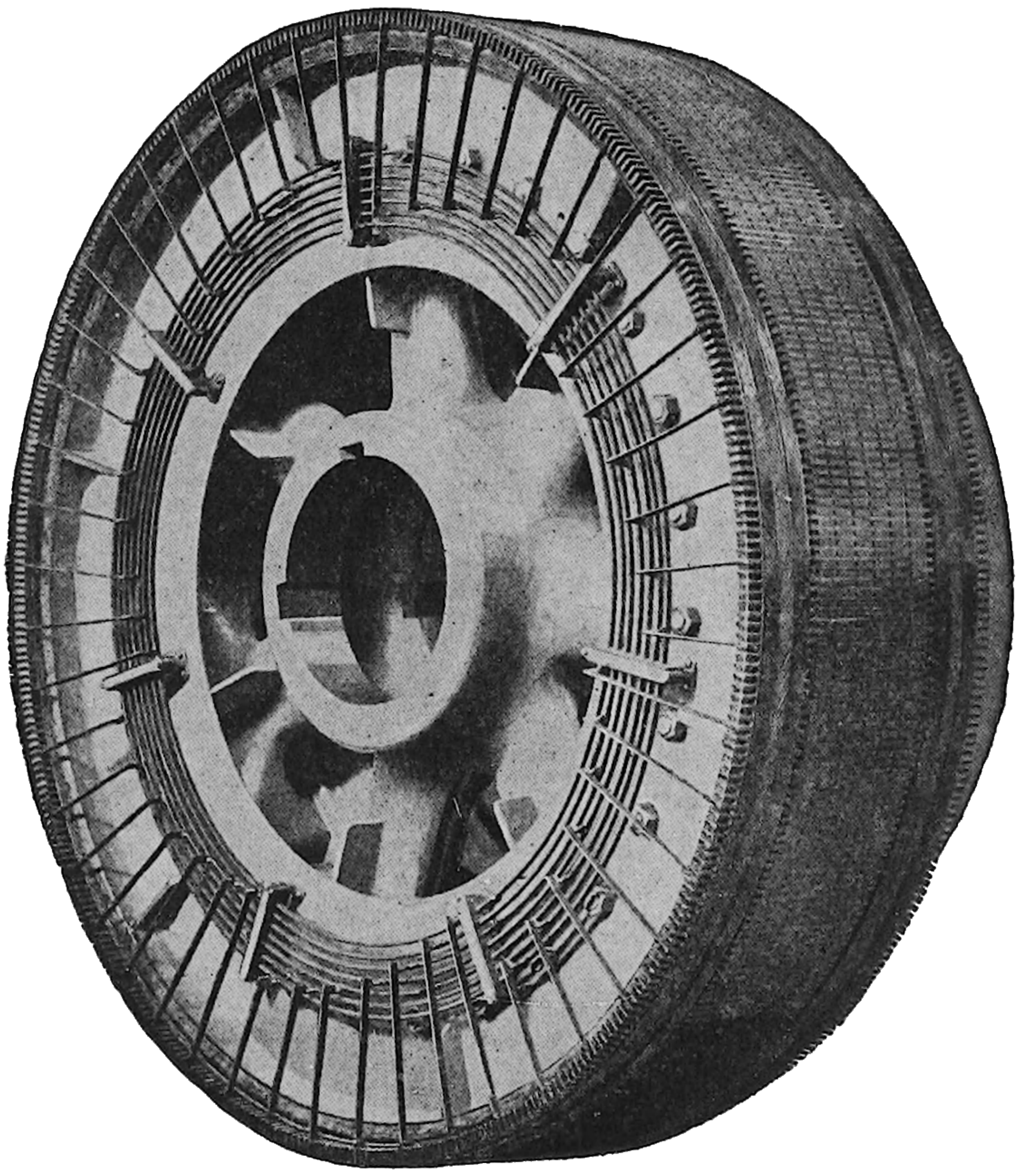


Fig. 48. Armature Showing Equalizer Ring
*Courtesy of General Electric Company*

ducts or air passages. The arms of the spider have cast upon them wings or fan blades. These serve as a powerful centrifugal fan to

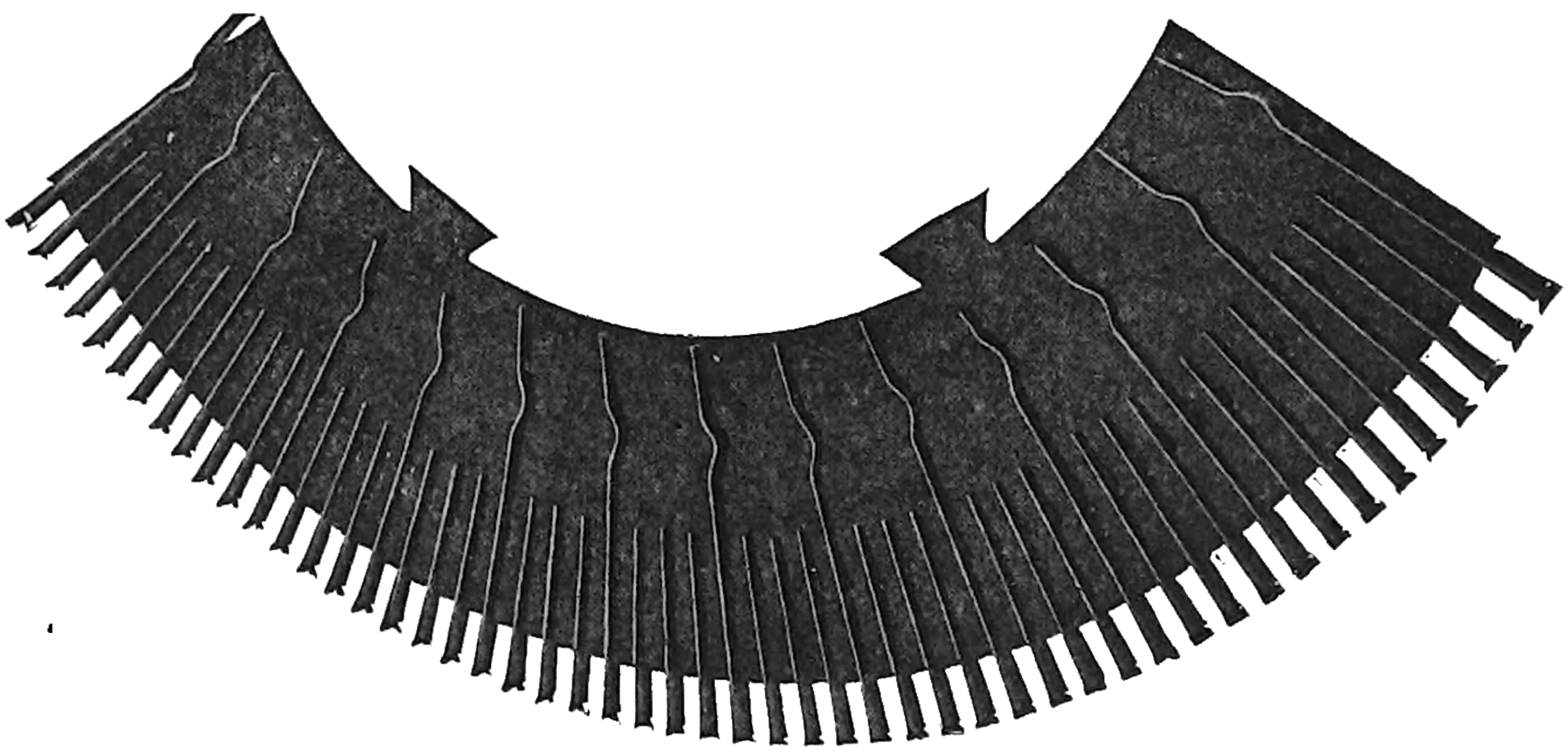


Fig. 49. General Electric Armature Space Block

keep a constant blast of air passing between the laminations and windings and around the poles. An armature embodying these features is called a *ventilated armature.*

The armature coils are of the form-wound copper strip type, held in the slots by wooden wedges. Equalizing rings are provided on generators having multiple-wound armatures. These rings, mounted on the end flange on the back of the armature, as shown in Fig. 48, are used to connect the armature windings between points of equal potential, so that any unbalancing that may occur will be equalized by the alternating currents that will flow through these rings between the sections. These currents, due to the armature reaction, equalize the pole strengths, thus causing an equal division of the direct current in the several paths, and they thereby improve

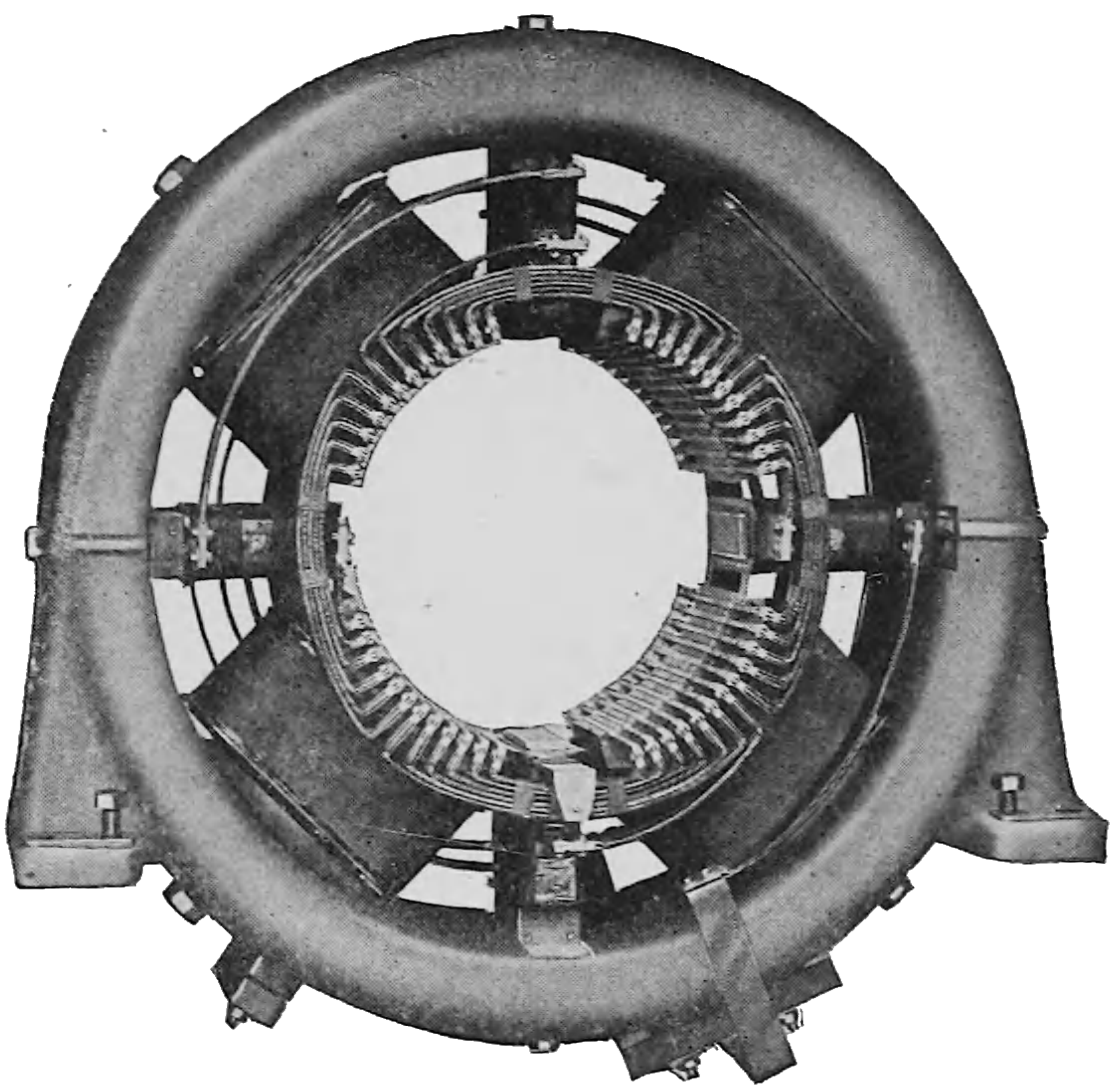


Fig. 50. Field Frame Showing Compensated Windings
*Courtesy of General Electric Company*

the commutation very much. Commutators and brush holders are of generous design, allowing large radiating and contact surfaces. In the General Electric railway generators all sizes above 1000 and below 400 kw. are equipped with commutating poles. These compensate armature reaction at all loads and secure excellent commutation. (See "Electro-Dynamic Company", page 68.)

During the past few years railway generators wound for potentials of 1200 to 1500 volts and capable of carrying three times normal load, have been developed. Owing to the necessity of carrying such heavy overloads, it is usual to provide, in addition to the commutating field, a compensating winding so proportioned as to practically nullify the effect of armature reaction. This winding consisting of heavy copper bars, is placed in slots in the pole surface and connected in series with the armature, commutating field, and series field. It will be readily seen that the current flowing in these windings will rise and fall at the same rate as the current in the armature winding, thereby preventing flux distortion and resultant sparking. In Fig. 50 can be seen the compensated windings for a 500-kw. field frame.

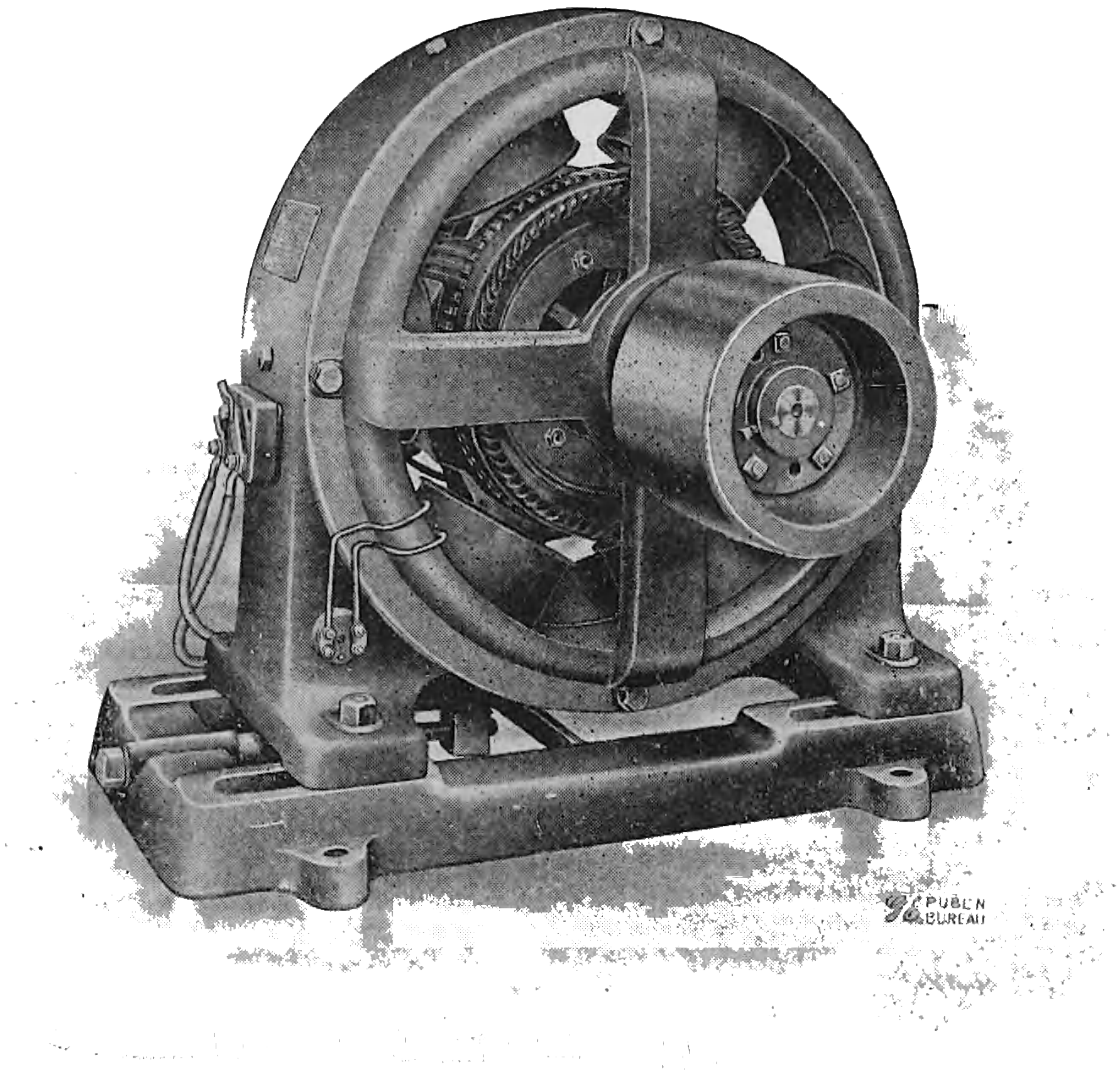


Fig. 51. General Electric Belted Generator on Cast-Iron Sub-Base

*Belted Types.* The General Electric Company builds several lines of belted machines. Fig. 51 illustrates their medium size belted machine. These are 6-pole, 16- to 150-kw. capacity, and running at speeds from 1100 to 500 r. p. m. They are wound for 125, 250, or 500 volts. Another line, called type D L C, employs commutating poles. These range in capacity from 20 to 150 kw., run at speeds from 1425 to 650 r. p. m., are 4- or 6-pole, and are wound for standard voltages of 125, 250, and 575. The main poles are made of laminated iron, while the commutating poles are of

from the pillow block and makes connection by copper brushes to a compensator. These compensators are similar in construction to transformers and consist of two or more insulated coils wound on a laminated iron core. They carry an alternating current and serve to maintain a neutral potential at their middle point, to which, there-

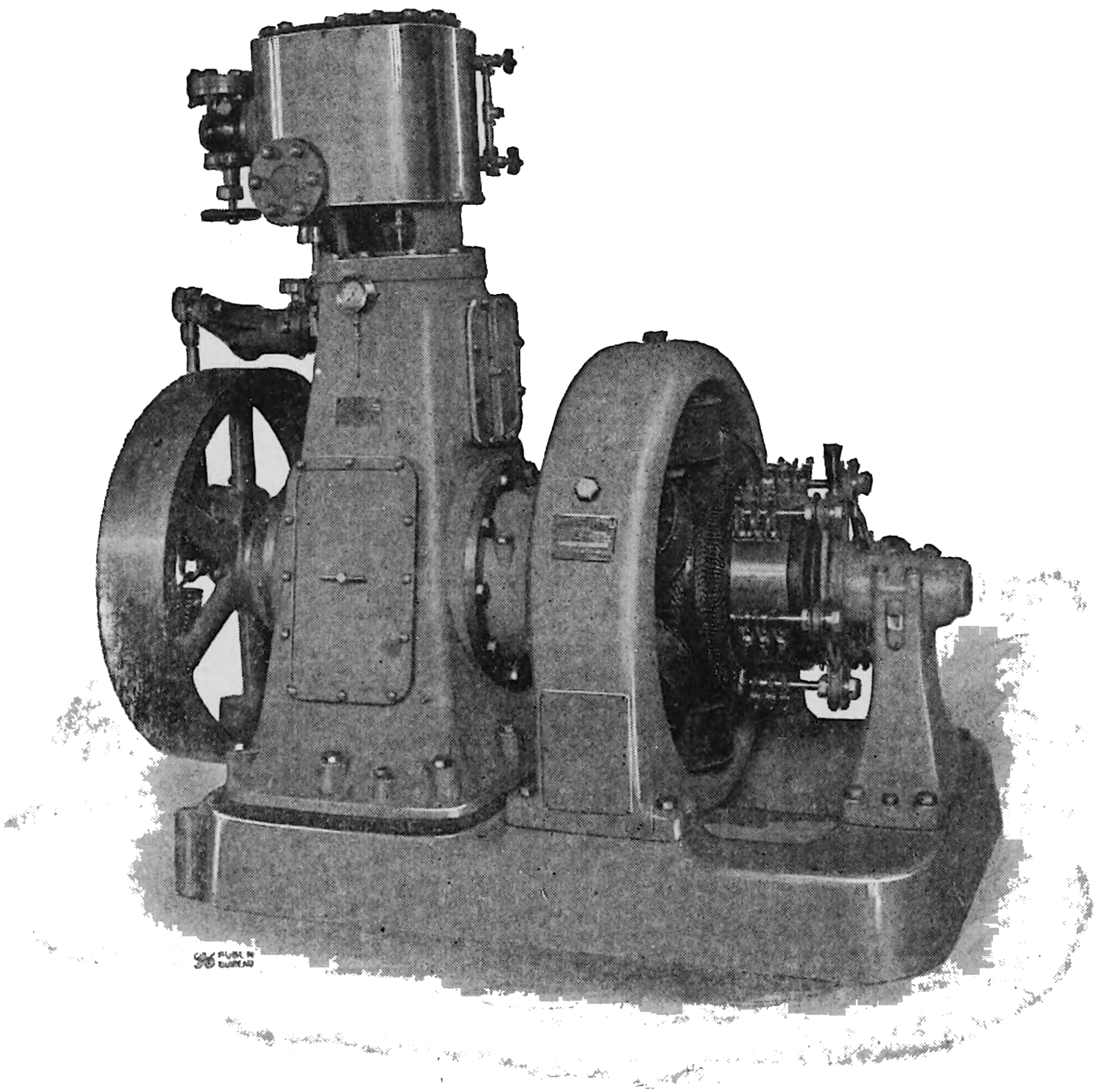


Fig. 54. Generating Set with Forced Lubrication Engine
*Courtesy of General Electric Company*

fore, can be connected the middle or neutral wire of a three-wire system.

*Generating Sets.* This company also manufactures a line of small direct-current generating sets, both generator and engine complete, in sizes from $2\frac{1}{2}$ to 75 kw., running at speeds from 700 to 280 r. p. m. In the smaller sizes the generators are 4-pole, 110-volt, while in the larger they are 6-pole, 125-volt. Designed primarily to meet the severe conditions of marine work, which demands light, very compact, and extremely durable sets of close regulation, these generators are in addition employed for power and lighting in isolated plants and as exciters in central stations. Fig. 54 illustrates a 50-kw. set of this type.

*Turbine-Driven Types.* The direct-current Curtis steam tur-

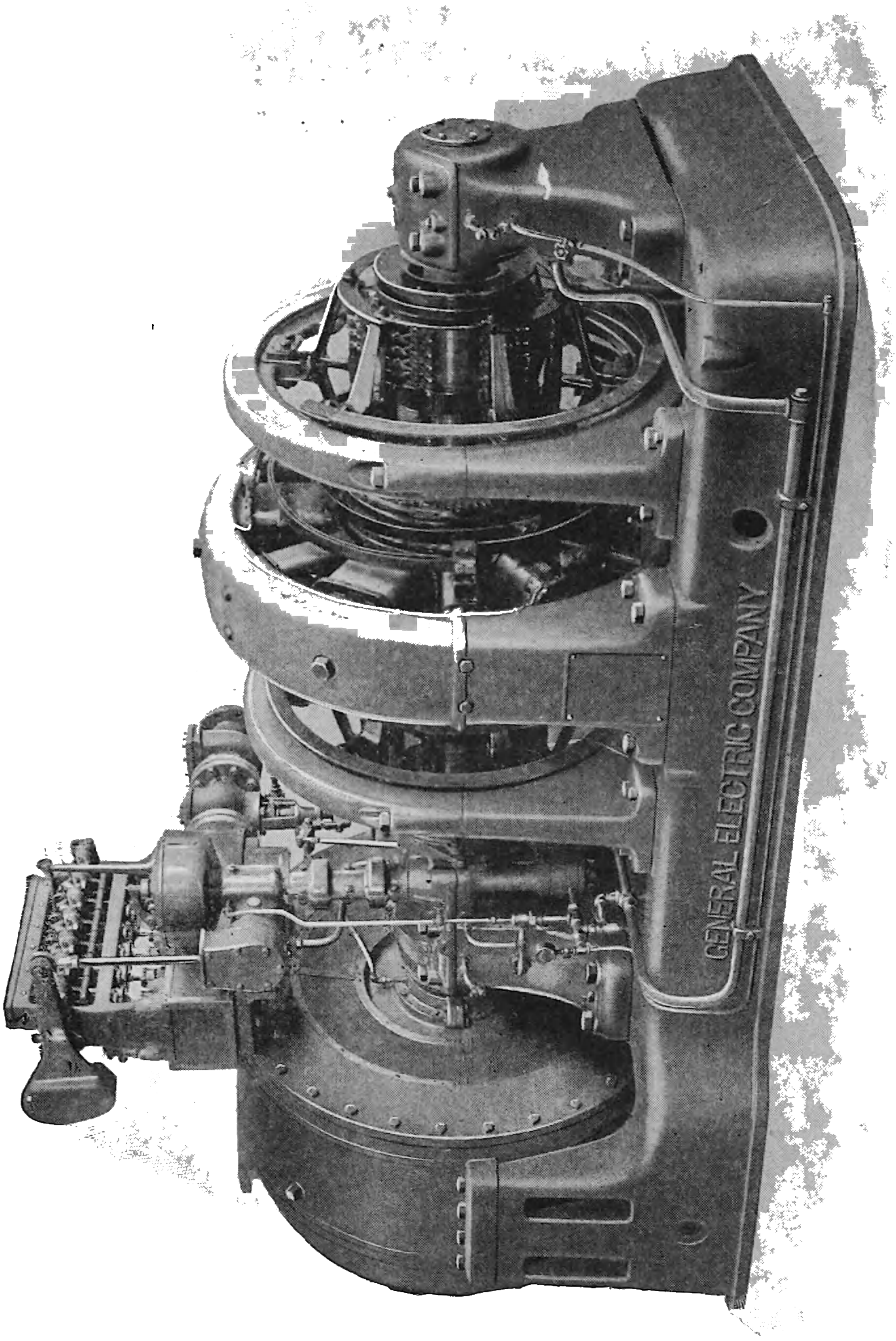



Fig. 55. Horizontal-Shaft Curtis Steam Turbine Driving Type C C Generator
*Courtesy of General Electric Company*

bine sets brought out by the General Electric Company are arranged with horizontal shaft as illustrated in Fig. 55. They are built in sizes from 5 to 300 kw., at 120 and 250 volts. The generators are of the most recent and improved types. By the use of commutating poles,

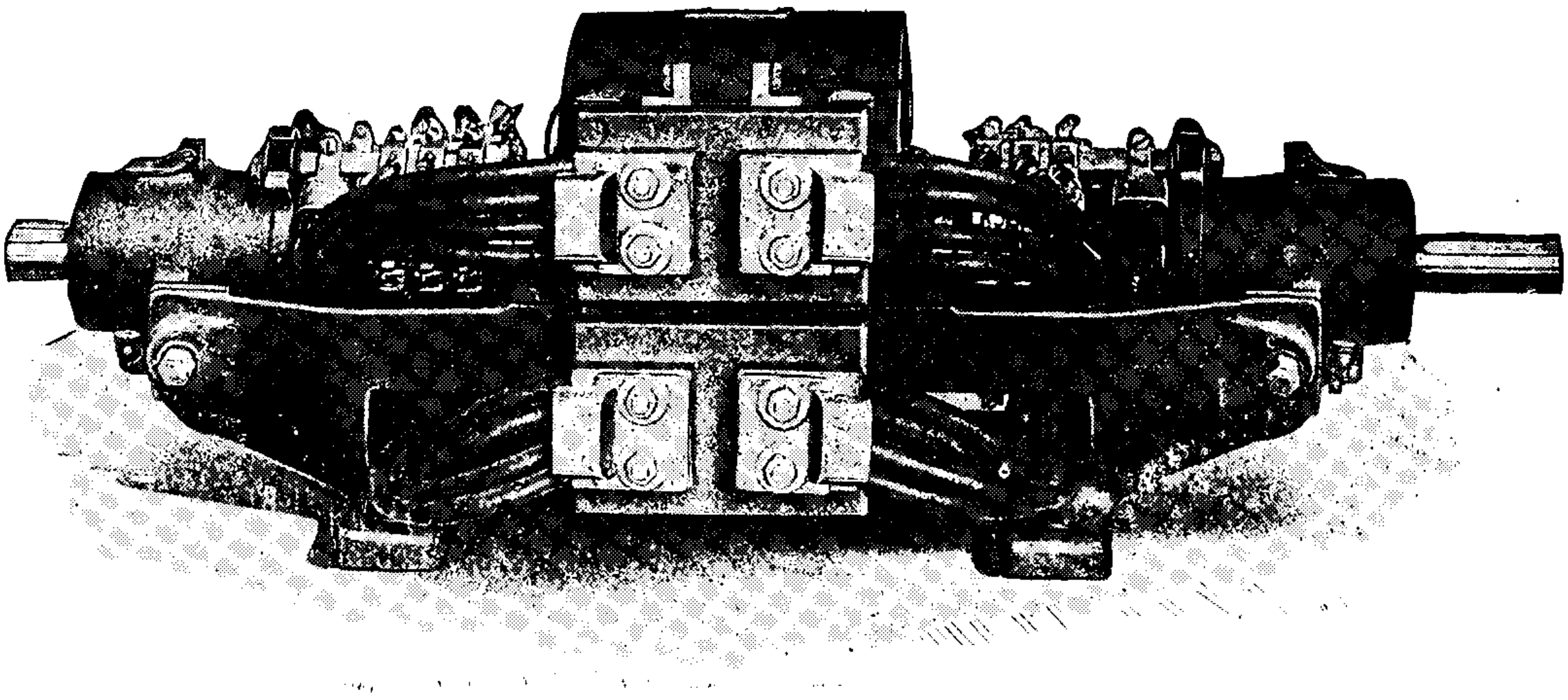


Fig. 56. General Electric 1000-Ampere Electrolytic Generator

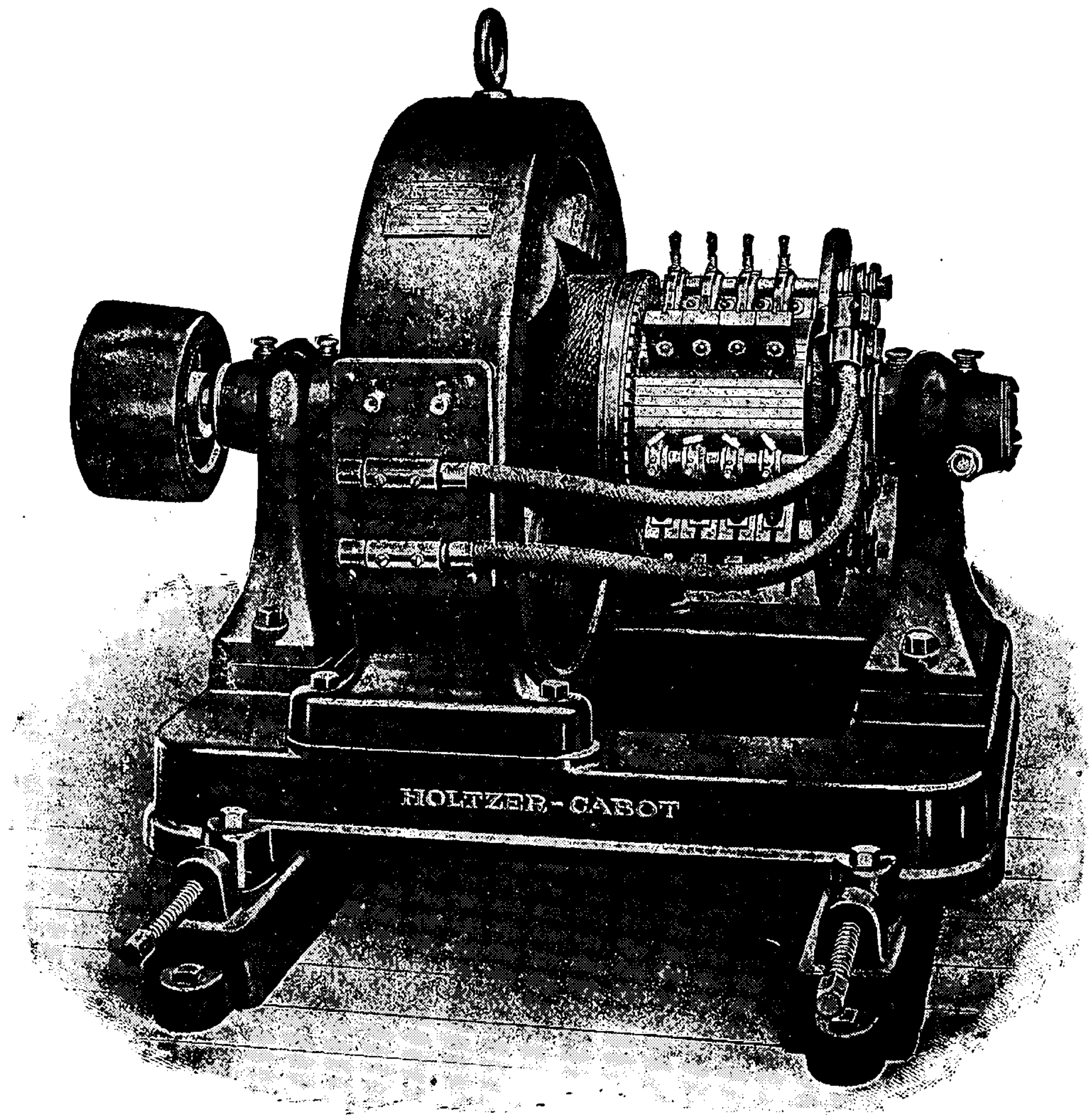



Fig. 57. Holtzer-Cabot Belted Generator

bearings of hard phosphor bronze, self-aligning and self-oiling, while the pedestals are bolted to the base. By changing the windings and

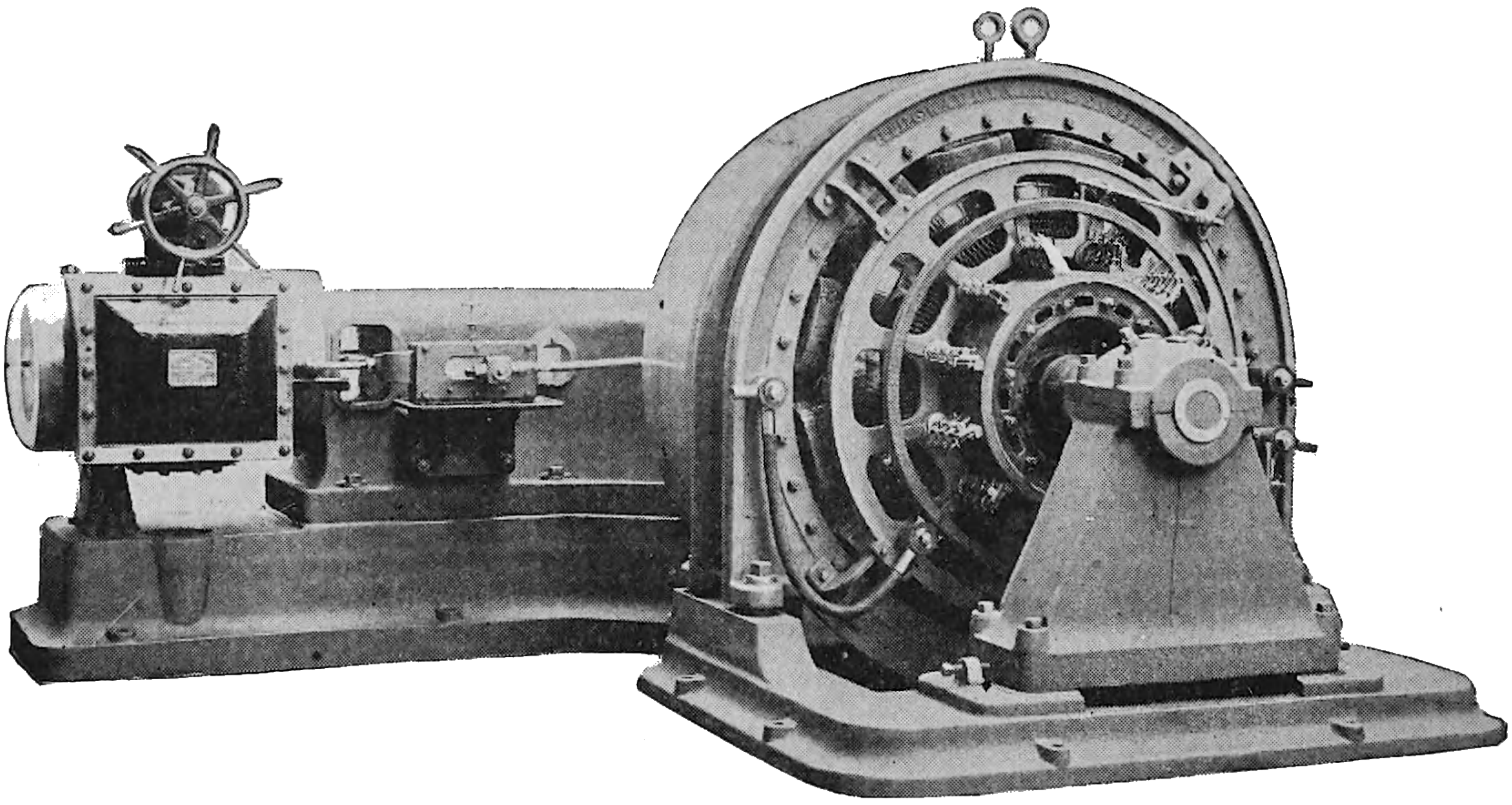


Fig. 59. 200-Kilowatt Engine Type Generator
*Courtesy of Ridgway Dynamo and Engine Company*

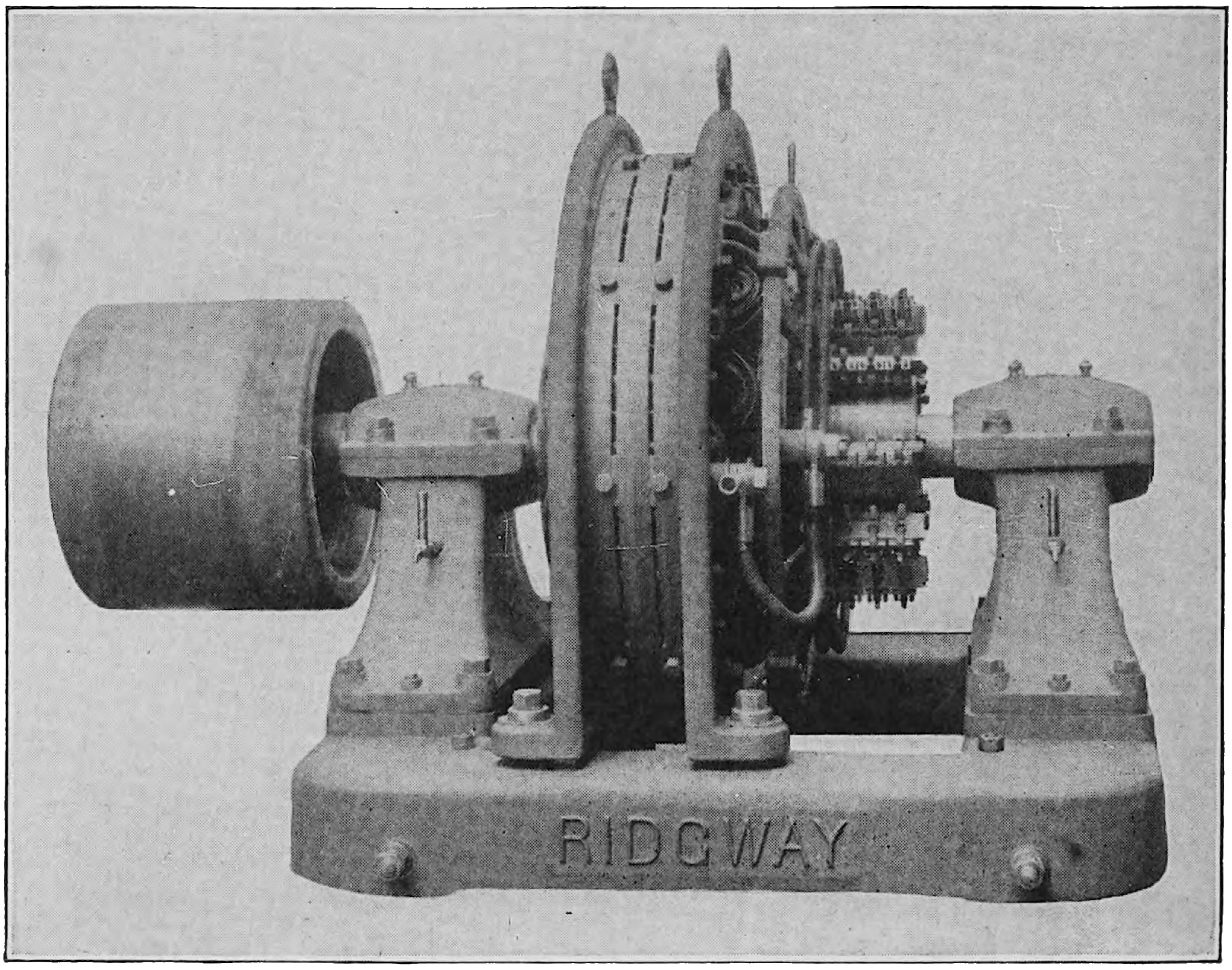



Fig. 60. Ridgway 150-Kilowatt Belted Generator

modifying the commutator and brush constructions, these frames are adapted to plating generators, as shown in Fig. 58.

**Ridgway Dynamo and Engine Company.** This company manufactures complete engine-driven units and also belted generators from 10 to 750 kw., in the three standard voltages of 125, 250, and 550, illustrated in Figs. 59 and 60. These machines in addition to employing the usual methods and materials of high grade generator construction, have several distinguishing features. The field ring or yoke is constructed of steel laminations, the punchings being securely

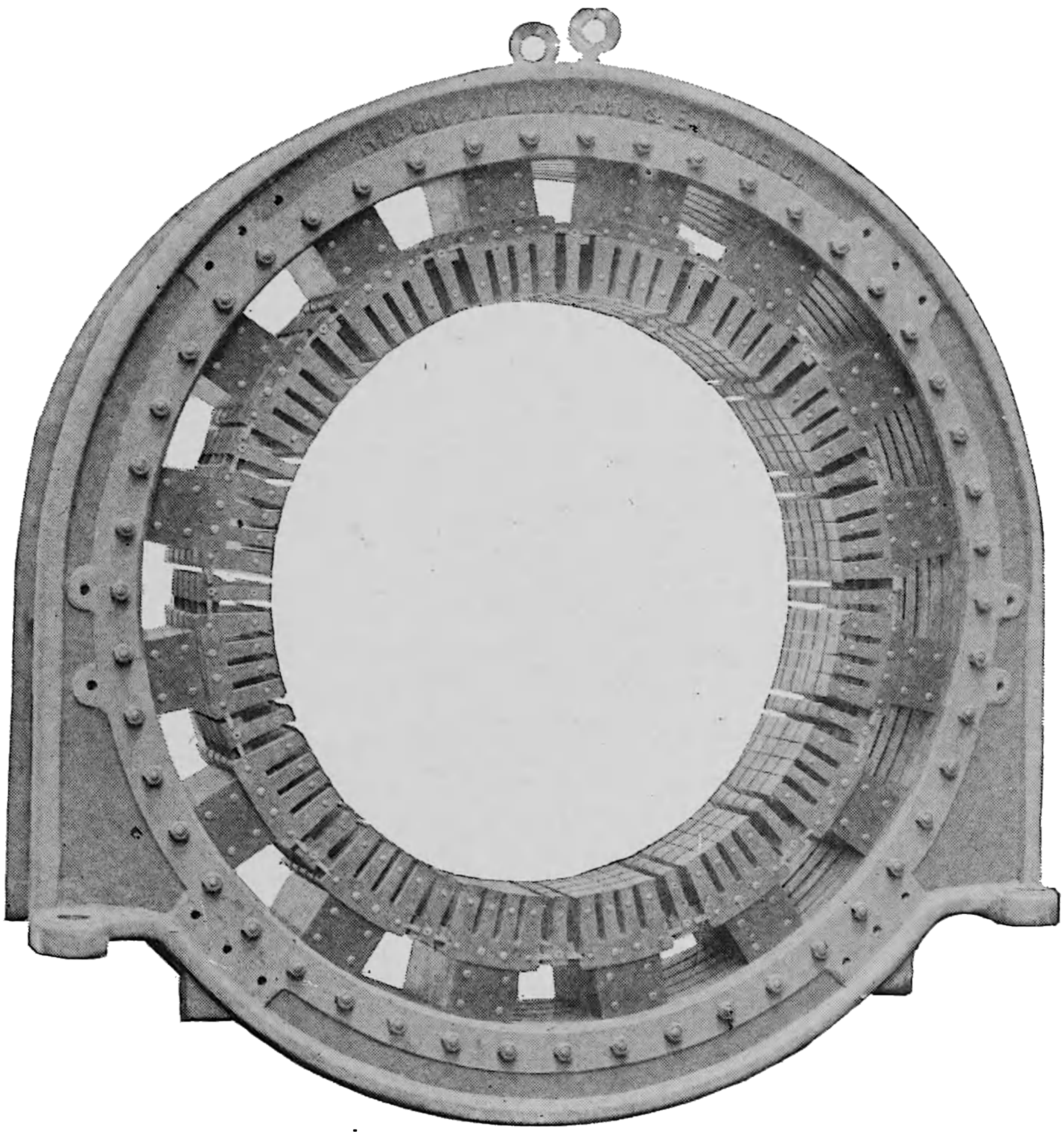


Fig. 61. Ridgway 400-Kilowatt Field Ready to Wind

held between heavy cast-iron clamping rings having a modified I-beam section. The pole pieces are also laminated and are built up in two separate parts. One part forms the core for the shunt field coil, while the other is the pole shoe. The two parts are firmly bolted to the field ring by heavy cap bolts that pass through the pole core and screw into the pole shoe.

Between the pole shoes are placed commutating poles, or interpoles. These poles also are built of laminated steel, and are supported from the pole shoes by brass keys driven into slots in the sides of the poles themselves and the adjacent pole cores. The pole shoes are provided with three slots each, through which are wound the "balancing coils". These coils take the place of the series field coils of the ordinary compound generator. Balancing coils lie parallel to the armature conductors and are so wound that the current in them flows in the opposite direction to that in the armature conductors. The coils are connected in series with the armature and thus are enabled to set up a local magnetic field, opposite in direction and just

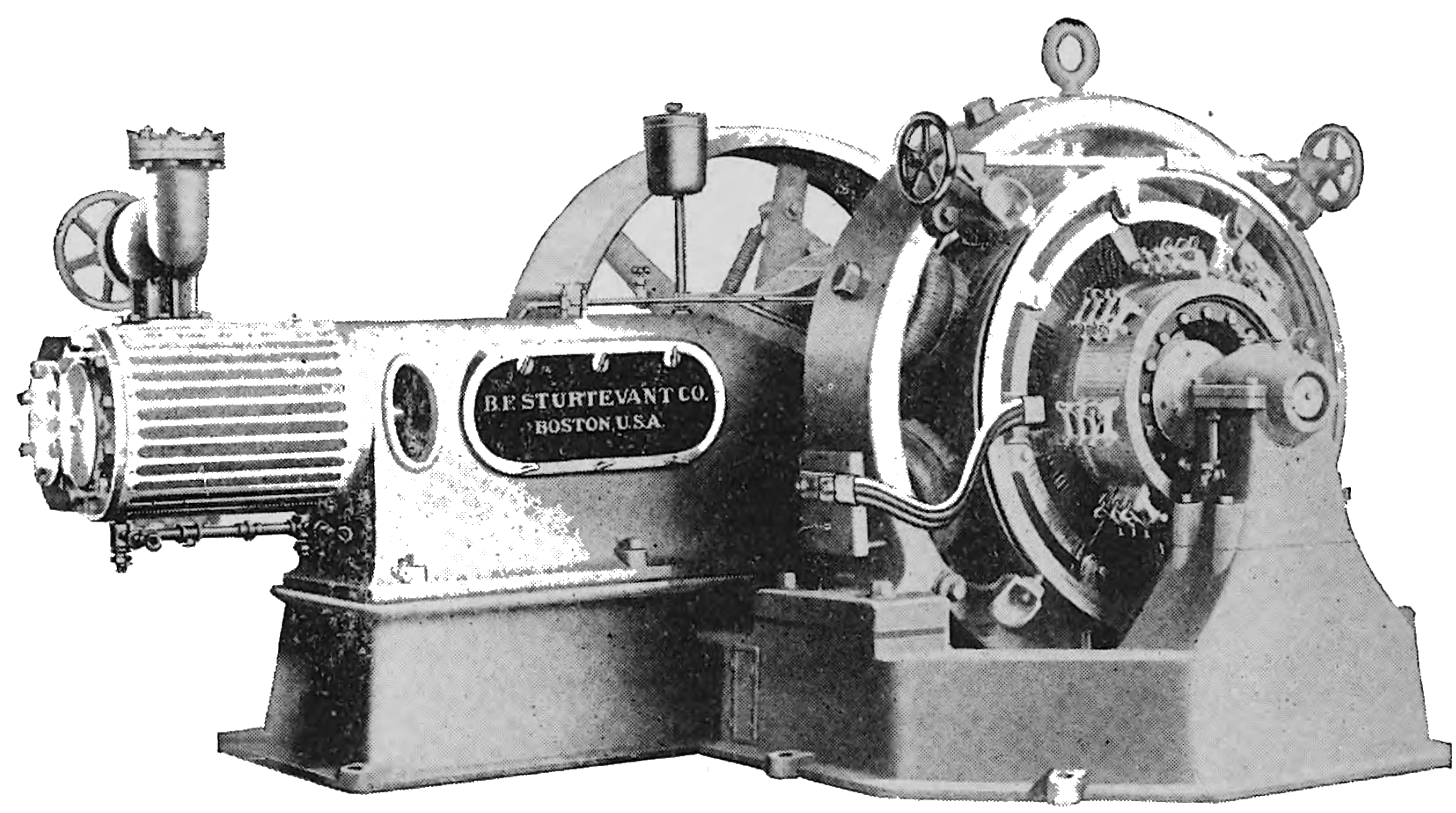



Fig. 62. Sturtevant 8-Pole Direct-Driven Generator

balancing that of the armature winding. This holds the field, due to the shunt coils, in the same place for all loads, and gives a fixed plane of commutation. The central portion of each balancing coil is wound around the commutating pole and sets up a commutating field, giving sparkless commutation with fixed brush position at any and all loads. Winding the balancing coils eccentrically and also adding a few extra turns produce a compounding effect. Fig. 61 illustrates the laminated steel field construction here described.

These machines become three-wire generators by the addition of two collector rings furnishing alternating voltage to a choke coil whose middle point is connected to the neutral wire of the system. The balancing coils are now divided and half are connected on one side and the remainder on the other side of the armature.

separately. The armature is of the ironclad type with the steel laminations mounted on a cast-iron spider. The armature coils are made waterproof and oilproof by dipping in armalac and baking for 24 hours in a temperature of 100°C. Within the armature core are space blocks having radial arms that act like the blades or the vanes of a centrifugal blower, thus increasing the ventilation.

This company also puts on the market a line of steam turbine generator sets ranging from 3 kw. at 3000 r. p. m. to 75 kw. at 2000 r. p. m., the generators being wound for voltages from 100 to 250. One of these is illustrated in Fig. 64.

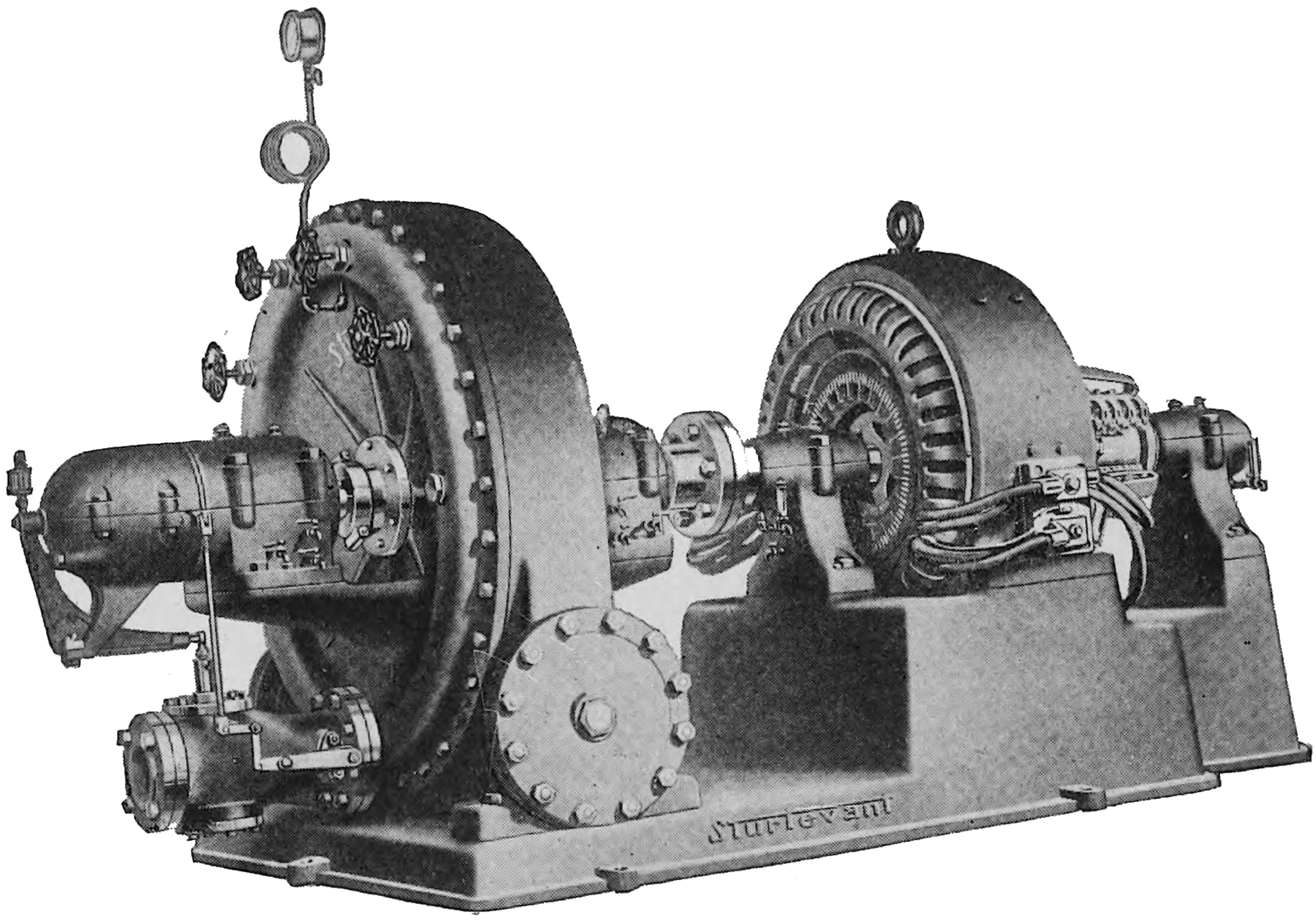
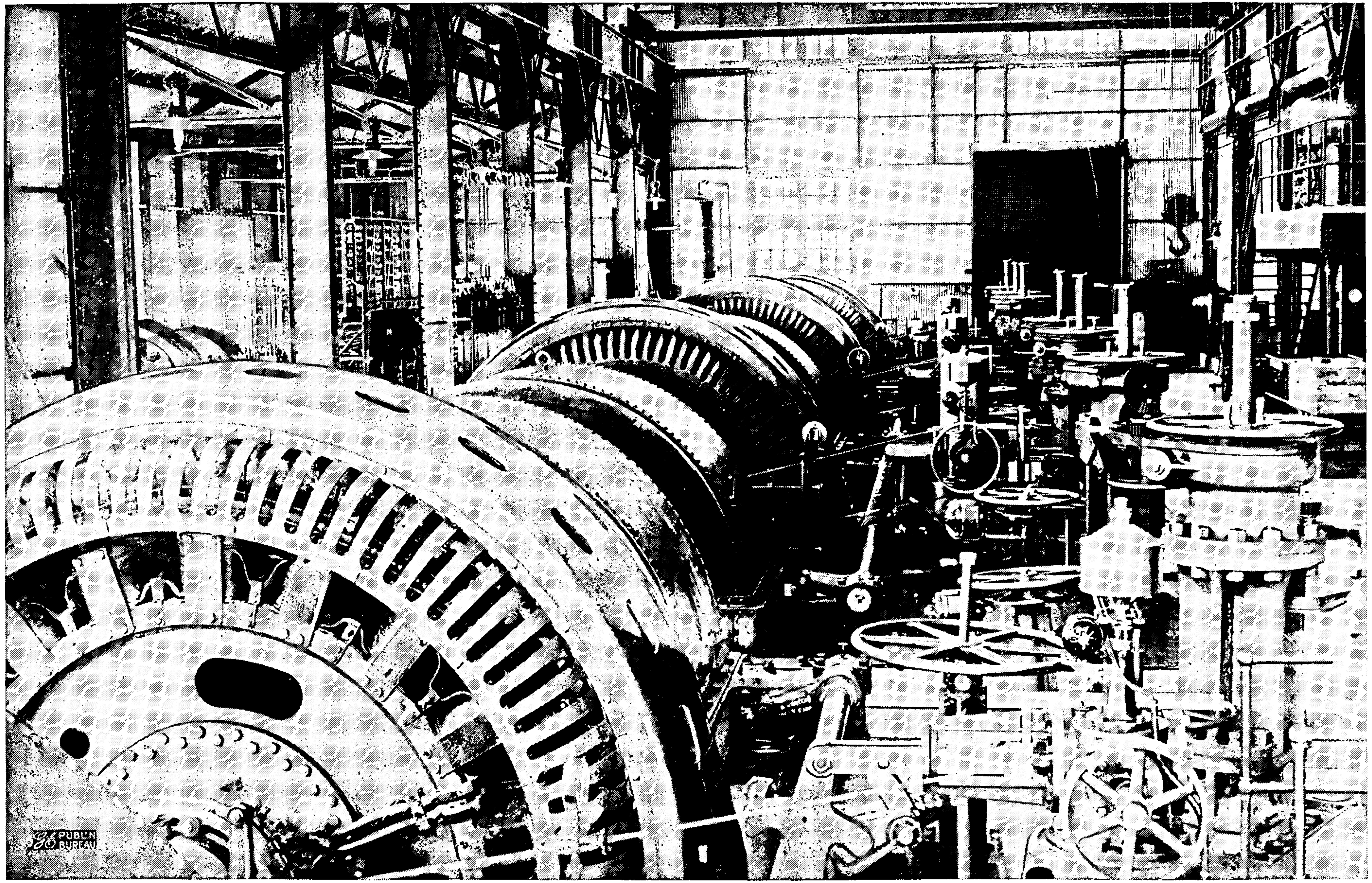



Fig. 64. Sturtevant Steam Turbine Direct-Connected to Generator

**Triumph Electric Company.** *Engine Types.* Fig. 65 shows one of a line of Triumph engine type generators, ranging in size from 30 to 1000 kw. The magnet frame is made of close grained cast steel with pole pieces of the laminated type bolted to the frame. Sizes smaller than 250 kw. have the frame split vertically, while the larger sizes have the frame split horizontally. The shunt and series coils are wound separately, the series coil being formed of solid bar copper, with spaces left between the coils. The armature is of the self-contained ironclad type. With the exception of the higher voltage and the smaller machines the armatures are bar-




OUR 8500-K.W. 4000-VOLT GENERATORS AT THE STANISLAUS STATION, SIERRA AND SAN FRANCISCO POWER COMPANY

*Courtes... General Electric Com...*

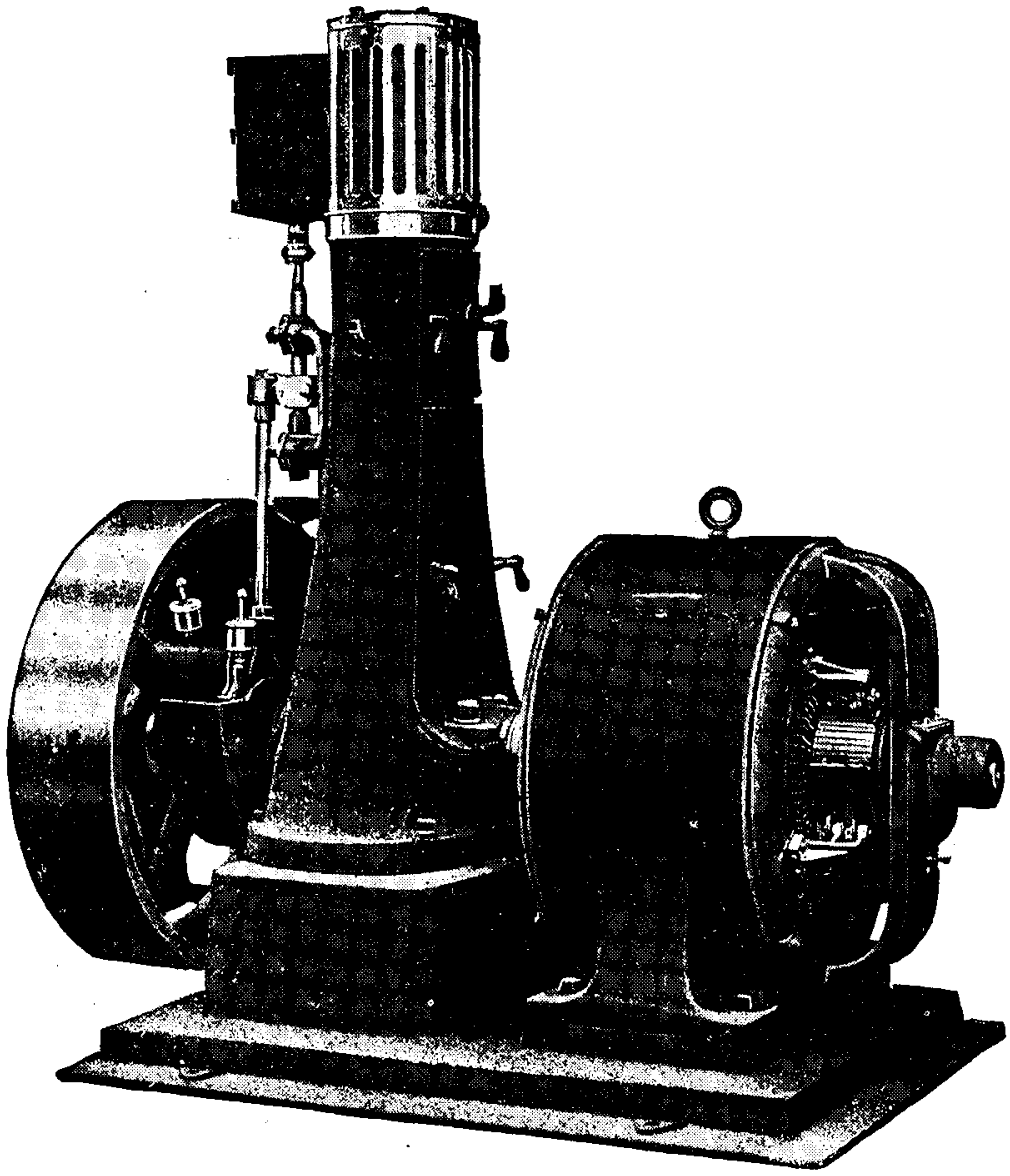


Fig. 66. Triumph Generator Direct-Connected to Troy Engine

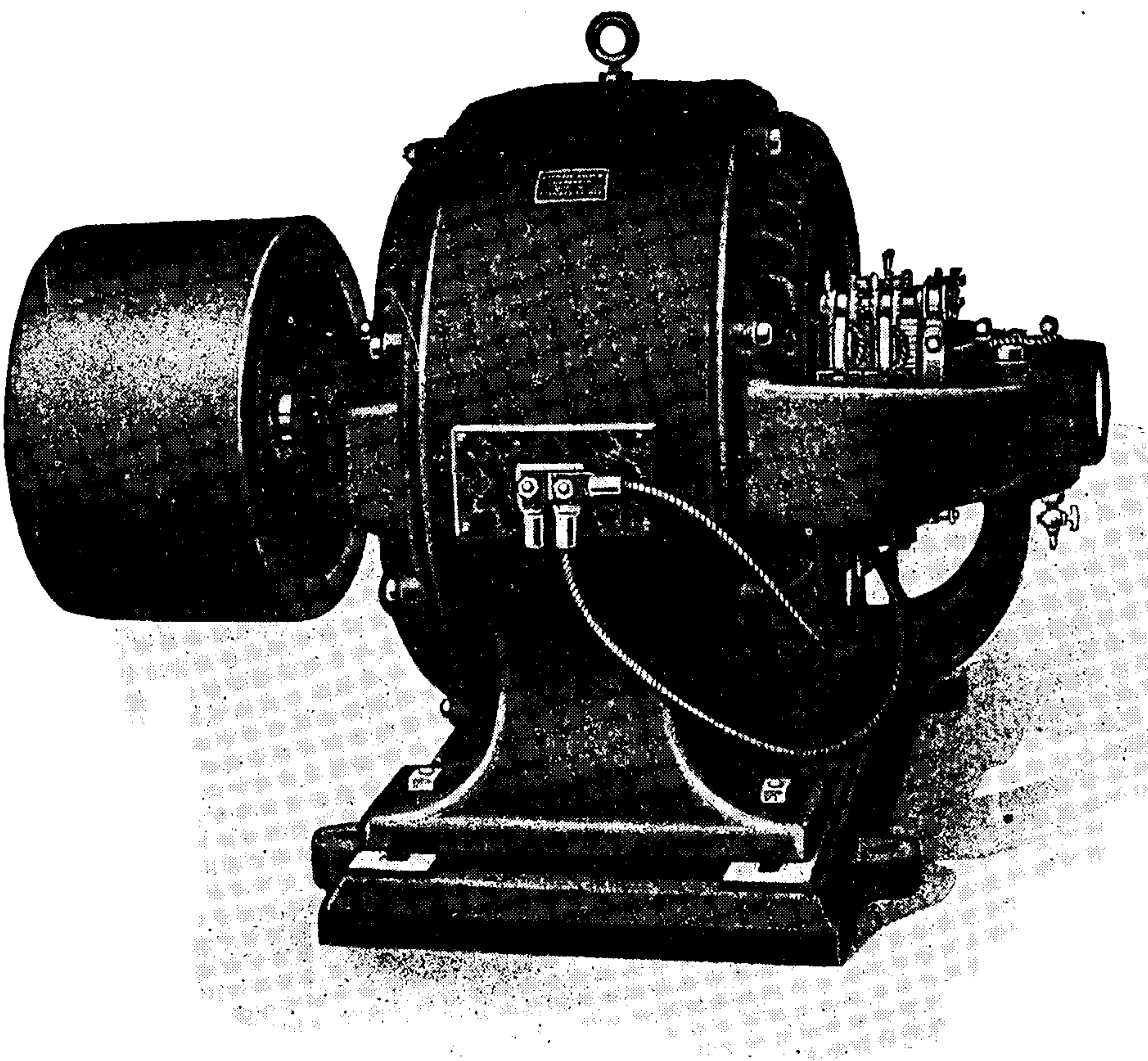


Fig. 67. Triumph Belted Generator

wound, each coil consisting of one continuous length of solid copper, and held in position by hardwood wedges.

*Generating Sets.* This company also builds a line of generating sets of the marine type as shown in Fig. 66, in sizes from 4 to 25 kw., all 4-pole machines and running at 500 to 350 r. p. m.

*Belted Types.* Triumph belted generators are built in sizes ranging from ½ to 100 kw. The frame is made of close grained

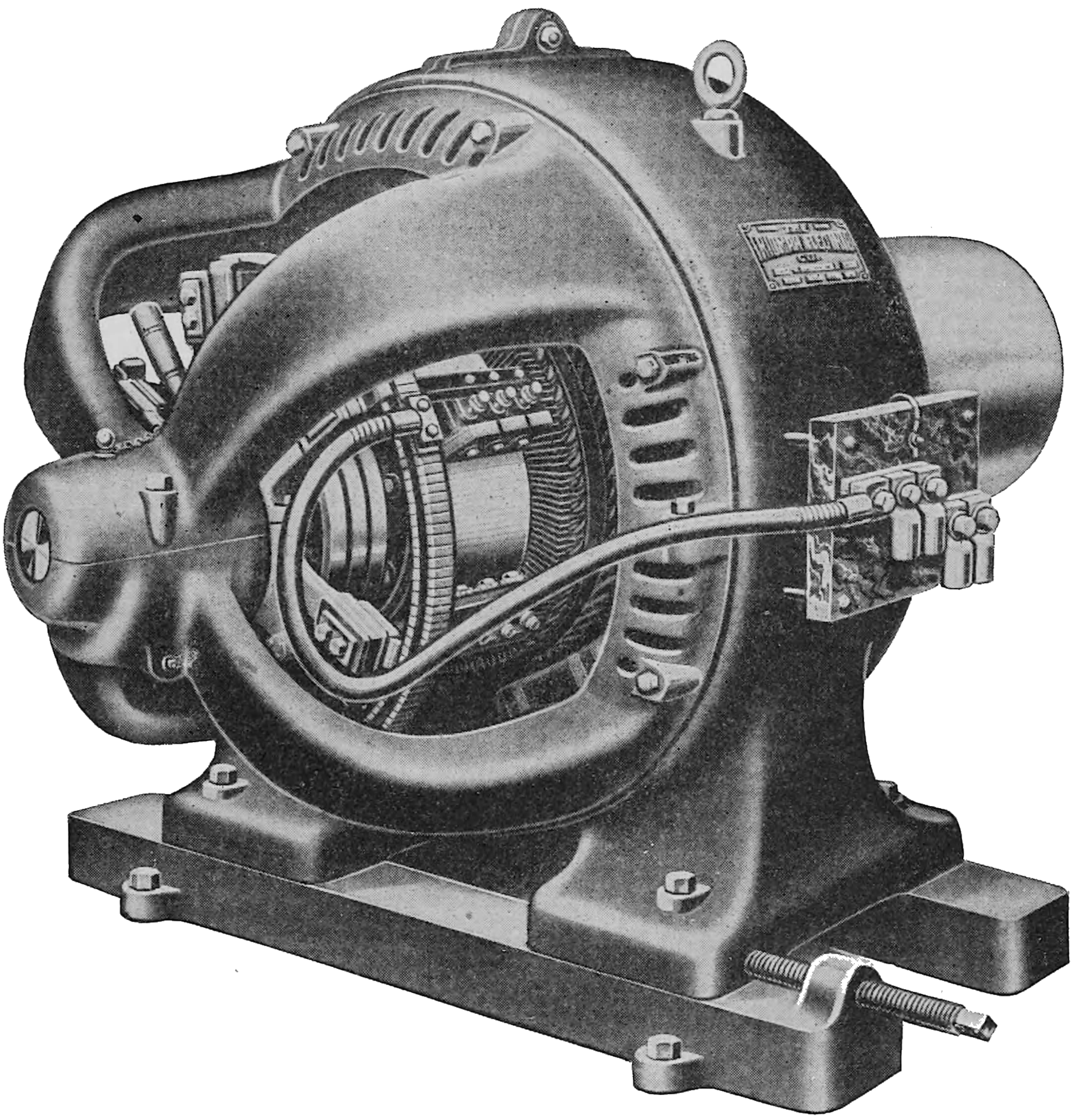


Fig. 68. Three-Wire Belted Generator
*Courtesy of Triumph Electric Company*

steel. The larger sizes are built with laminated poles and the smaller sizes employ solid steel poles with laminated tip or shoe. The larger frames employ a three-arm bracket, as shown in Fig. 67, to support the bearings, while in the smaller frames only a two-arm bracket is employed.

*Three-Wire Types.* This company's line of three-wire generators is illustrated in Fig. 68. These machines are built in all standard sizes from 25 kw. up and are wound for 250 volts. They differ from the single voltage machines only by the addition of three collector rings tapped into the direct-current armature winding at the proper points. These collector rings are attached to three reactance coils, connected in star, their neutral point being joined to the neutral wire of the three-wire system.

**Westinghouse Electric and Manufacturing Company.** *Interpole Type.* This company builds a line of direct-connected generators. designated as type Q, in sizes from 25 to 1000 kw. Up to 100 kw. they are wound for 125 or 250 volts at full load; from 100 up to 300 kw. they are wound for either 125, 250, or 600 volts at full

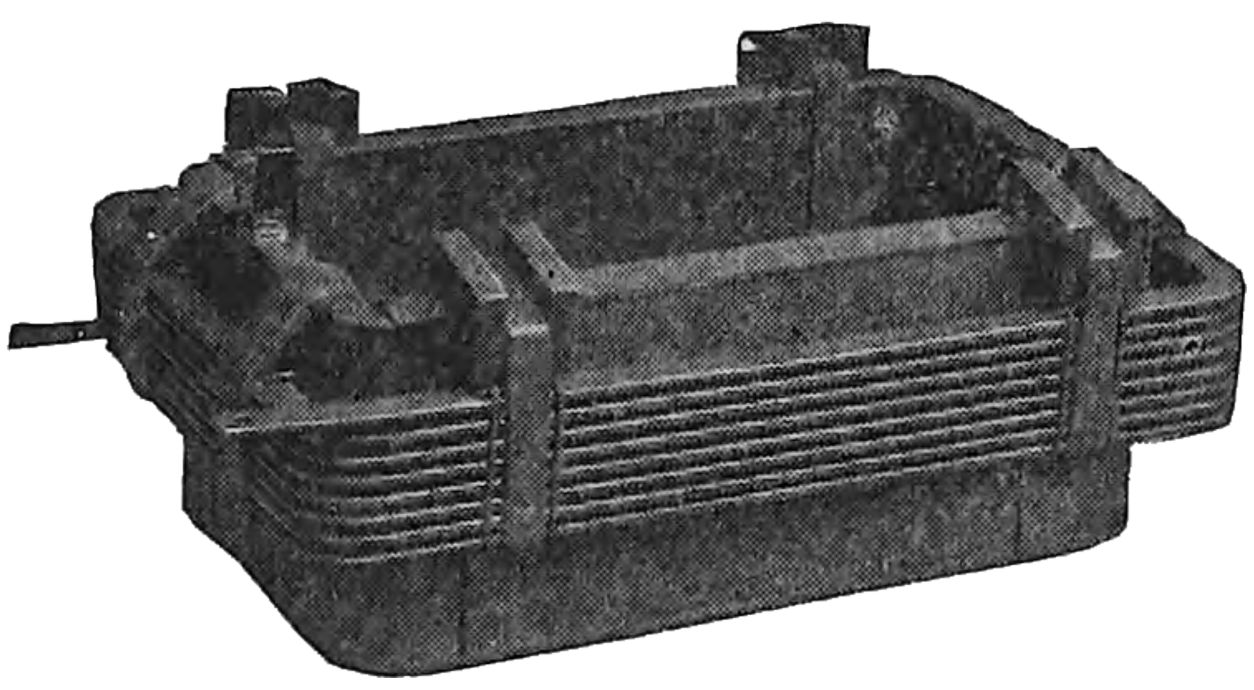


Fig. 69. Westinghouse Type Q Main Coil Windings

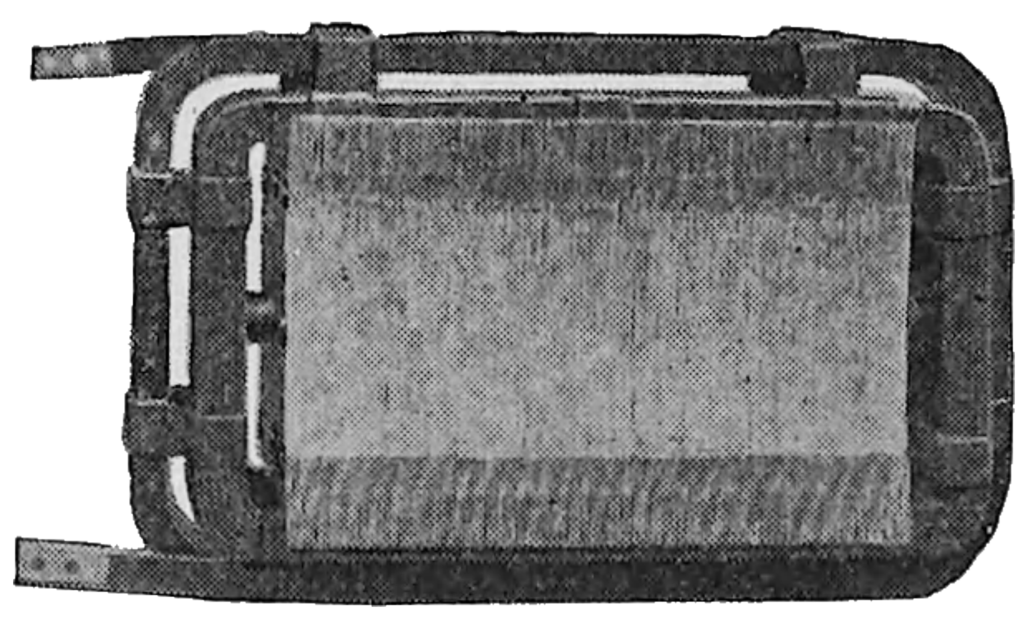


Fig. 70. Westinghouse Type Q Field Coils Showing Air Space

load; and above 300 kw. they are wound for 250 or 600 volts at full load. They are all compound-wound and employ commutating poles or interpoles. The no-load voltages are 118, 230, and 550. The field frames are of cast steel of approximately elliptical cross section. Machines having a capacity of 50 kw. and greater have their frames divided horizontally, while machines of small capacity have their frames cast in one piece. The pole pieces are laminated and through bolted into the frame. The main field coils are constructed so as to afford the best ventilation. An air space is provided between the inside of the shunt coil spools and the sides of the poles. The series coils are made of bare edge-wound strap windings. There is an air space between adjacent turns and between each shunt and series coil, permitting a free circulation of air about each conductor. This construction is shown in Figs. 69 and 70. The commutating poles are made of one piece of steel and are firmly bolted to the frame. The commutating pole coils are of edge-wound copper

Another line of machines, designated type S, furnishes the smaller sizes. The methods of manufacture and materials for the various parts are the same as in the other lines, but the outward appearance is entirely different, since the bearings are supported by brackets of the skeleton type with radial arms and an outer ring bolted to the frame. (See motor of same type, Fig. 105.) The standard belted machines range from 2 to 85 kw. for 125 and 250 volts and from $3\frac{1}{2}$ to 75 kw. at 550 volts. When direct-connected they require special windings and the capacity of any frame changes, the output being roughly proportional to the speed of the armature.

Still another line, called type R, gives eight sizes from $\frac{3}{4}$ to $7\frac{1}{2}$ kw.; the smallest four sizes being bipolar, the others 4-pole. These are intended for belt driving, although the multipolar frames can be adapted for direct driving.

*Three-Wire Types.* Any engine type, any self-contained, and any type S generator of this company above 5 kw., provided the voltage is 250 or 550, may, by the addition of properly connected collector rings, become a three-wire generator. The Westinghouse Company prefers the two-phase arrangement. This necessitates four collector rings, as shown in Fig. 72. It further requires two compensators or autotransformers. These consist each of a single winding upon a laminated core and are each connected to two of the collector rings. The middle points of the autotransformers are connected together and to the neutral of the three-wire system.

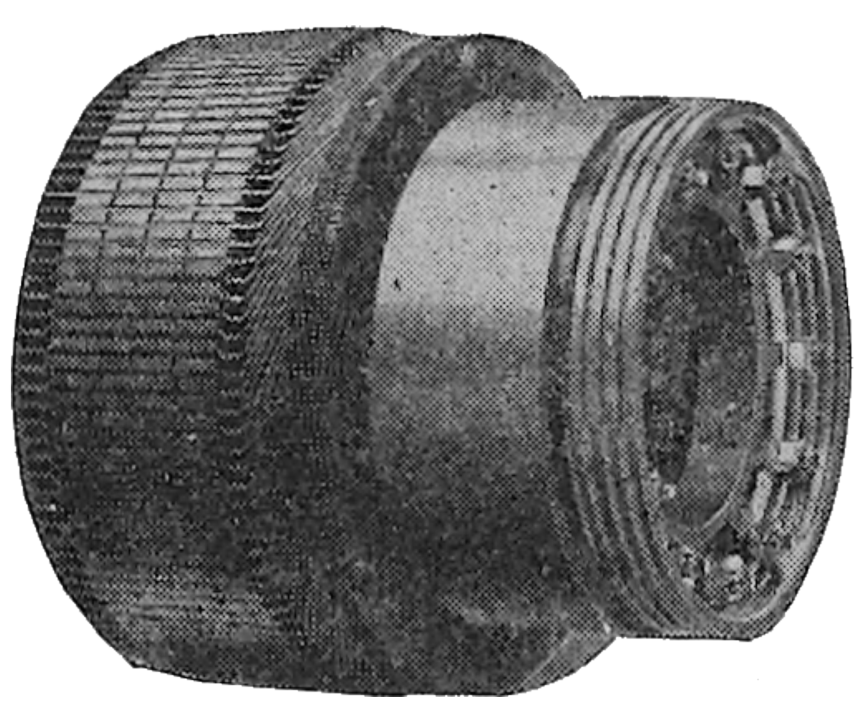


Fig. 72. Armature of Westinghouse Three-Wire Generator

## MOTORS

**General Characteristics.** Direct-current motors are either shunt, series, or compound. A shunt motor runs at practically constant speed for all loads, has a torque almost directly proportional to the armature current, and has a starting torque usually 50 to 100 per cent greater than full load running torque. A series motor runs at greatly decreasing speed for increasing loads, has a torque that increases almost as the square of the armature current or at least much faster than proportional to it, and has a powerful starting torque. A compound-wound motor approximates the shunt or the series type in its characteristics, depending upon what winding preponderates.

**Speed Classification.** Direct-current motors, according to their speed performance, fall into four different classes:

(1) *Constant speed motors,* in which the speed is either constant or does not materially vary, as shunt motors and compound motors in which the shunt field preponderates.

(2) *Multispeed motors* (two-speed, three-speed, etc.), which can be operated at any one of several distinct speeds, these speeds being practically independent of the load, such as motors with two armature windings.

(3) *Adjustable speed motors,* in which the speed can be varied gradually over considerable range, but when once adjusted remains practically unaffected by the load, such as shunt or slightly compounded motors designed for a considerable range of shunt field variation.

(4) *Varying speed motors,* or motors in which the speed varies with the load, decreasing when the load increases, such as series motors and compound motors in which the series winding preponderates.

## DESCRIPTION OF TYPES

**Allis-Chalmers Manufacturing Company.** The larger constant speed motors of this company employ the same frames as their belt generators. These motors include many sizes at 110 and 220 volts from 50 to 400 horsepower, ranging in speed from 800 to 180 r. p. m. Allis-Chalmers type K machine, shown in Fig. 73, is built in different frame sizes with a number of ratings for each frame, depending upon the winding and the speed. The smallest shunt-wound constant speed size in the 110-volt line is $\frac{1}{2}$ h. p. at 500 r. p. m., and the largest is 80 h. p. at 500 r. p. m. They are also wound for 220 and 500 volts. They can be used as adjustable speed motors with a range in speed of 1 to 3. They can be wound as any type compound or series motors, thus becoming varying speed motors.

The cylindrical field magnet yoke is of open hearth steel and is machined on each end to receive the housings that carry the bearings. The housings are held in place by through bolts and on 4-pole machines can be rotated 90 degrees or 180 degrees to allow side wall or ceiling mounting; bipolar machines can be arranged for floor or ceiling mounting. The pole cores fastened to the yoke by cap screws are circular in cross section and made of open hearth steel. The pole shoes are of steel punchings riveted together and fastened to the cores by screws. The field coils effectively impregnated so as to be

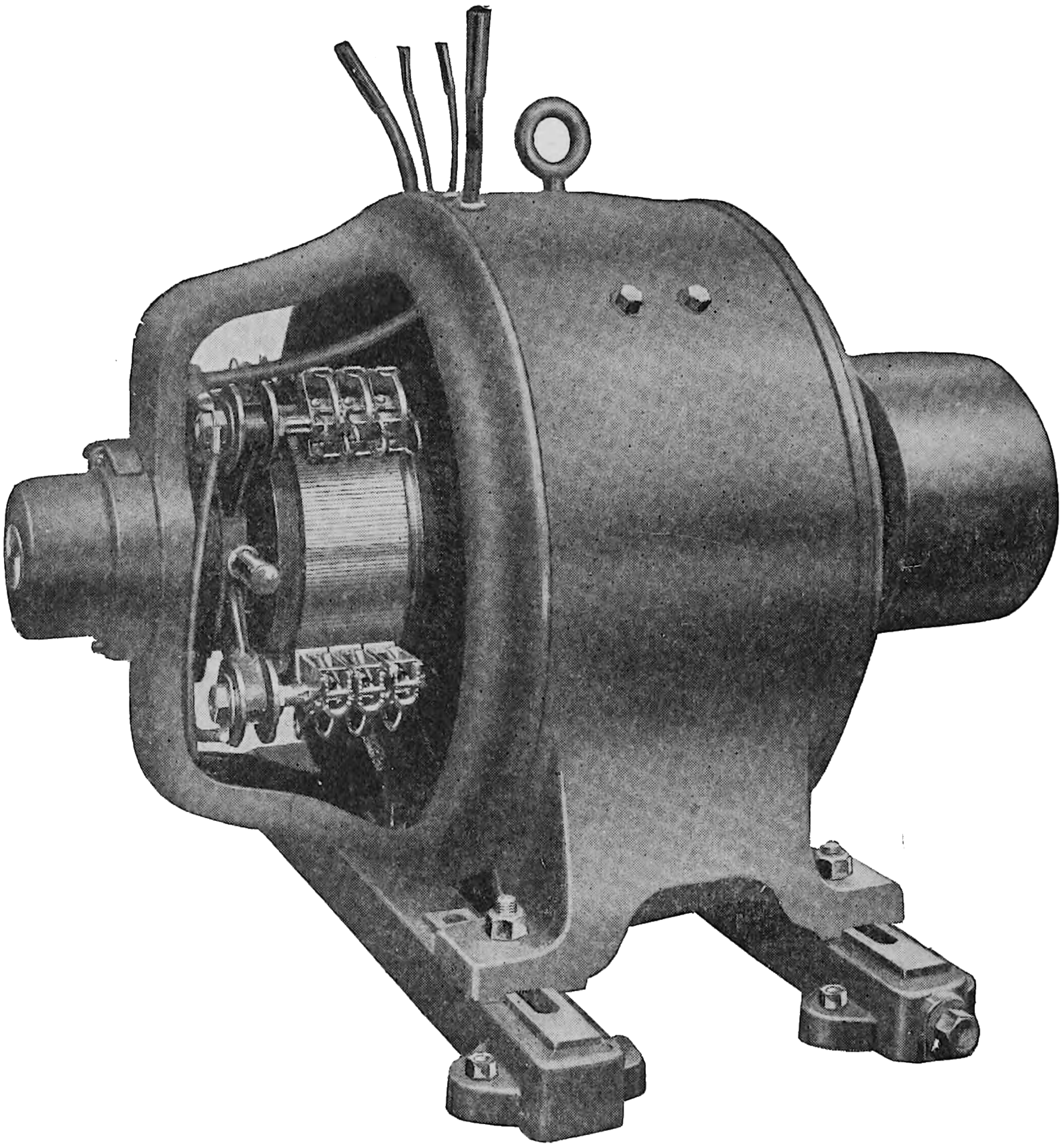


Fig. 73. Allis-Chalmers Type K Motor

moistureproof are wire machine-wound. The armature is ironclad, of the ventilated type with interchangeable form-wound coils.

Fig. 74 shows an Allis-Chalmers type K motor direct-connected to the work. Standard motors of this type are made open at the ends; they can, however, also be made semi-enclosed and totally enclosed by the addition of suitable metal enclosing covers fitted to the end housings. The semi-enclosed type uses perforated covers

poles are of solid steel. The armature is ironclad with ventilating ducts. The coils are wire-wound, a sufficient number being bound

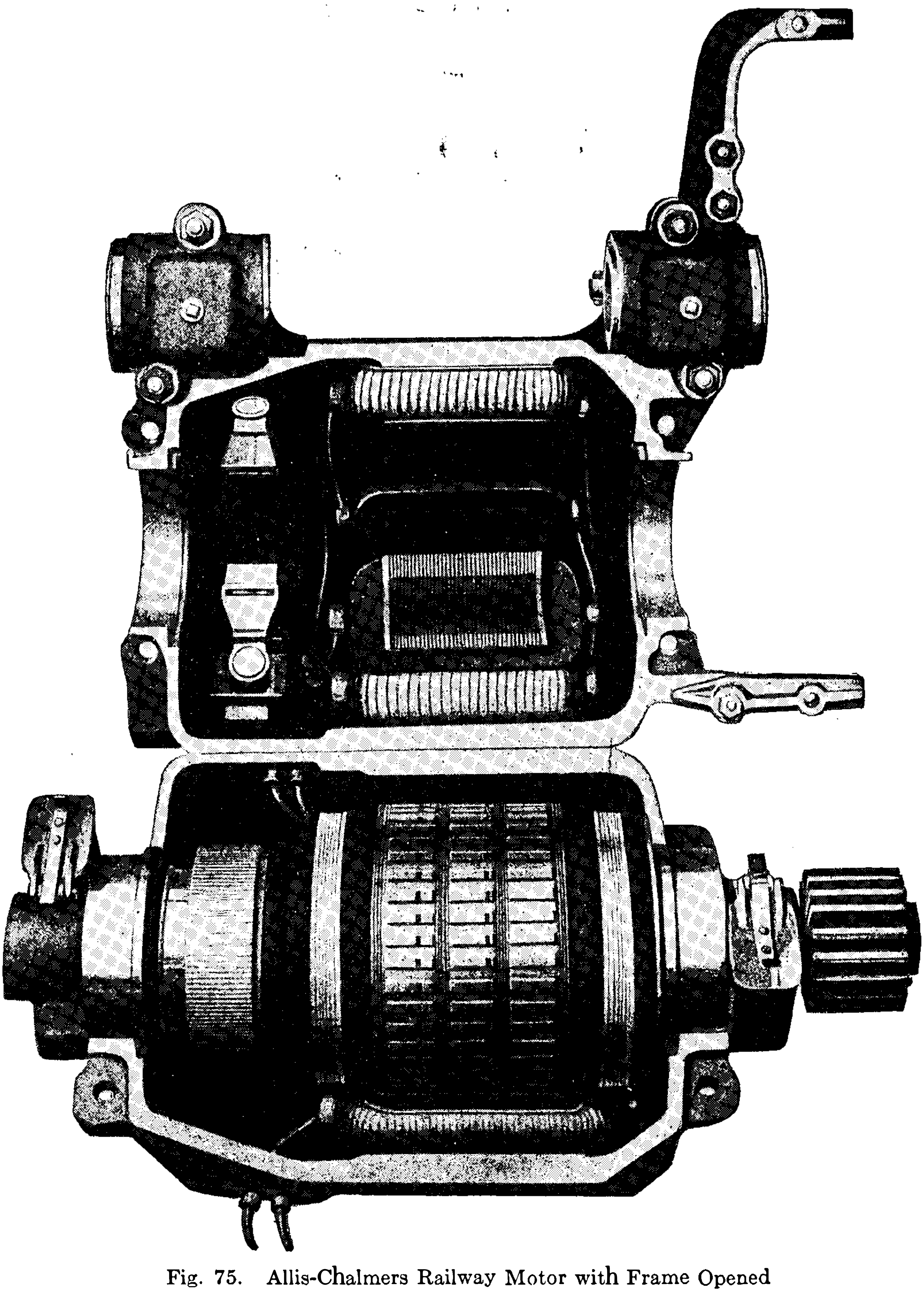


Fig. 75. Allis-Chalmers Railway Motor with Frame Opened

and insulated together to form a coil group. The two brush holders are rigidly mounted in the top half field frame.

**C & C Electric & Manufacturing Company.** This company employs the frames of their line of standard belted generators, shown

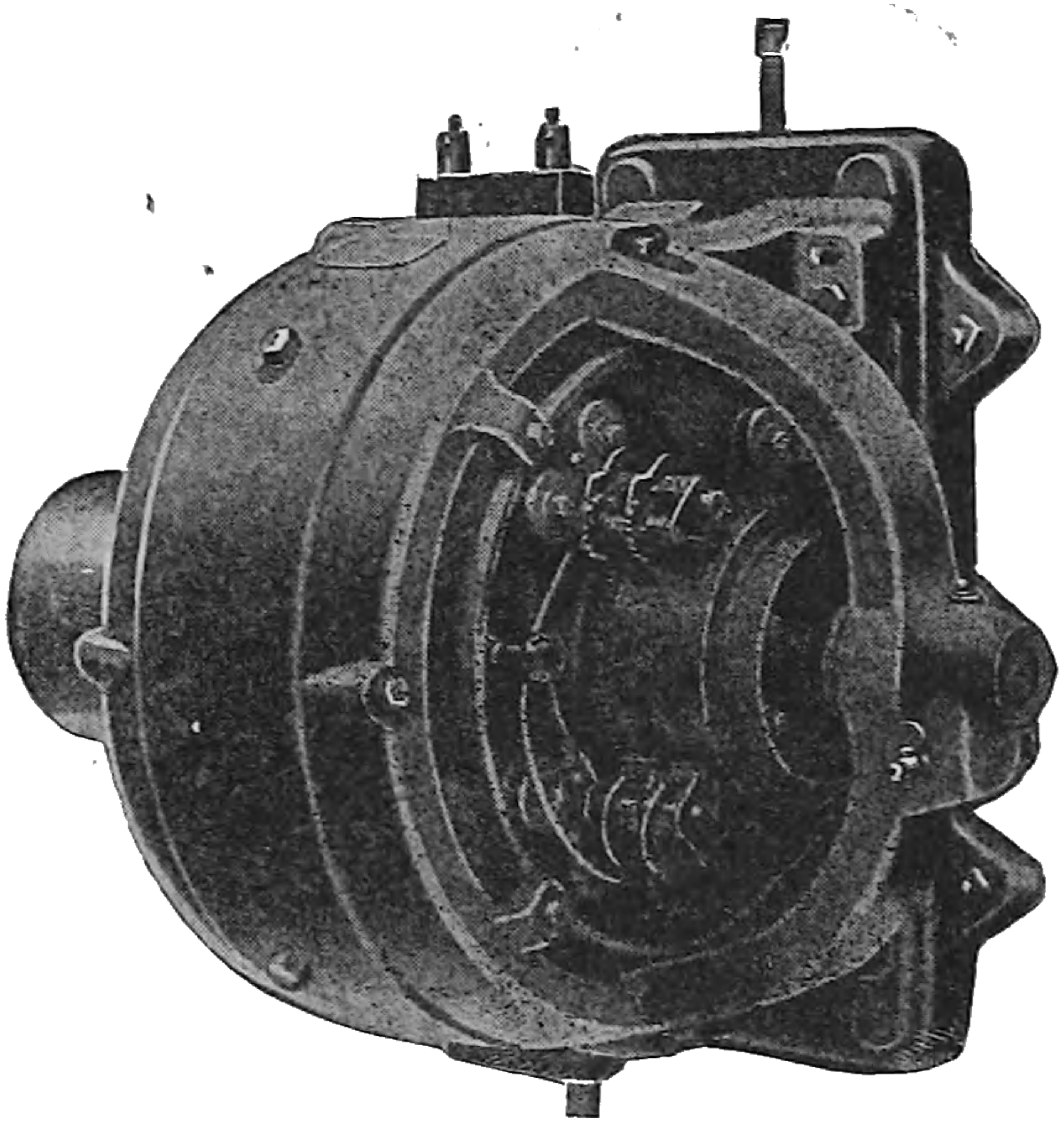


Fig. 76. C & C Open Wall S L Motor

in Fig. 26, for constant speed motors of the larger sizes. These machines are wound for 125, 250, or 500 volts. For the smaller sizes

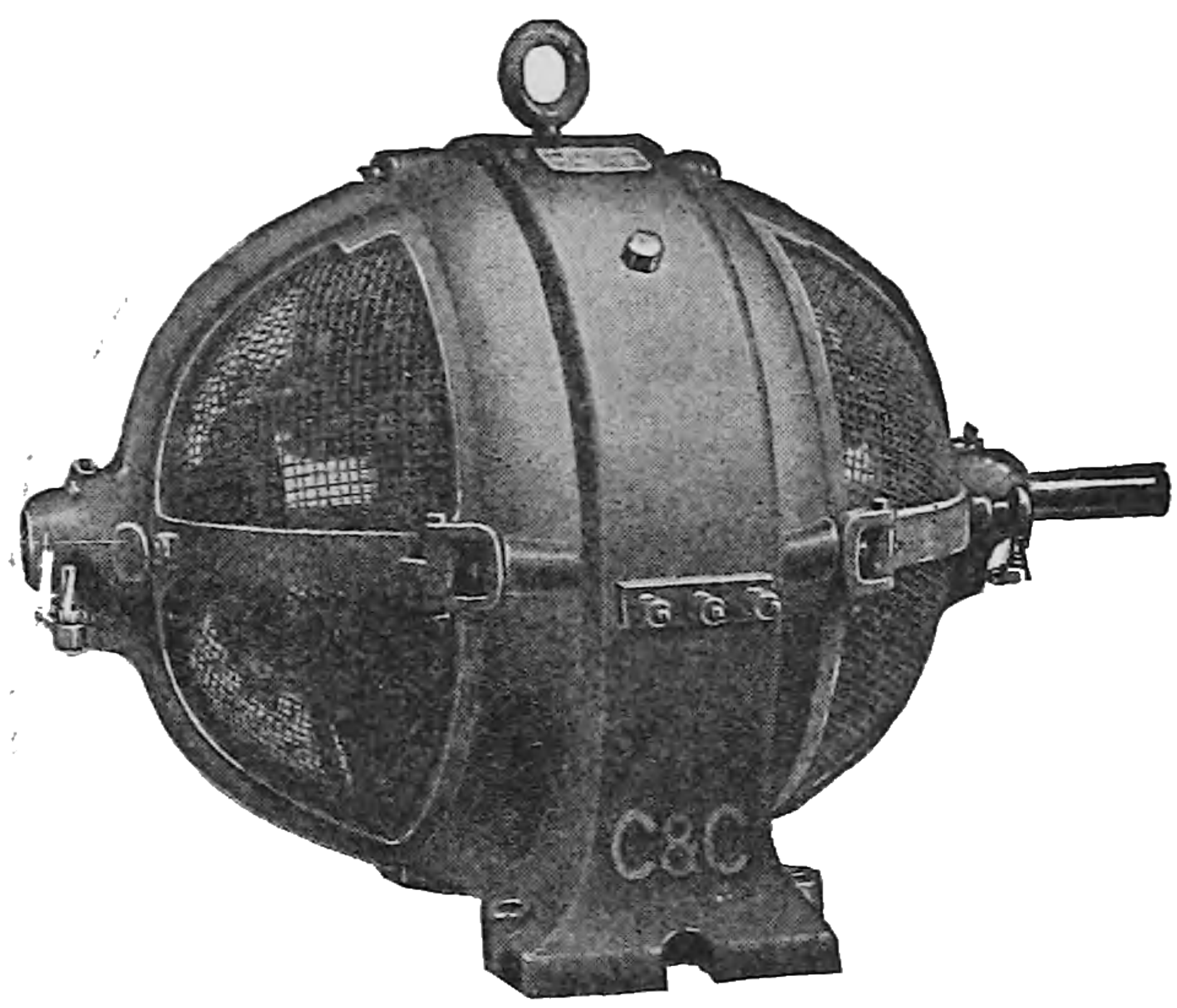



Fig. 77. C & C Semi-Enclosed S L Motor

they employ the type SL frames wound shunt or compound for constant speed. The SL frames are arranged for ceiling and wall mounting as well as with vertical shaft projecting upward or down-

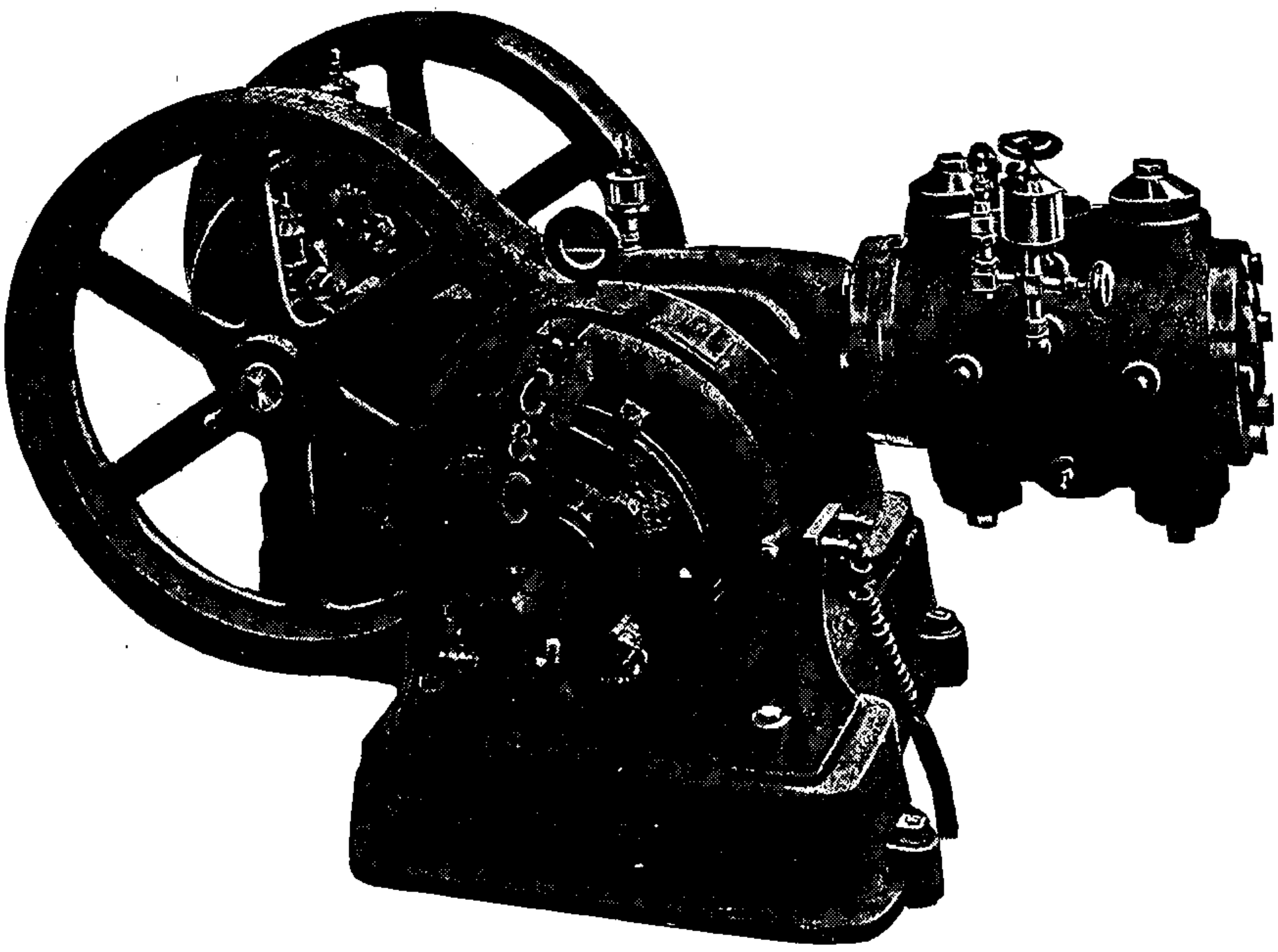


Fig. 78. C & C Type S L Motor Driving Reciprocating Compressor

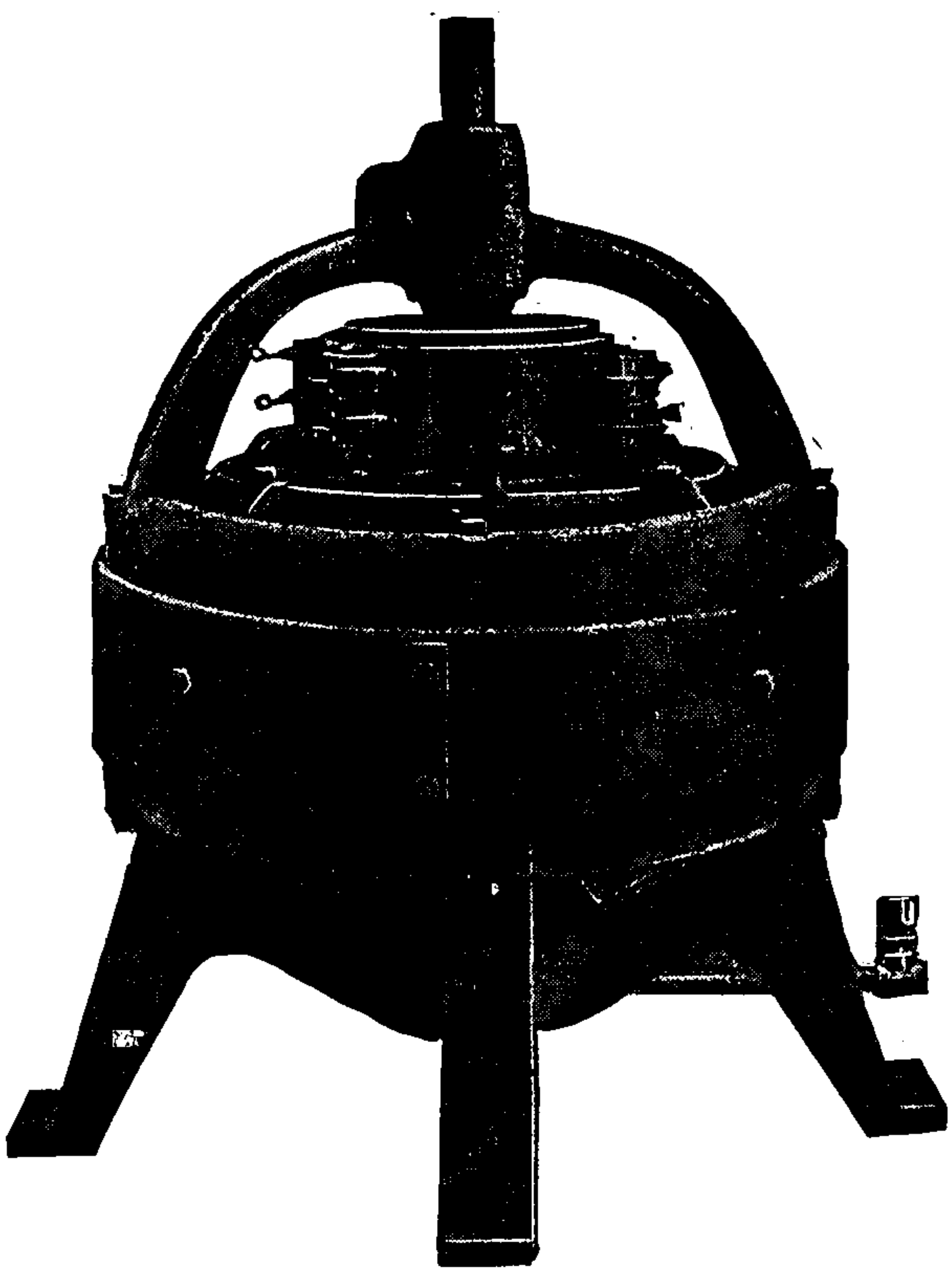


Fig. 79. C & C Vertical Type S L Motor

able speed motors which give speed ranges of 2 to 1; $2\frac{1}{2}$ to 1, or 3 to 1, as desired. It also can be arranged for floor, side wall, or ceiling mounting or with vertical shaft.

By adding proper covers to the open type it becomes enclosed or semi-enclosed, the latter either grid or gauze. Enclosed motors are particularly adapted to operate in flour mills, woodworking shops, boiler rooms, etc., where the air is continually filled with fine par-

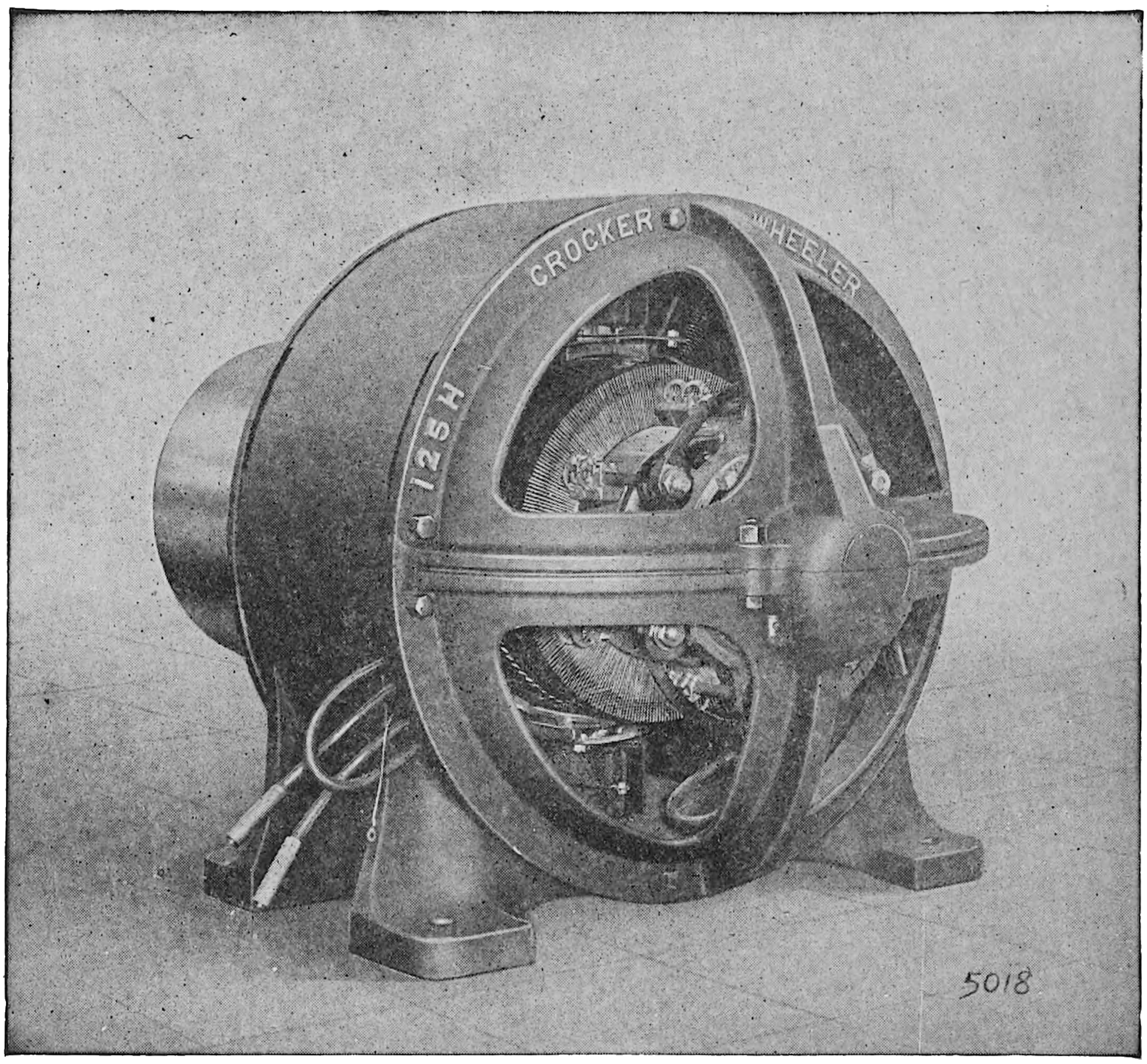



Fig. 81. Crocker-Wheeler Form H Commutating Pole Motor

ticles. Being almost airtight, they are of a larger frame for a given output than open ventilated motors; but with proper windings and frame they may be practically of the same efficiency as the open types. They are not well adapted for continuous running, but do admirably for intermittent service. For the smaller sizes of constant speed machines, the Crocker-Wheeler Company uses a 2-pole motor called by them form L. They are made in sizes from $\frac{1}{16}$ to $7\frac{1}{2}$ horsepower for operation on 115-, 230-, or 500-volt circuits and are suited for application to all sorts of light machinery. The special

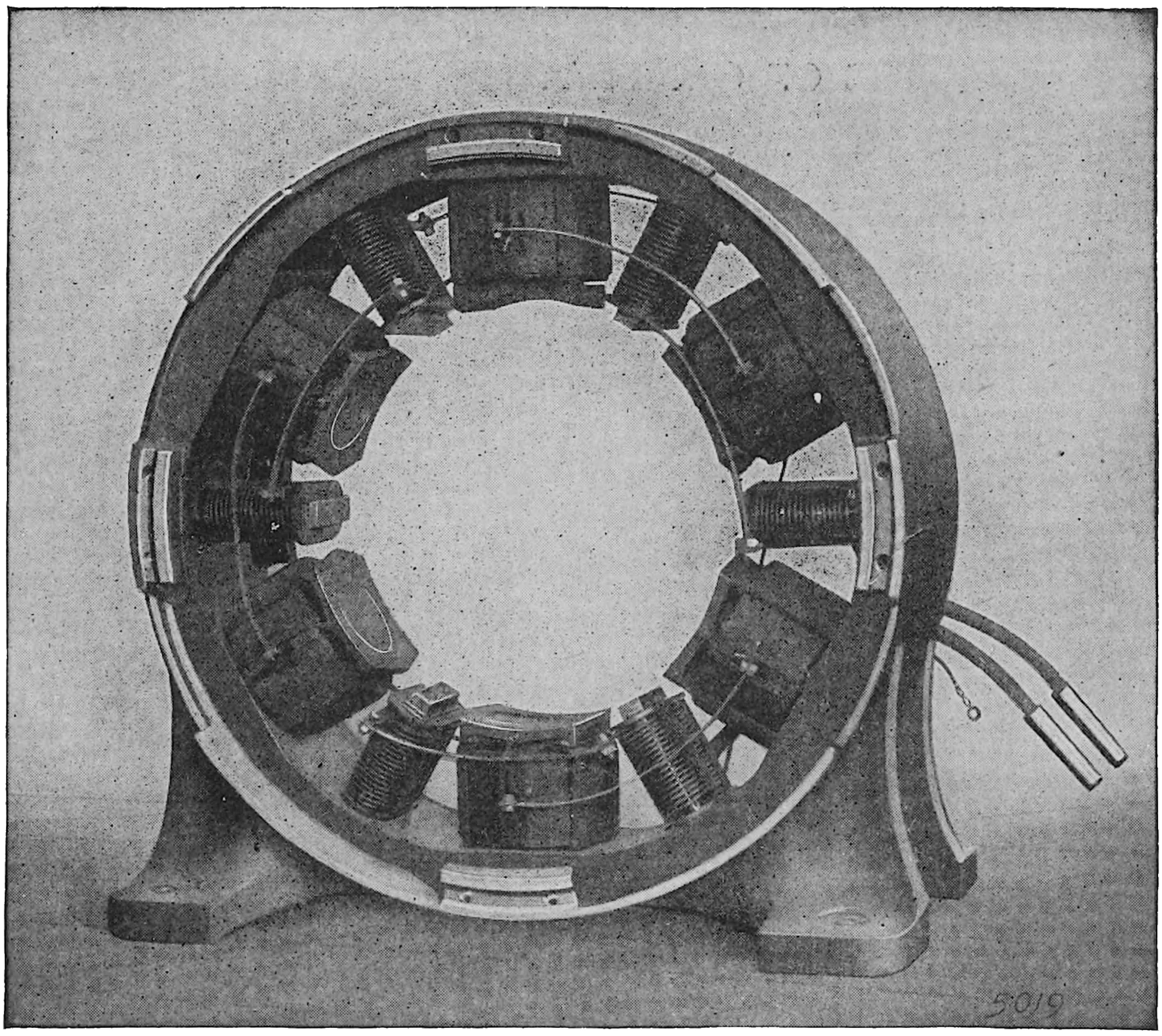


Fig. 82. Frame and Field Coils of Commutating Pole Motor
*Courtesy of Crocker-Wheeler Company*

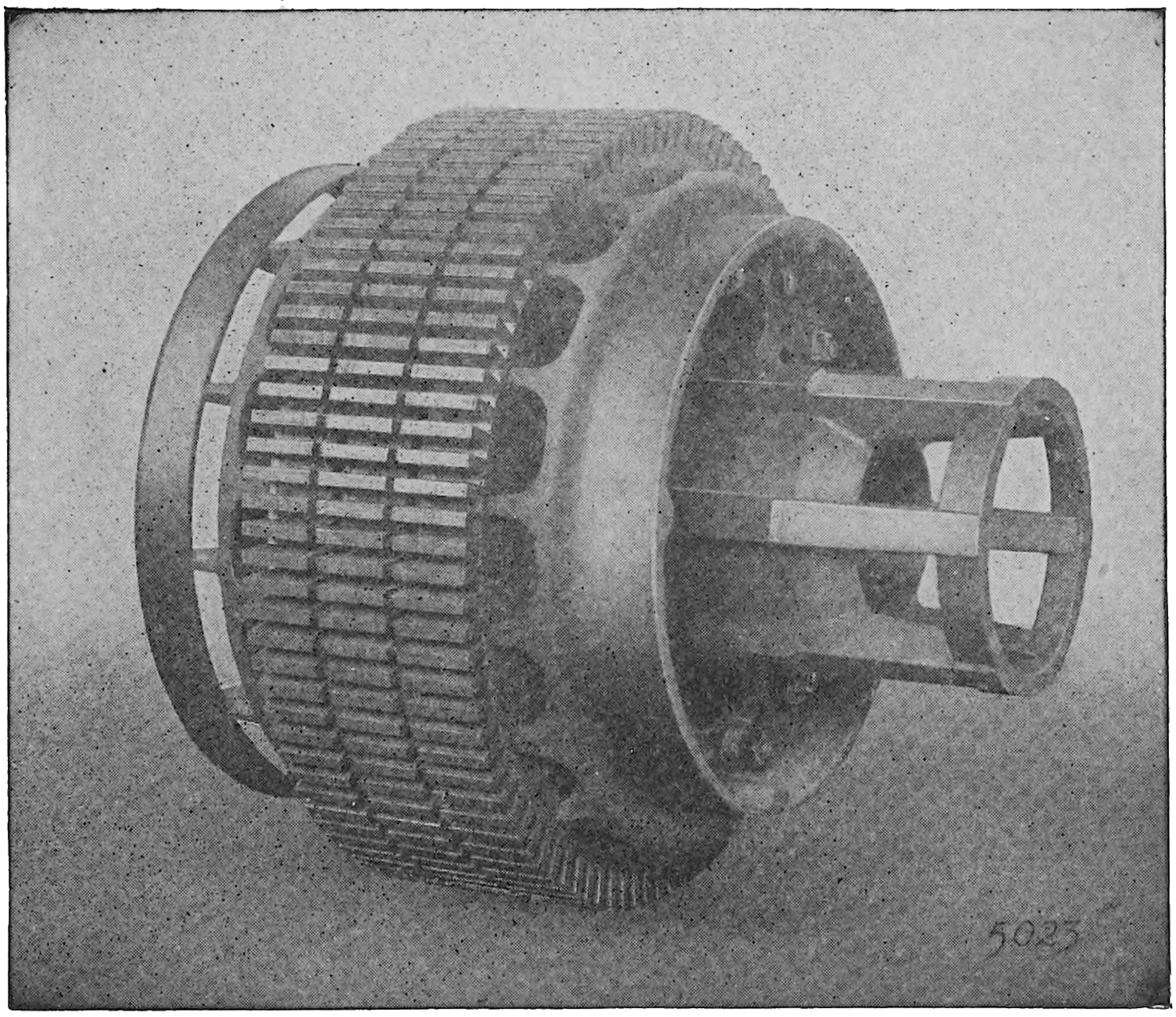


Fig. 83. Crocker-Wheeler Armature Core for Form H Motor

feature in this line is that the frame is of cast steel with the poles cast integral with the rest of the frame and carrying laminated pole shoes. The sizes from $\frac{1}{3}$ to 3 horsepower furnish, when properly wound, adjustable speed motors providing speed variations of 2 to 1, $2\frac{1}{2}$ to 1, or 3 to 1.

Fig. 84 shows one of this company's many applications. To supply the demand for traveling crane motors, they have developed a line of motors shown in Fig. 85. These are made in sizes from $1\frac{1}{2}$ to 60 horsepower operating on 115, 230, or 500 volts. They are series-wound, compact, of strong and durable construction, with rectangular frame, and are protected against dirt and moisture by enclosing covers.

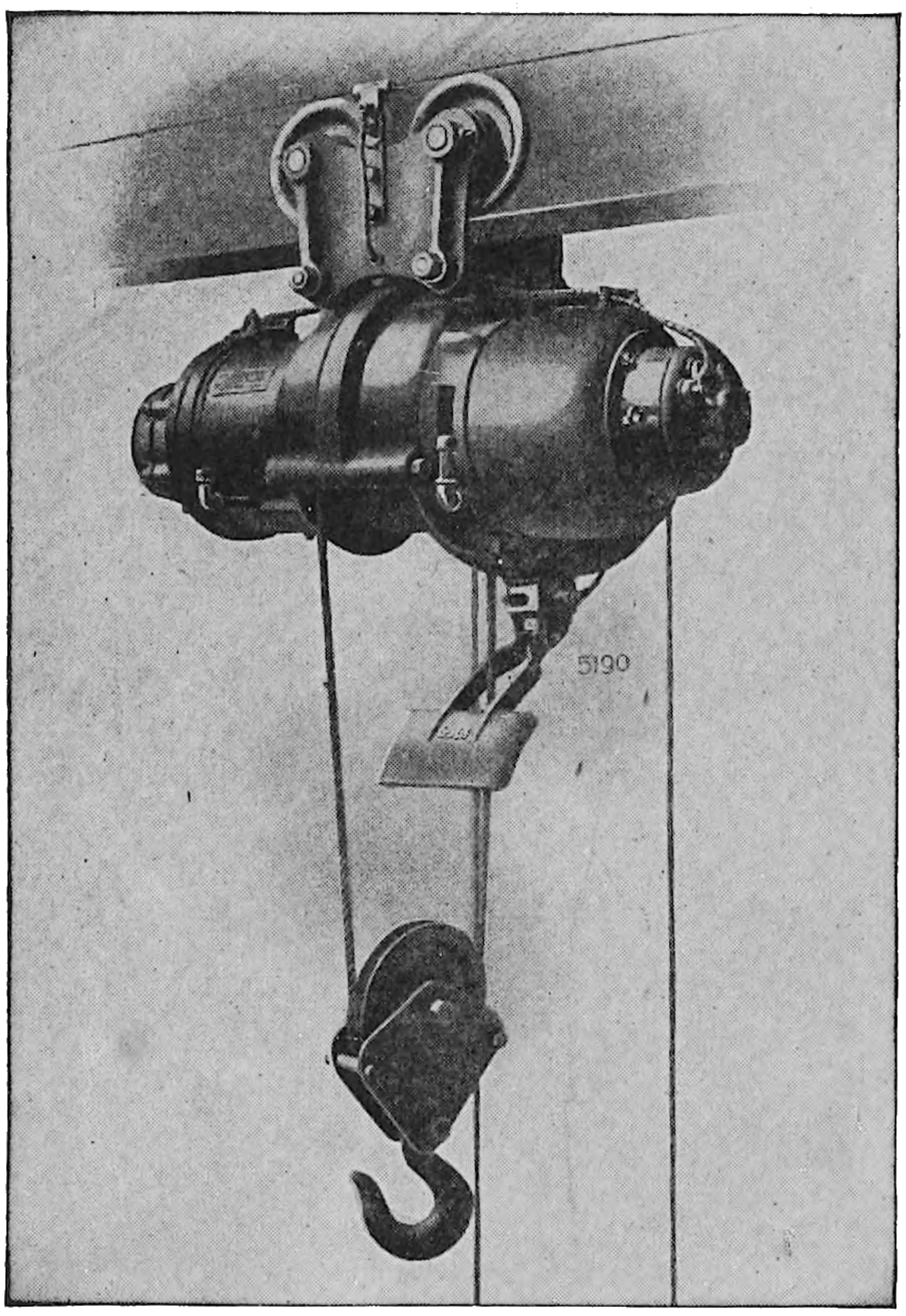



Fig. 84. Traveling Hoist Driven by Crocker-Wheeler Motor

**Electro-Dynamic Company.** A prominent type of adjustable speed motor is that of the Electro-Dynamic Company in which speed variations as great as from 6 to 1 may be obtained by field weakening. Sparking is prevented by the employment of interpoles; that is, auxiliary poles, small compared with the main poles, are located between the latter and provided with coils connected in series with the armature. The flux of these interpoles is in direct opposition to that of the armature and gives the commutation field. Since the coils of the interpoles are connected in series with the armature, the commutation field is not affected by weakening the shunt or main motor field to obtain the increased armature speeds, and is, furthermore, proportional to the load, thus producing sparkless commutation at all loads and speeds within the limits of the design of the machine. As the action of the interpoles is reversible the motors can be run equally well in either direction.

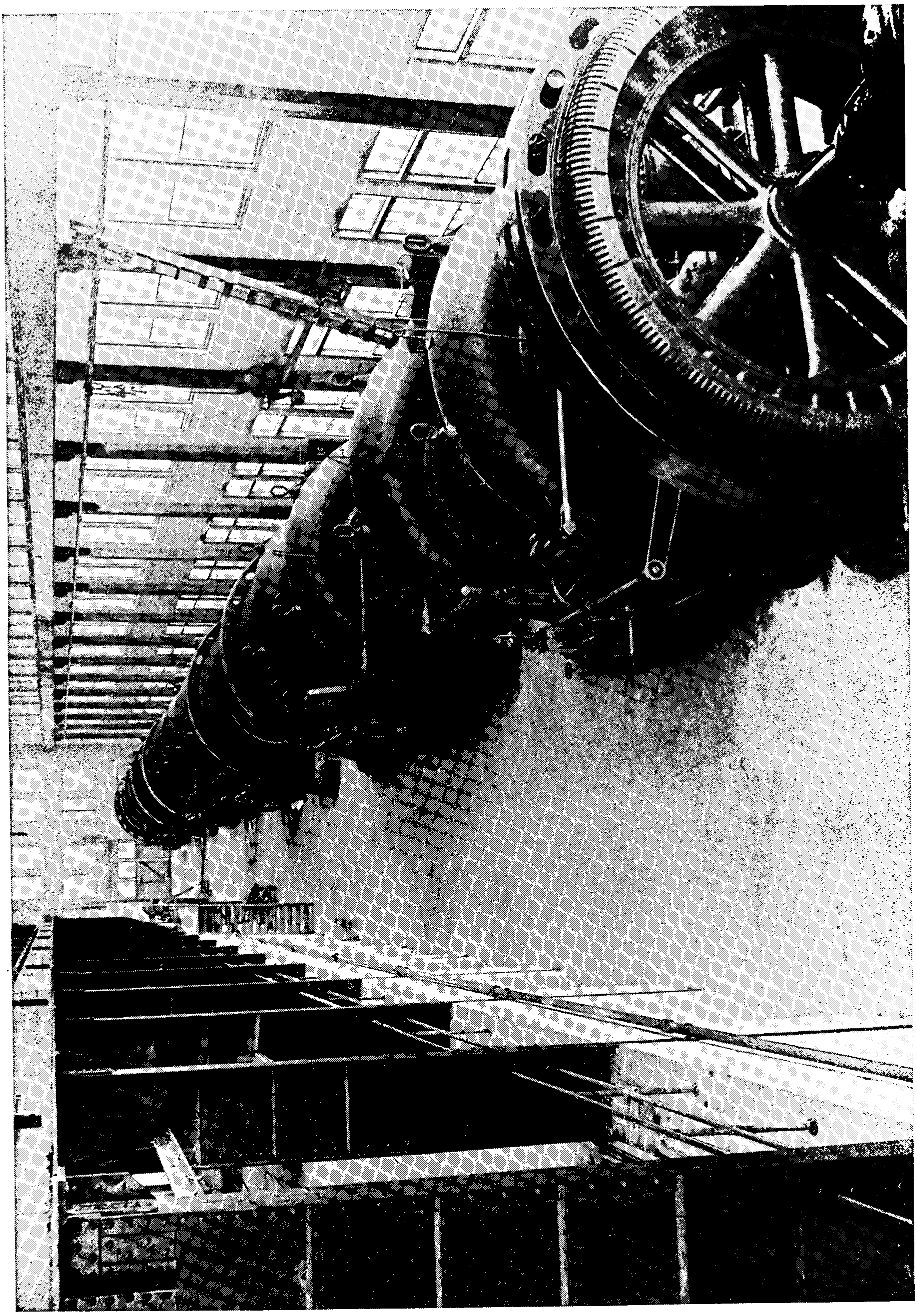


Fig. 86 is a view of one of these motors with the bearing housings and armature removed, showing the interpoles. These motors are manufactured in sizes from ½ to 75 horsepower as 4-pole machines and in sizes from 40 to 150 horsepower as 6-pole machines, operating

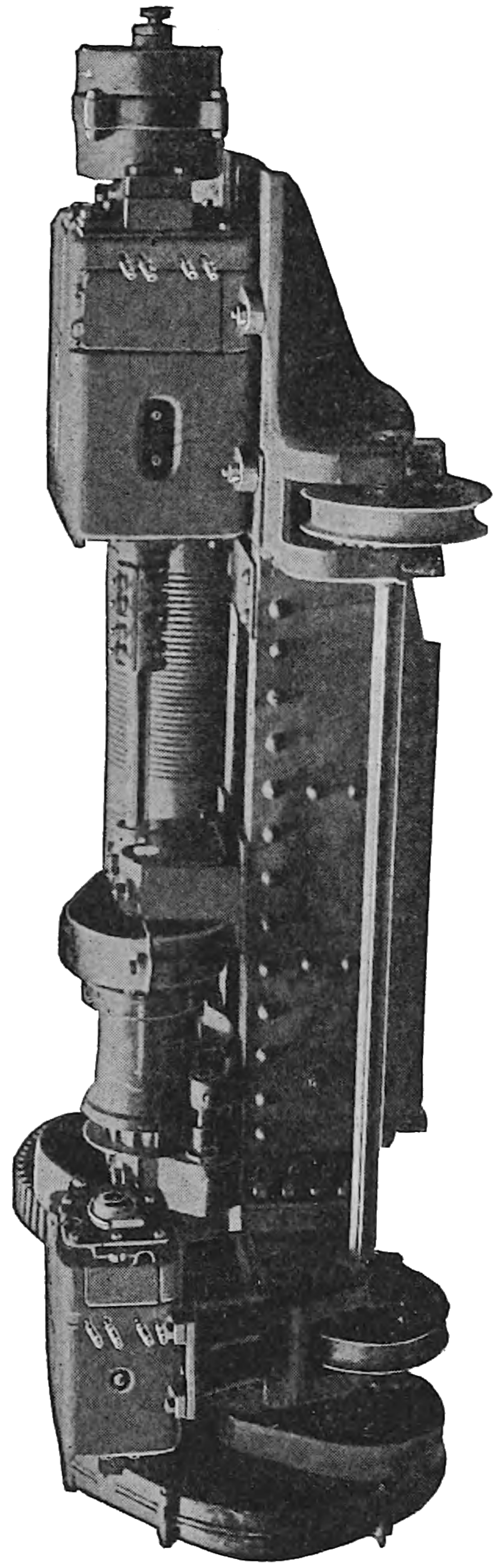


Fig. 85. Traveling Crane Operated by Crocker-Wheeler Motor
*Courtesy of Crocker-Wheeler Company*

on 110-, 220-, or 500-volt circuits and giving speed variations of 6 to 1, 5 to 1, 4 to 1, 3 to 1, 2 to 1, or 1½ to 1. The field yoke is of the best electrical steel cast in one piece. The main poles are made of cast electrical steel or of laminated steel and are bolted to the field yoke. They are skewed along the axis to prevent noise and to

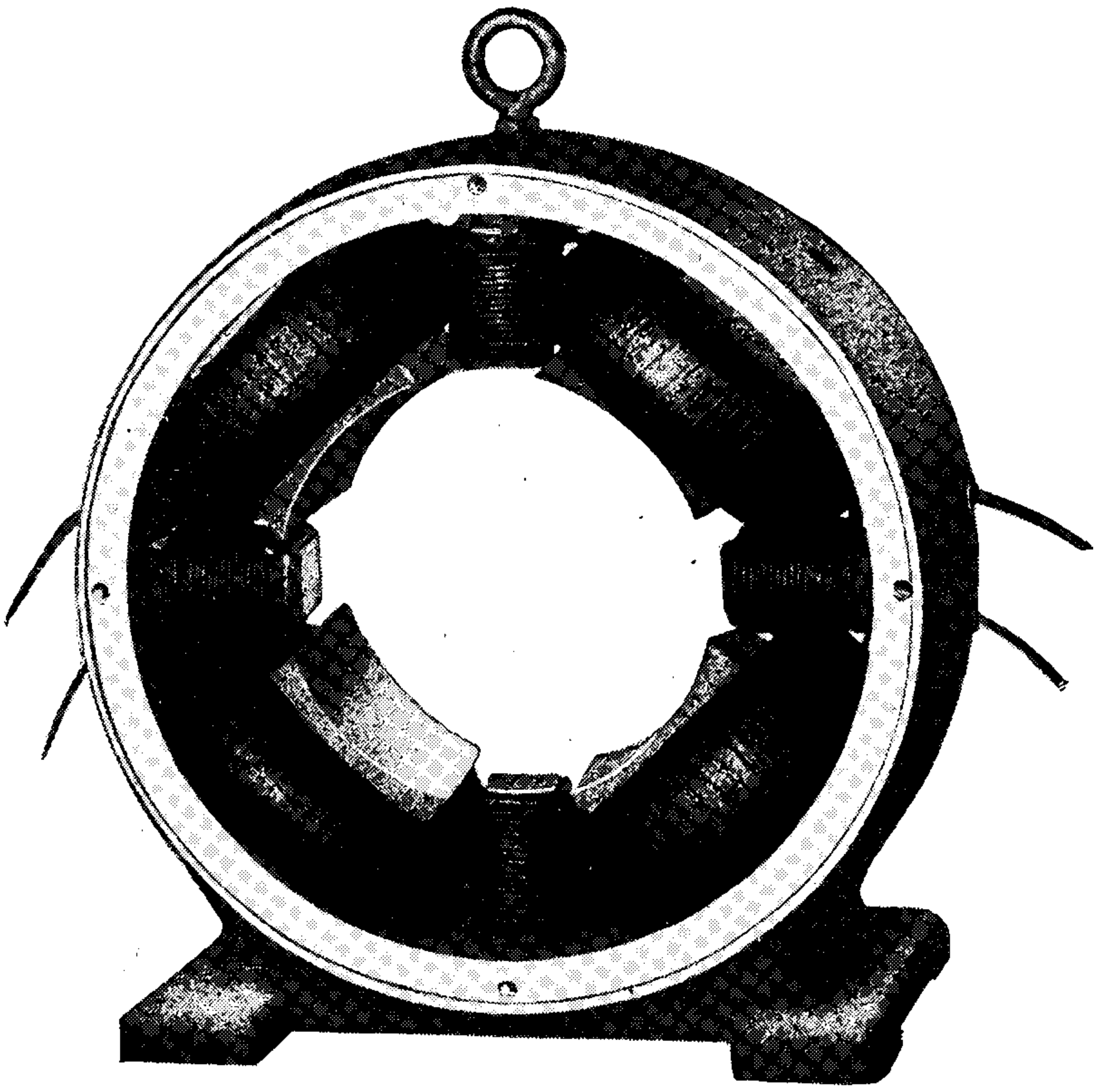


Fig. 86. Electro-Dynamic Motor Showing Interpoles

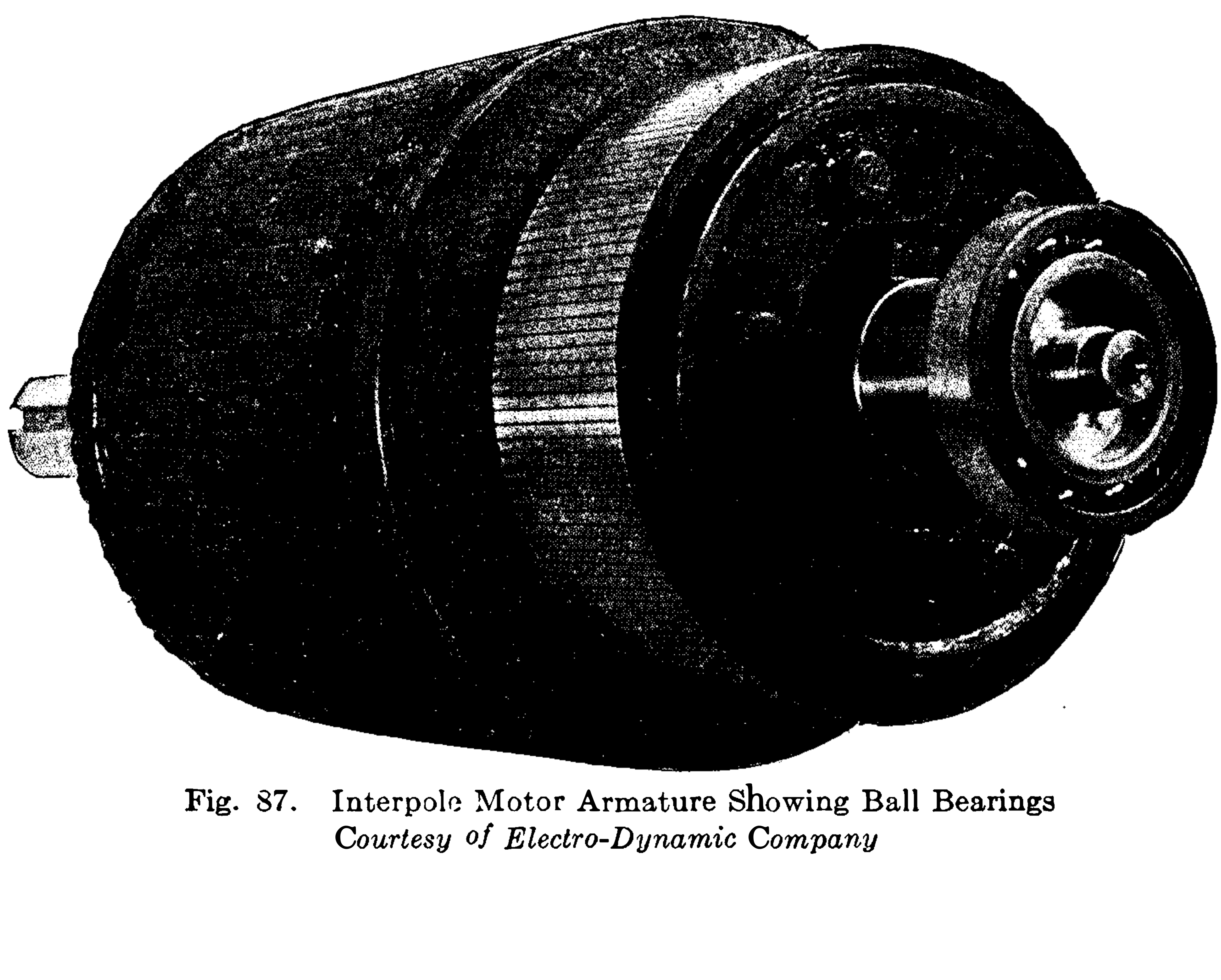


Fig. 87. Interpole Motor Armature Showing Ball Bearings
*Courtesy of Electro-Dynamic Company*

**Fairbanks, Morse & Company.** This company manufactures several lines of constant speed shunt-wound motors, using the same frames as for their lines of belted generators. The separate motors range from 150 horsepower at 650 r. p. m., like Fig. 38, down to 2 horsepower at 1800 r. p. m., like Fig. 37. The same frames are also compound-wound, giving a drop in speed of about 20 per cent between no load and full load. They are wound to operate on 115-, 230-, or 550-volt circuits. The smaller sizes are made in all the varieties of open, semi-enclosed, or enclosed, and arranged for floor, ceiling, side wall, or vertical mounting. Fairbanks, Morse & Company also furnishes a line of adjustable speed motors with speed variation of 2 to 1 or 4 to 1, as called for. Their frames, similar to Fig. 37, also furnish a line of commutating pole motors. Fig. 89 shows one of their smaller motors driving an exhaust fan.

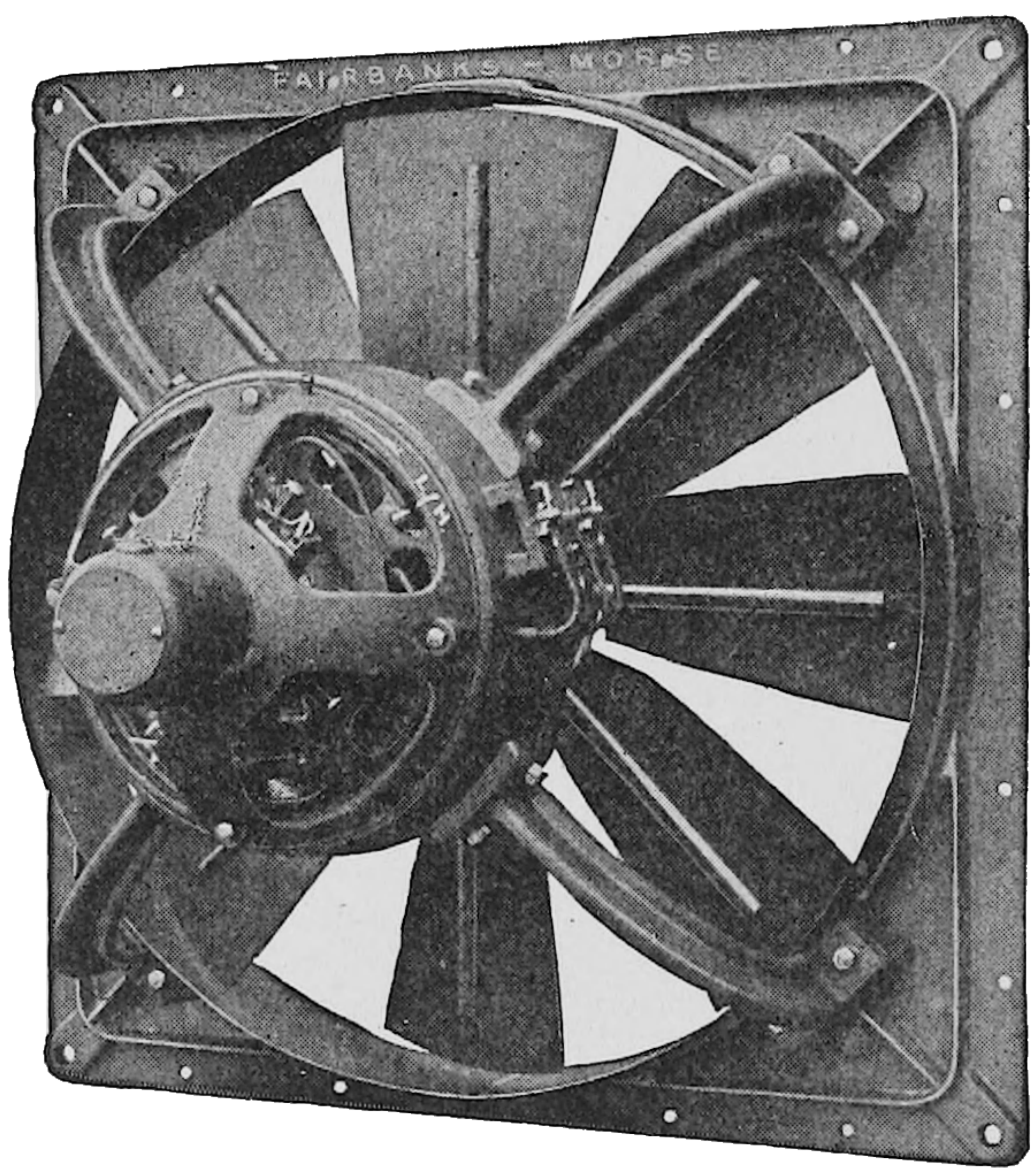



Fig. 89. Fairbanks-Morse D. C. Motor Driving Exhaust Fan

**Fort Wayne Electric Works.** For the largest direct-connected, constant speed motors, such as would be needed for driving air compressors, for instance, this company employs the frames of their engine type generators shown in Fig. 42. Their medium capacity, belted, constant speed motors from 25 to 105 horsepower, shown in Fig. 90, are practically identical with their belted generators. These sizes are 6-pole machines and are made for slow, medium, or moderate speeds operating on 115-, 230-, or 500-volt circuits. Their Northern type B motors, shown in Fig. 91, serve for their smaller sizes. The yoke or field frame is of soft cast steel, circular and in one piece. The poles are of laminated sheet steel through bolted into the frame. The field coils are form-wound and rendered moistureproof. The armature is of the slotted drum type with ventilating ducts. The form-wound armature coils are held in place by

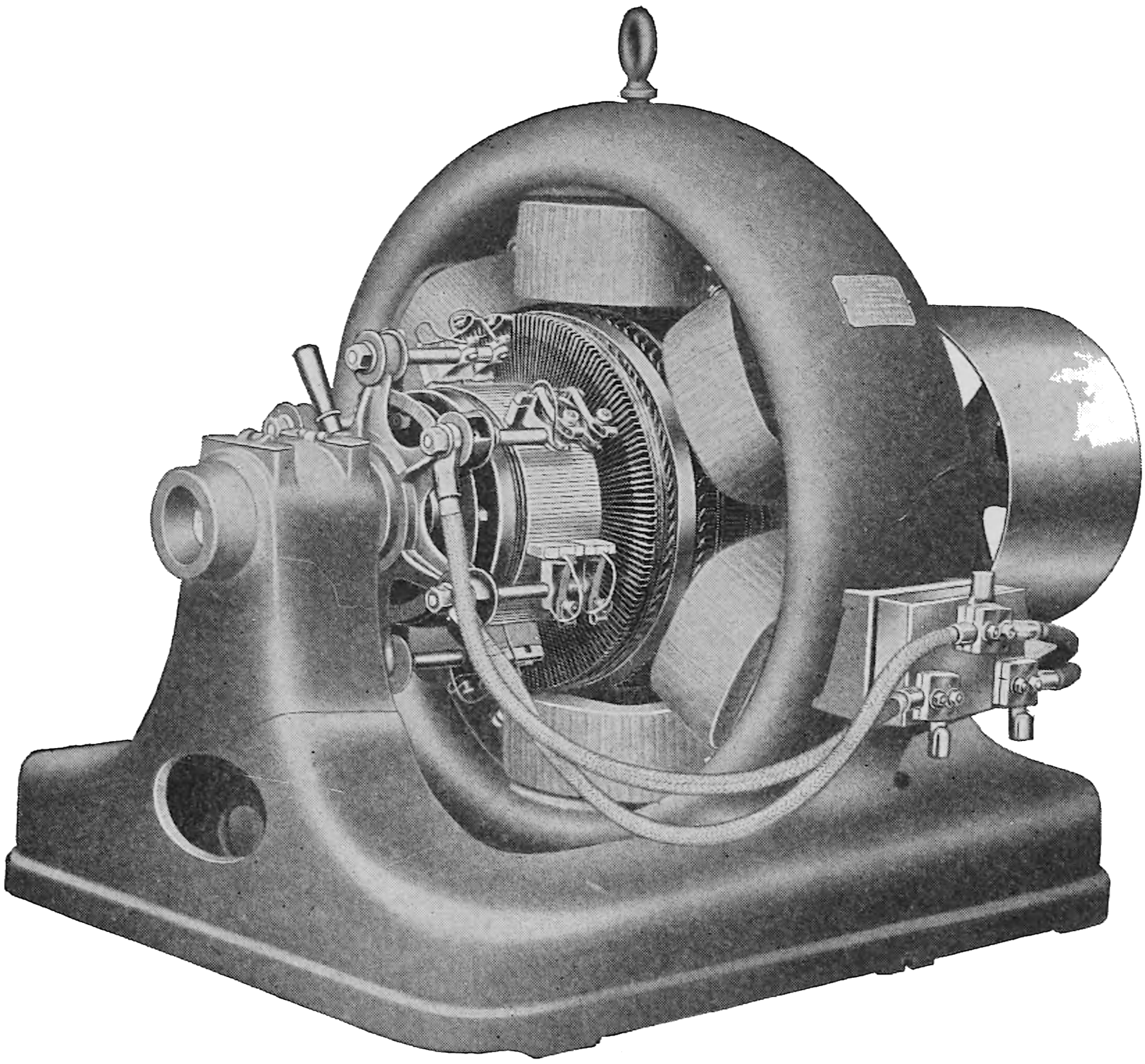


Fig. 90. Fort Wayne 6-Pole Belted Motor

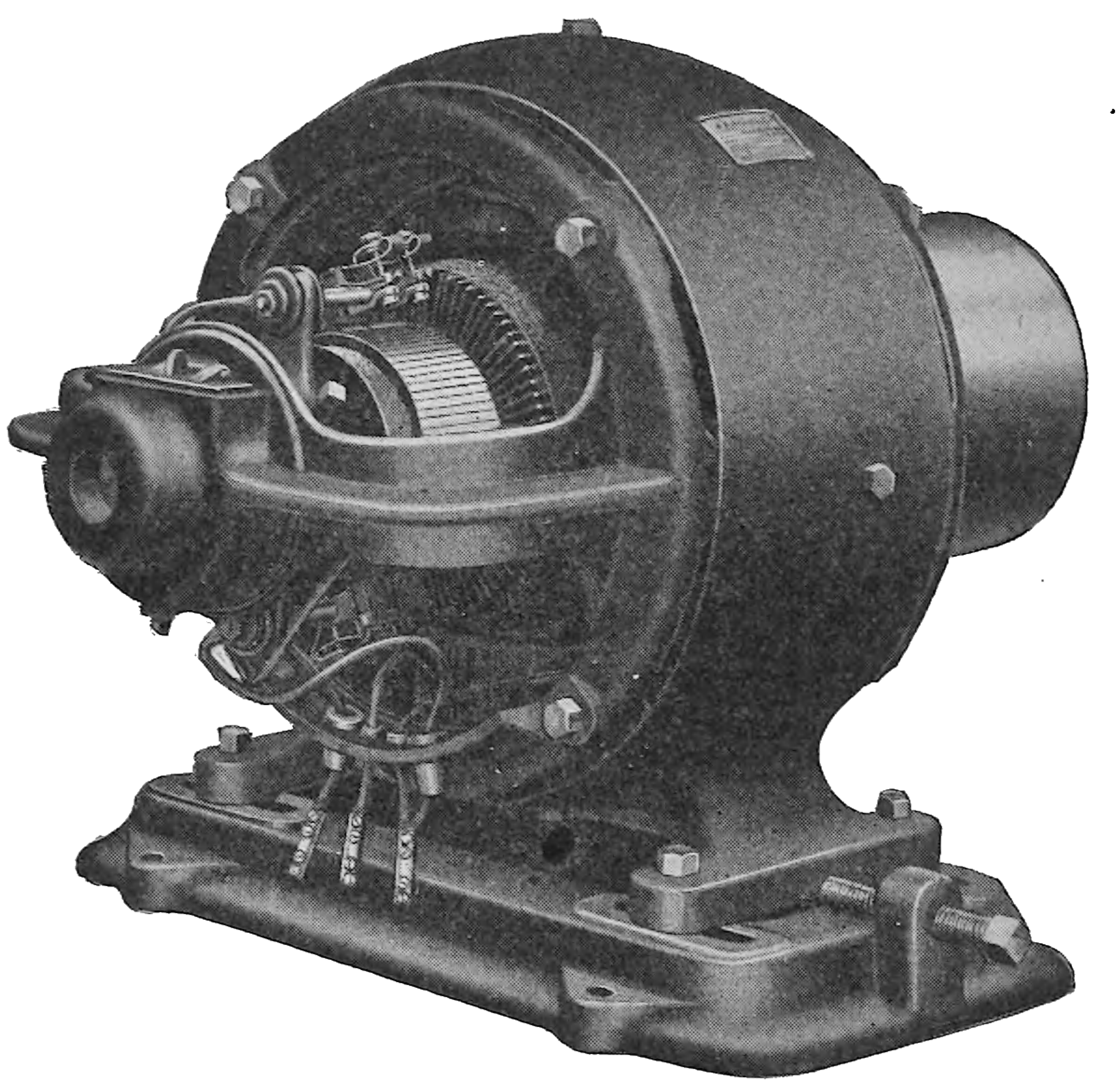


Fig. 91. Fort Wayne Northern Type B Motor

binding bands recessed flush with the armature surface. The commutator is mounted upon and keyed directly to the shaft. The bearings are carried by end bonnets attached to the frame casting by four cap screws. By changing the end flanges through 90 degrees

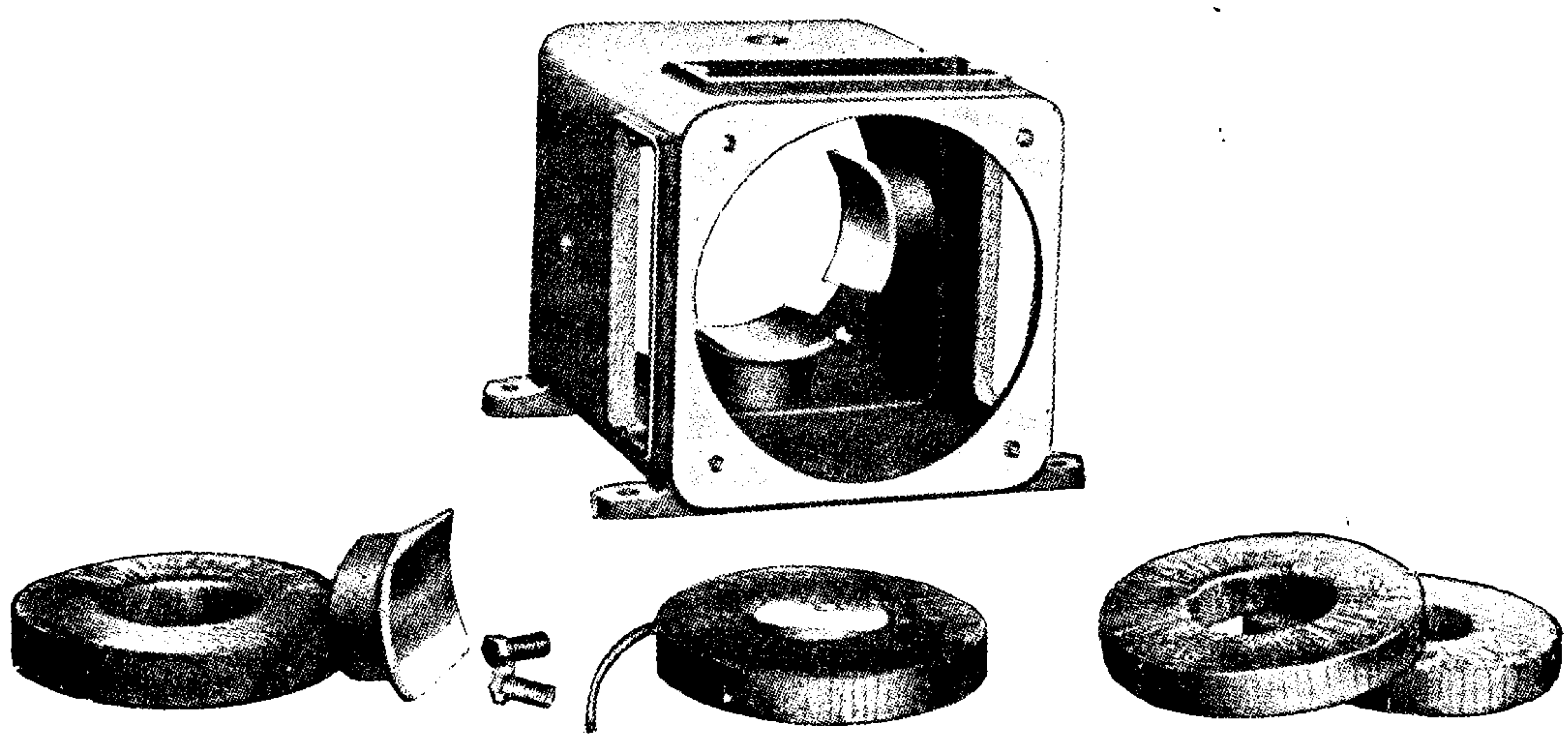


Fig. 92. Fort Wayne Type K Motor Field Coils and Frame

or 180 degrees, the same motor can be arranged for side wall or ceiling mounting. This line can also be arranged as semi-enclosed and totally enclosed motors, as well as furnishing vertical types.

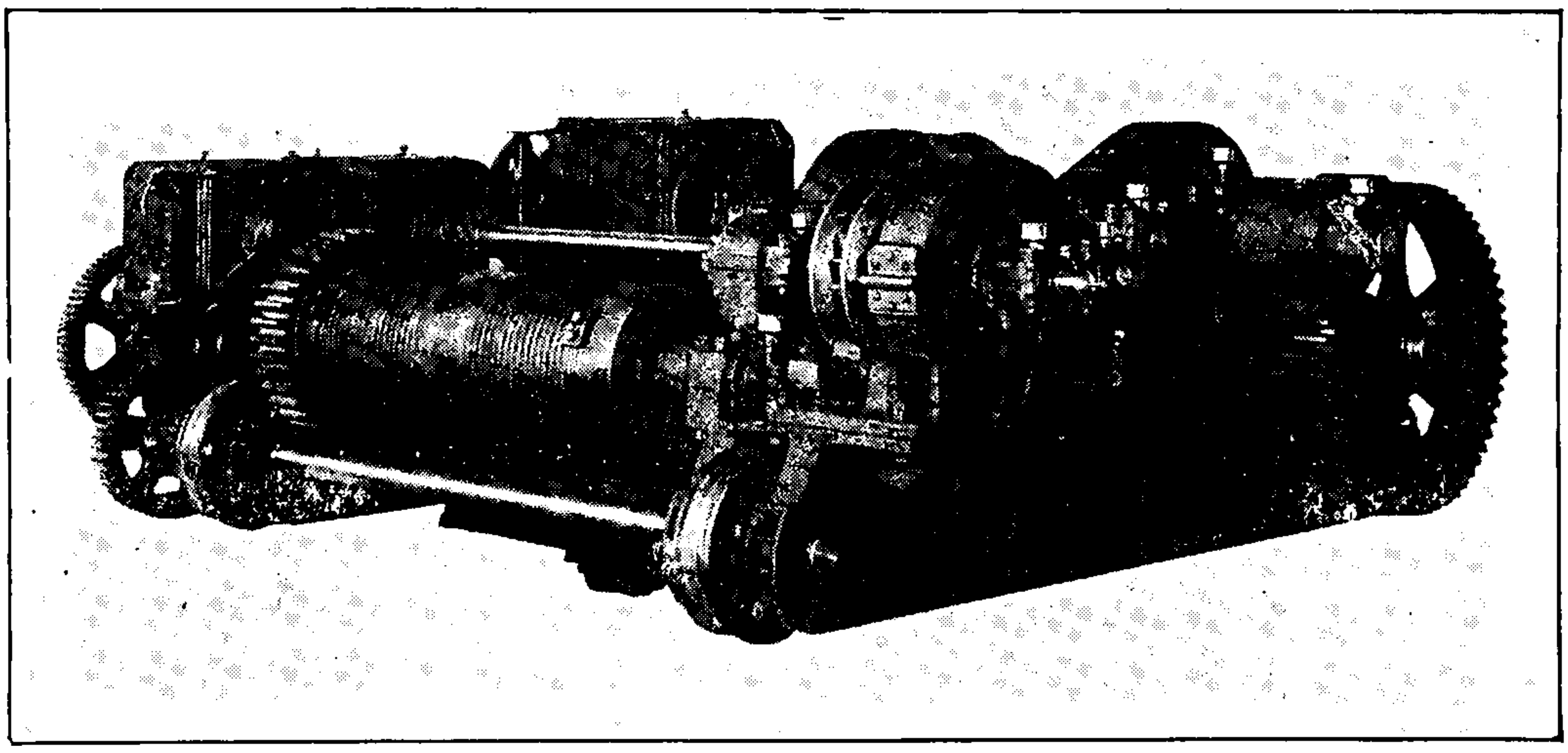


Fig. 93. Fort Wayne Type K Motor Driving Electric Crane
*Courtesy of Toledo Bridge and Crane Company*

When furnished with interpoles or, as this company calls them, regulating poles, they become adjustable speed motors.

Fort Wayne Electric Northern type K motors are series-wound and reversible. They are built to operate on 110, 220, or 500 volts

For the smaller machines the General Electric Company has a line of commutating pole machines, called type C V C, from 2- to 20-horsepower ratings. A feature of these machines is the field windings of rectangular, cotton covered wire, wound on horn fiber spools. The main field coils are also armor-wound with a single layer of enameled copper wire, serving the double purpose of protecting the active winds from mechanical injury and assisting to a better degree of heat radiation than would be possible with the old style

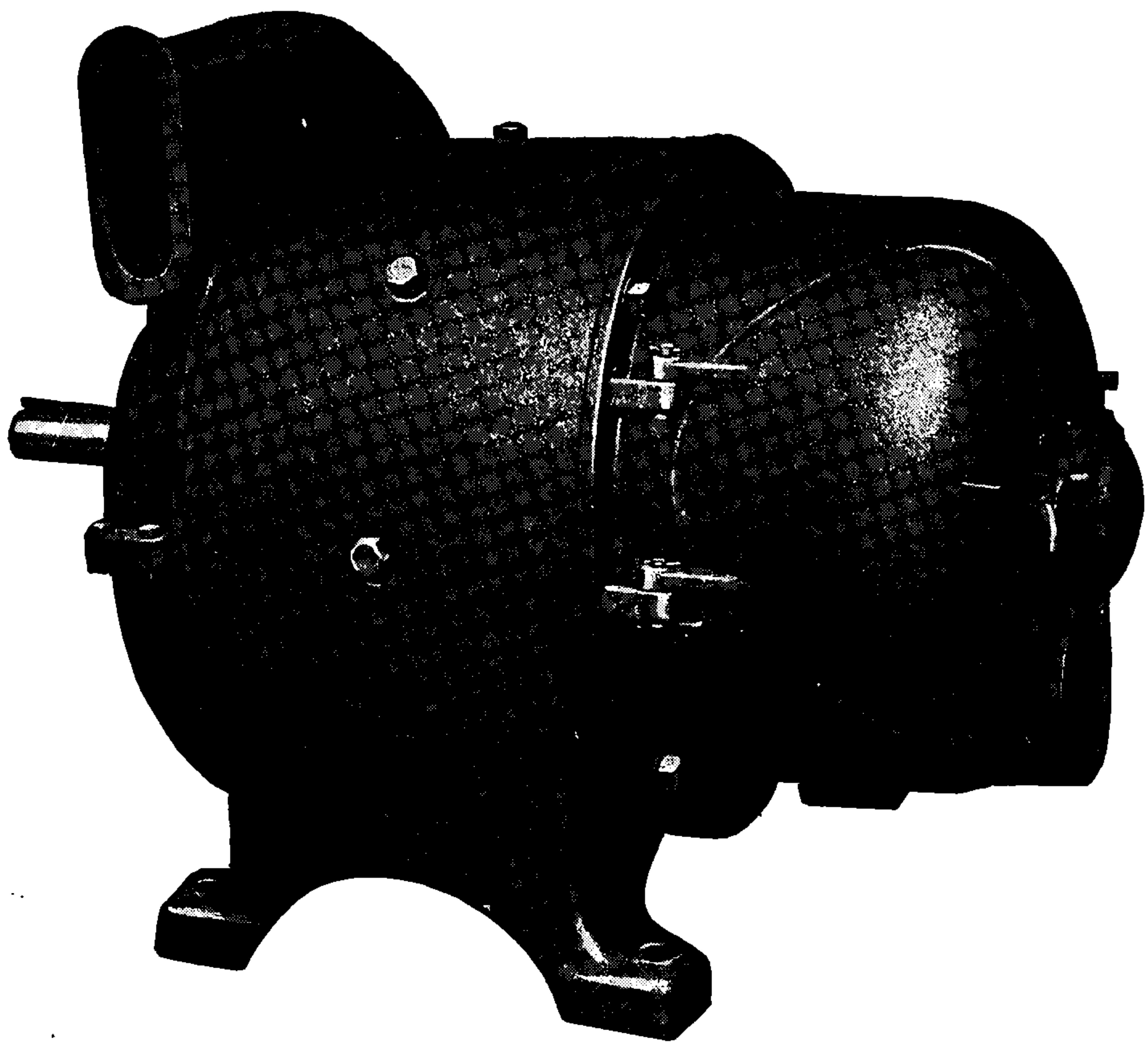


Fig. 95. D L C Motor Totally Enclosed and Ventilated with Involute Type of End Shield
*Courtesy of General Electric Company*

taped or cord protected coil. This line allows of any style of mounting or any degree of enclosure. The field windings may be shunt series or compound, giving rise to constant, adjustable, or varying speed motors. The direct-current mill motors brought out by the General Electric Company are of octagonal frame and fireproof construction in five sizes from 30 to 150 horsepower at 230 volts. They employ interpoles and are series-, shunt-, or compound-wound as desired. One of this line is illustrated in Fig. 96.

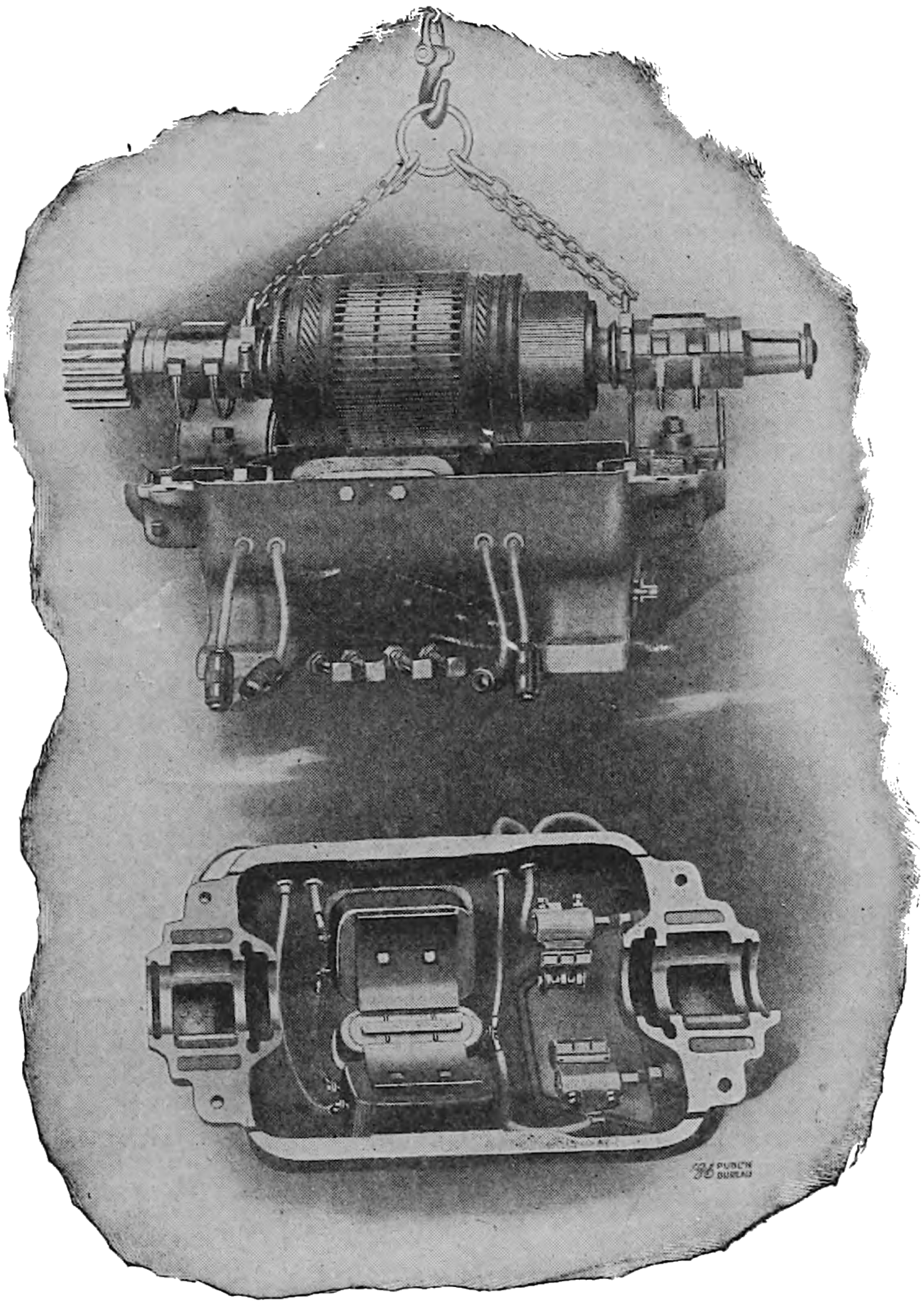


Fig. 96. General Electric Mill Motor Showing Armatures Being Lifted from Frame

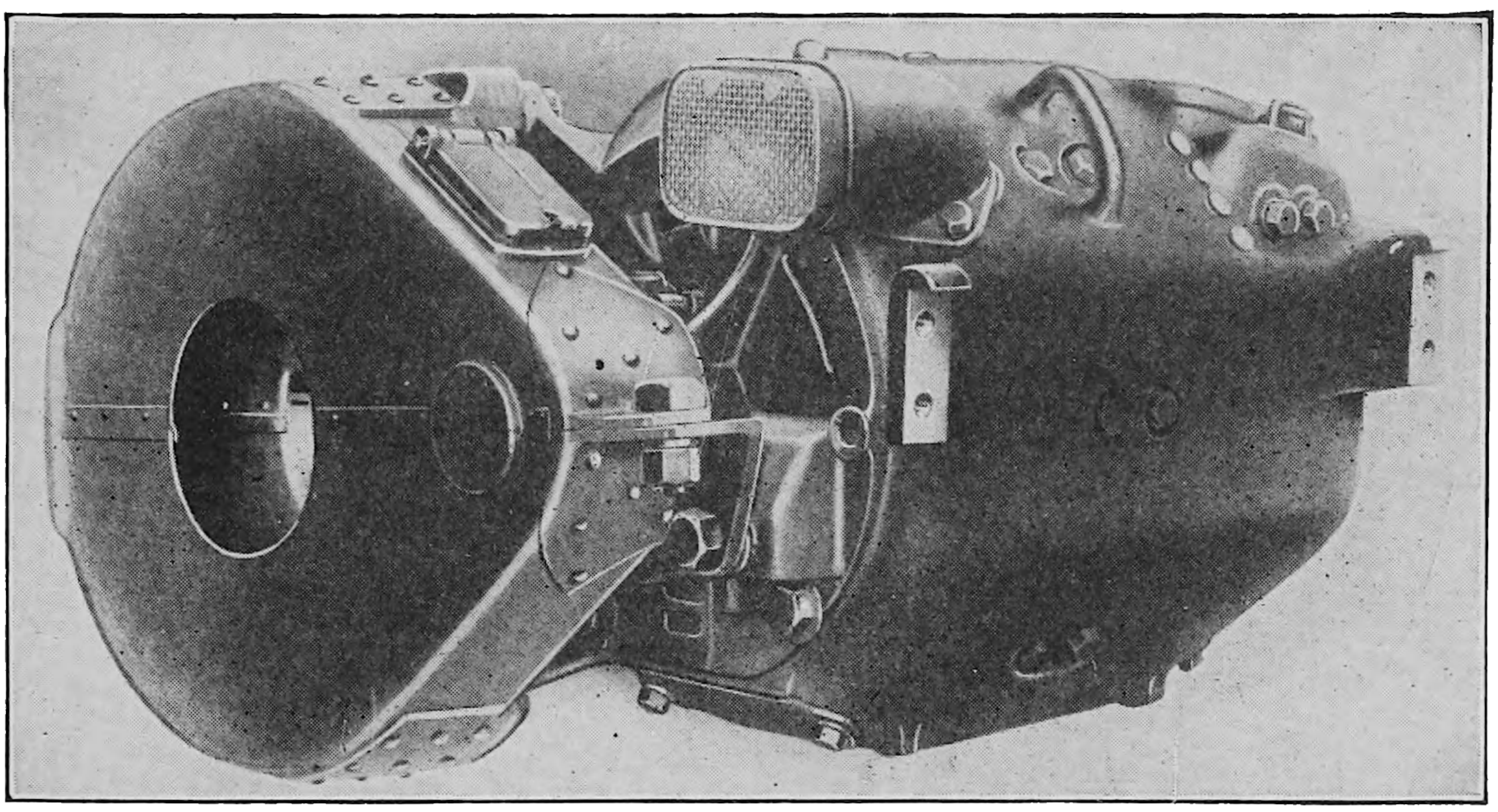


Fig. 97. General Electric Railway Motor

Another complete line of motors is that of the General Electric railway motors, the latest forms of which also use commutating

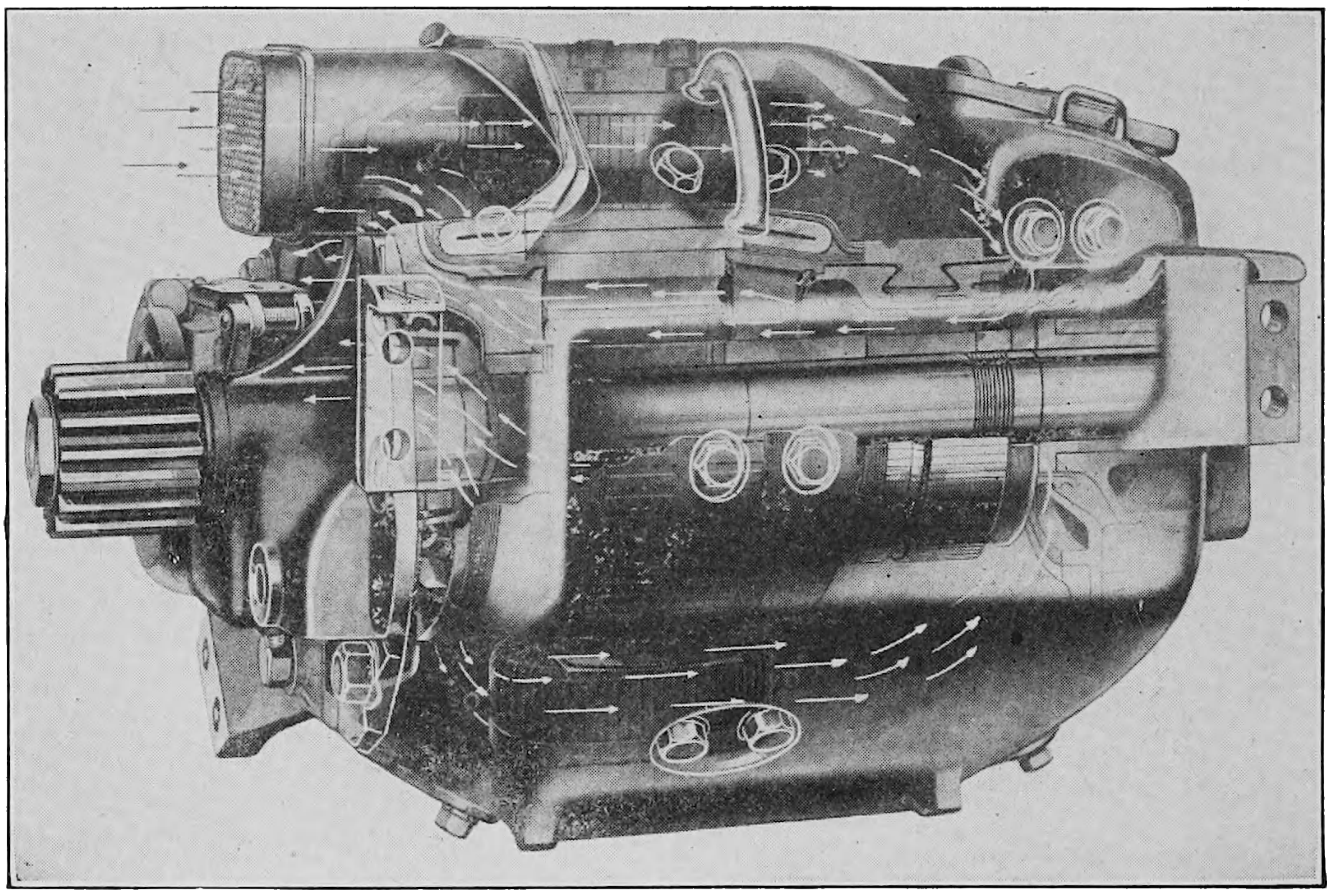


Fig. 98. General Electric Railway Motor Showing Method of Ventilation

poles and forced ventilation obtained by means of a centrifugal fan integral with the pinion and armature core head. The outer appearance and method of ventilation are shown by Figs. 97 and 98. Besides their larger machines, this company also puts upon the market a complete line of fan motors and small power motors from $\frac{1}{50}$ to $\frac{1}{4}$ horsepower, inclusive. These latter are known as drawn-shell type motors. The frame is punched out of soft steel and then forced into shape. The yoke and pole pieces are made of punched laminations, as shown in Fig. 99.

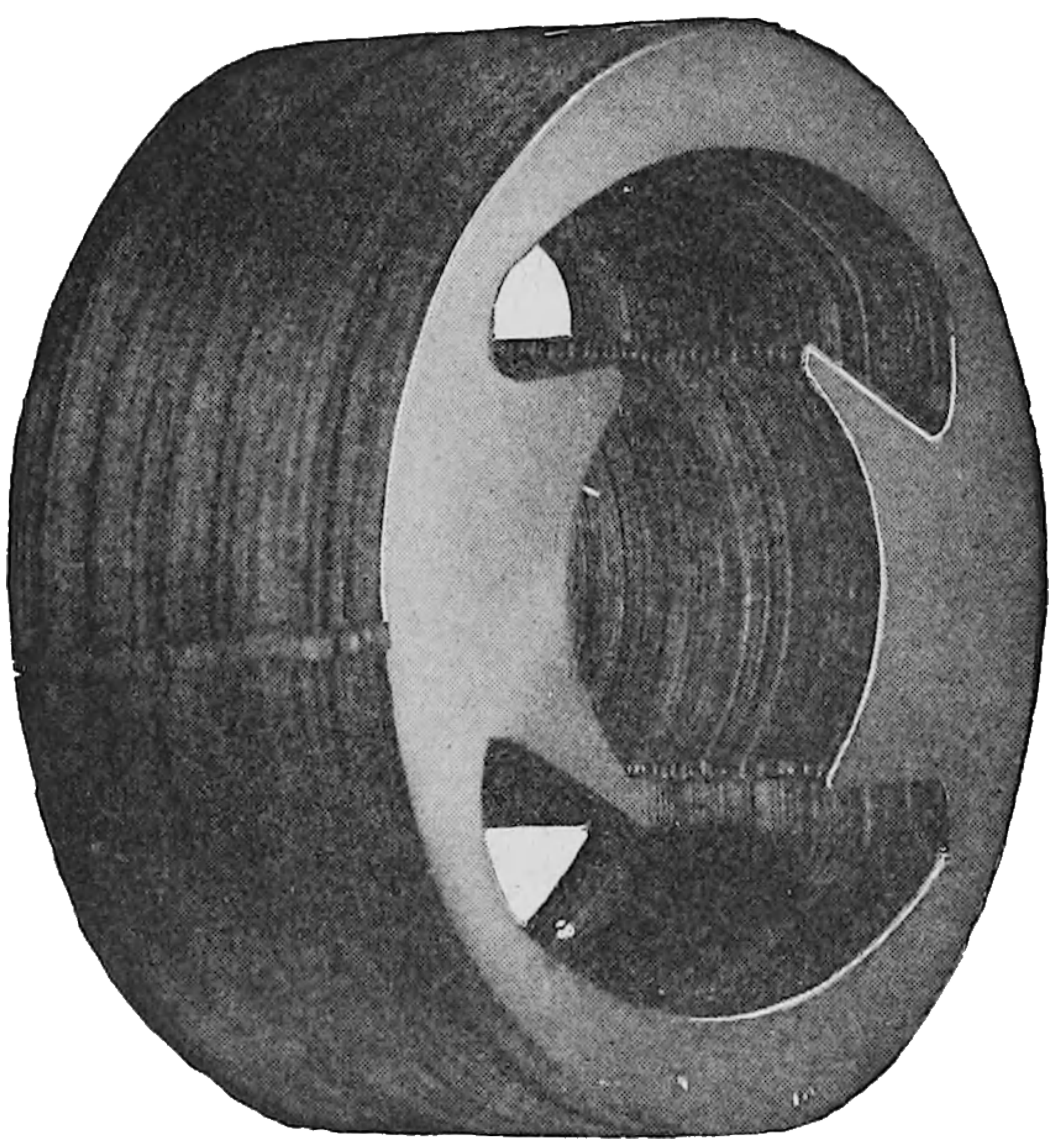


Fig. 99. Laminated Field of General Electric Drawn-Shell Electric Motor

in sizes from $\frac{1}{4}$ to 30 horsepower and with speed variations as great as 10 to 1 and as small as desired. It is a simple shunt-wound machine, obtaining its speed variation by altering the reluctance of the magnetic circuit of the machine so as to weaken or strengthen the magnetic field. The principal parts of this machine are shown in Fig. 102, a portion of the illustration being in section. The end of the armature shaft on which the commutator is mounted revolves in a sleeve that slides in the journal bracket. This sleeve is moved back and forth by means of a forked lever controlled through a rod and nut, by the screw on the spindle of the handwheel. The helical

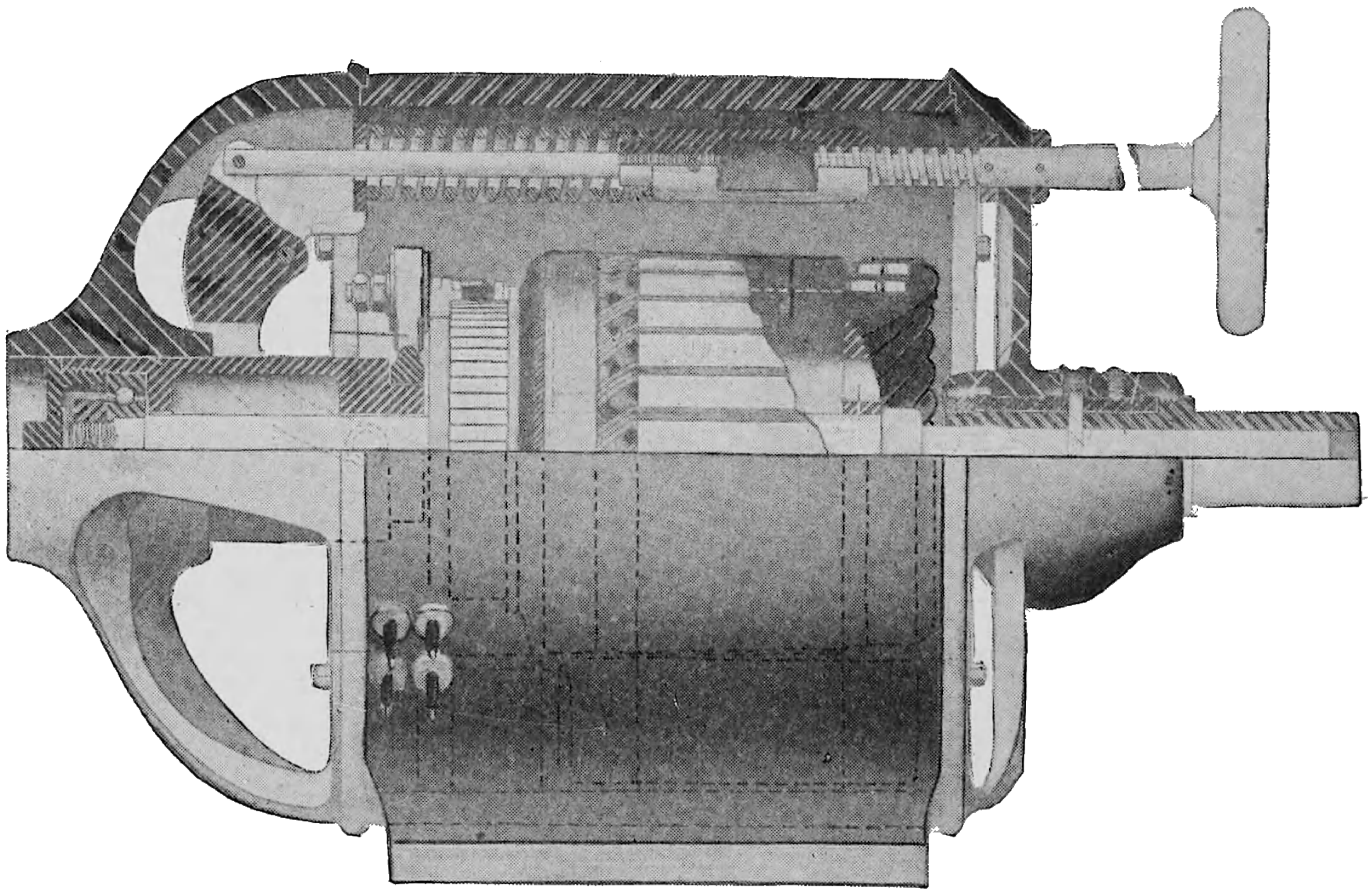


Fig. 102. Part Section of Reliance Adjustable Speed Motor

compression spring surrounding the lever rod always balances the magnetic pull that is exerted by the poles on the armature core. The armature core is slightly tapered, the commutator end being larger in diameter than the other end, and the pole faces are bored to the same taper. When the armature is drawn towards the journal bracket on the commutator end, the air gaps are increased in length and decreased in area. This increases the reluctance, thereby weakening the field and increasing the speed.

Sparking at the brushes when operating at weak fields is prevented by means of special commutating poles midway between the main poles. These commutating poles are in series connection with the armature and laterally displaced from the main poles on the side toward which the armature is withdrawn. The machine is so designed as to give sparkless commutation at all loads at any speed in either direction. The brush rigging is mounted on the end of the sleeve containing the ball bearing, and therefore this bearing, brush rigging, and armature move in unison with no lateral displacement of the brushes on the commutator. The driving end of the shaft

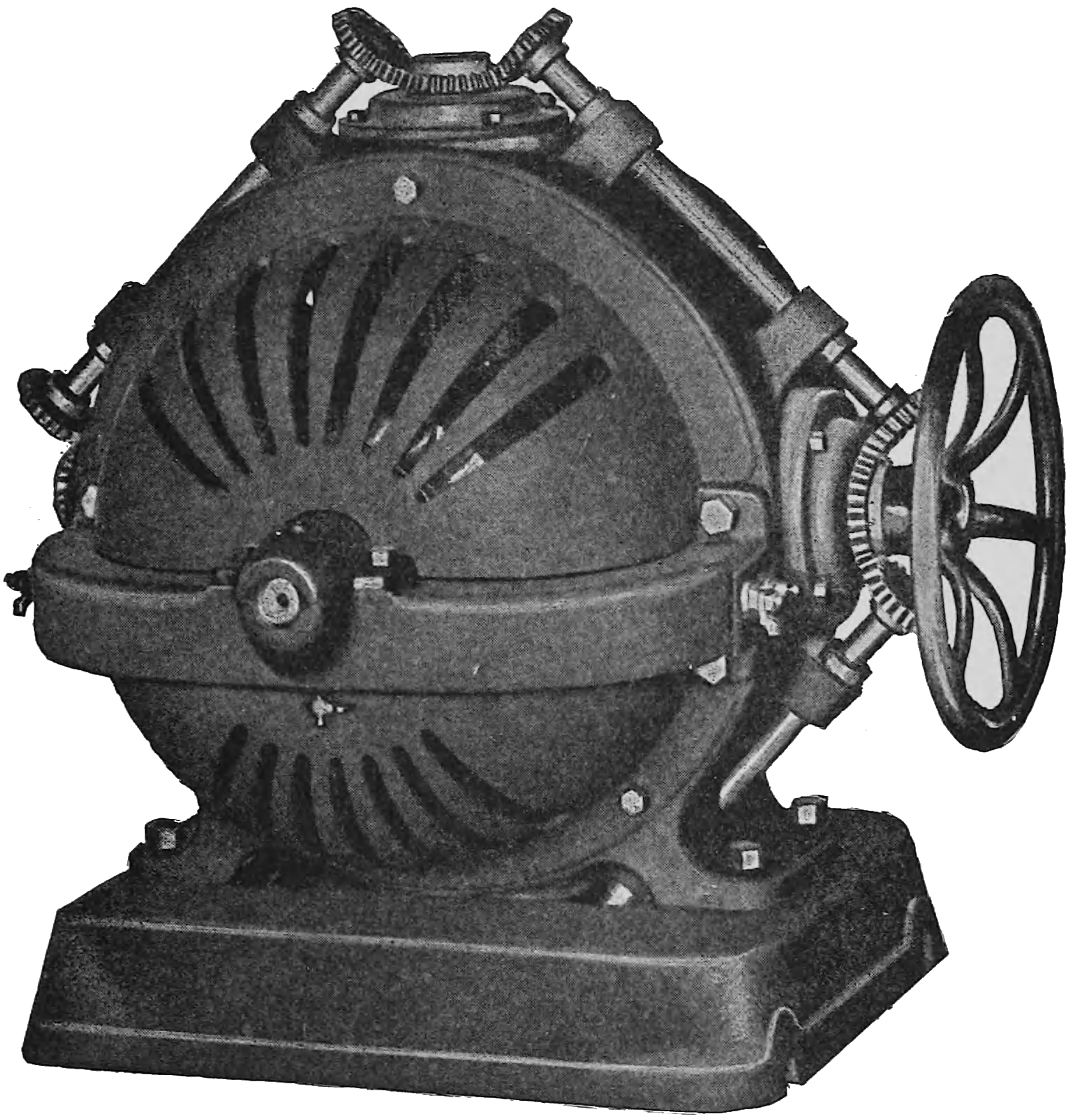


Fig. 103. Stow Multispeed Motor of the Semi-Enclosed Type
*Courtesy of Stow Manufacturing Company*

slides in a sleeve that revolves with it but does not slide endwise; the driving gear, coupling, or pulley are mounted on the end of this sleeve.

This company also puts a line of constant speed motors on the market ranging from $\frac{1}{2}$ to 50 horsepower; 15 horsepower and smaller are wound for either 115 or 230 volts, while the larger sizes are wound only for 230 volts.

**Stow Manufacturing Company.** The Stow multispeed motor, as it is called, really belongs to the adjustable speed class, obtaining its speed variations by changing the reluctance of the magnetic circuits. It is bipolar in sizes from $\frac{1}{4}$ to 4 horsepower, and 4-pole from 4 to 20 horsepower. Fig. 103 shows one of the 4-pole type. The pole

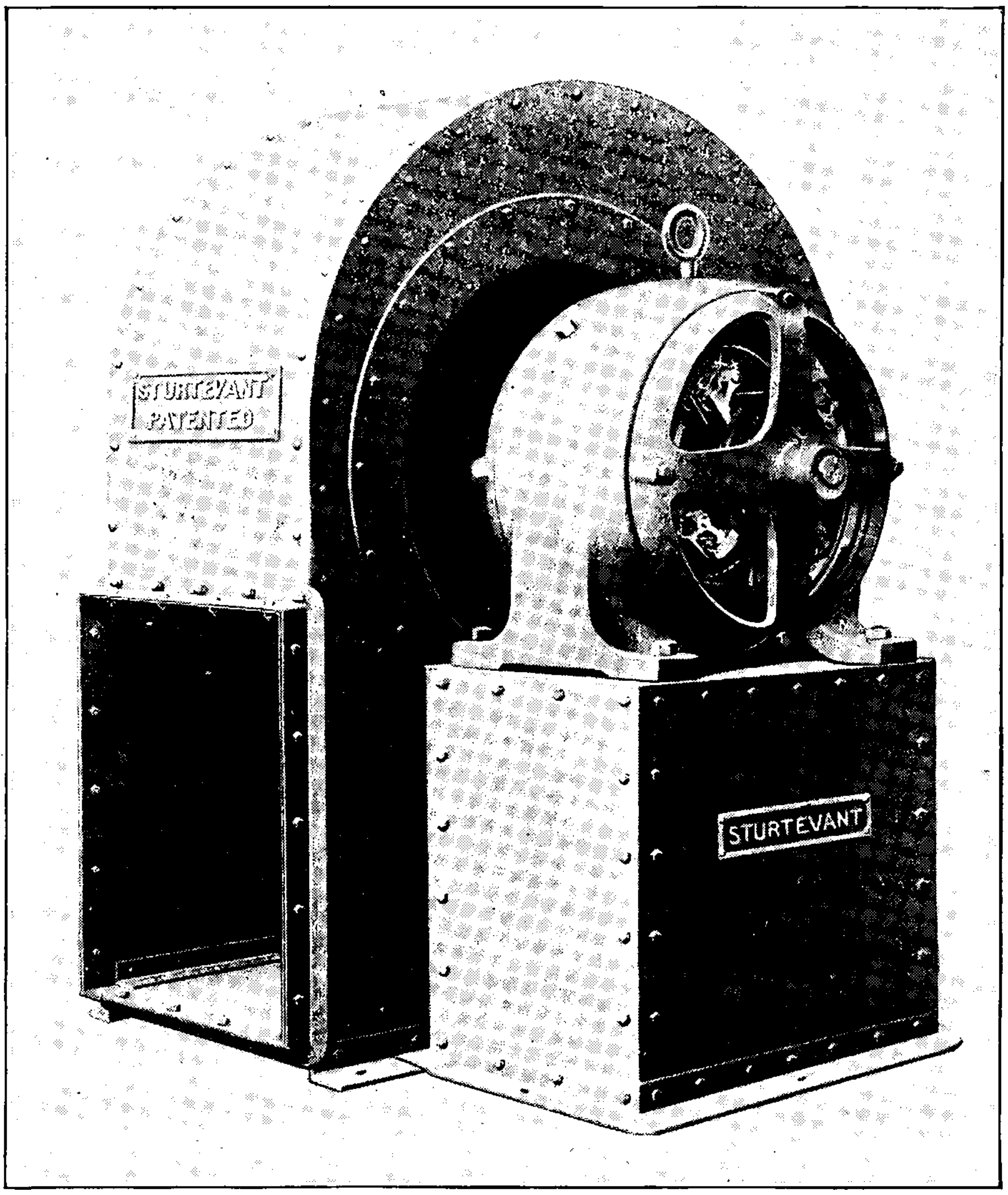



Fig. 104. Sturtevant 4-Pole Motor Driving Ventilating Fan

cores are made hollow and provided with iron or steel plungers, the position of which is adjustable through pinions and worm gears operated by a large handwheel placed on the top or the side of the machine as preferred. When the plungers are withdrawn, the total flux decreases because of the lengthening, and because of the decrease in the effective area of the air gap and also the decrease of effective metal in the field cores. The speed must necessarily increase with

driven generator frames of the design shown in Fig. 67. Six frames are bipolar from $\frac{1}{2}$ to 5 horsepower and eight frames are 4-pole from $7\frac{1}{2}$ to 40 horsepower. They can be wound shunt, series, and compound, thus becoming besides constant speed motors, also varying and adjustable speed motors.

**Westinghouse Electric and Manufacturing Company.** A line of motors, designated type S, consists of thirteen frames. Used as constant speed motors, they have ratings from 2 to 75 horsepower at 110 volts, from 2 to 150 horsepower at 220 and 500 volts, and from 6 to 100 horsepower at 600 volts. They are mounted in any of

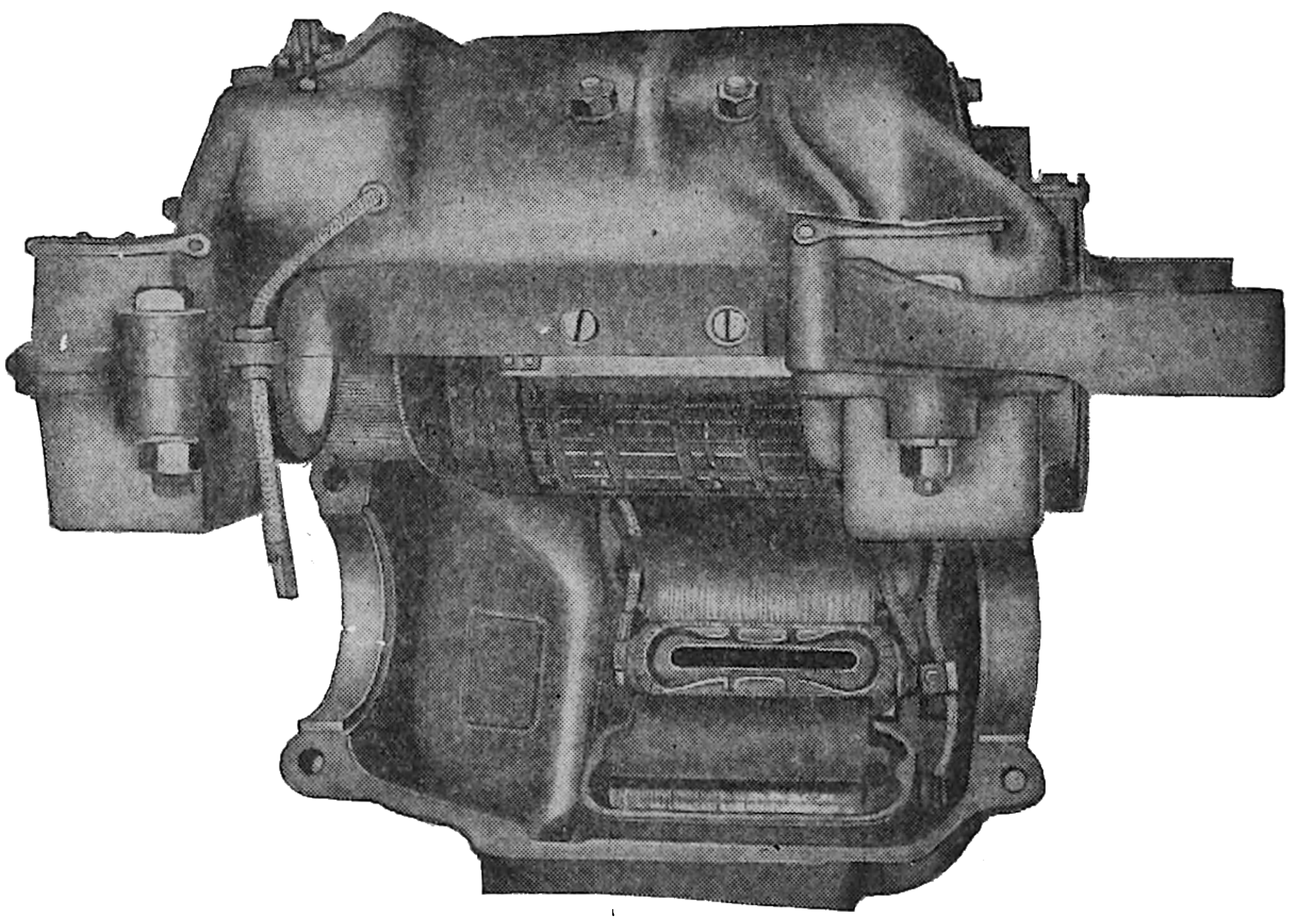


Fig. 106. Westinghouse Interpole Railway Motor with Lower Frame Down for Inspection

the four positions and built open, partially enclosed, or totally enclosed. They can be used also as adjustable speed motors for speed variations of 1 to $1\frac{1}{2}$ or 1 to 2. They are likewise employed as elevator motors, Fig. 105, when compounded by adding a series winding used in starting but cut out for normal running. Adding auxiliary poles, or interpoles, to these shunt-wound machines gives adjustable speed motors of greater speed variation, of $\frac{1}{2}$ to 23 horsepower at a speed ratio of 1 to 4, of $\frac{1}{2}$ to 50 horsepower at a speed ratio of 1 to 2.

This company also manufactures small power motors and a complete line of fan motors. The small power motors are built in three sizes of $\frac{1}{20}$, $\frac{1}{12}$, or $\frac{1}{8}$ horsepower at speeds from 1000 to 2500 r. p. m. and for 110 or 220 volts. They are similar in construction to the bipolar type R machines, fully enclosed, and either series- or shunt-wound. Westinghouse fan motors are of drawn steel construction and series-wound for 110 or 220 volts with speeds from 650 to 2100 r. p. m. Some of their smallest fan motors are wound for 30 volts.

The Westinghouse Company also puts upon the market lines of railway motors, mill motors, and hoisting motors. Their railway motors are built with the usual moistureproof and dustproof cast steel frames. They are 4-pole series-wound for 500 to 750 volts.

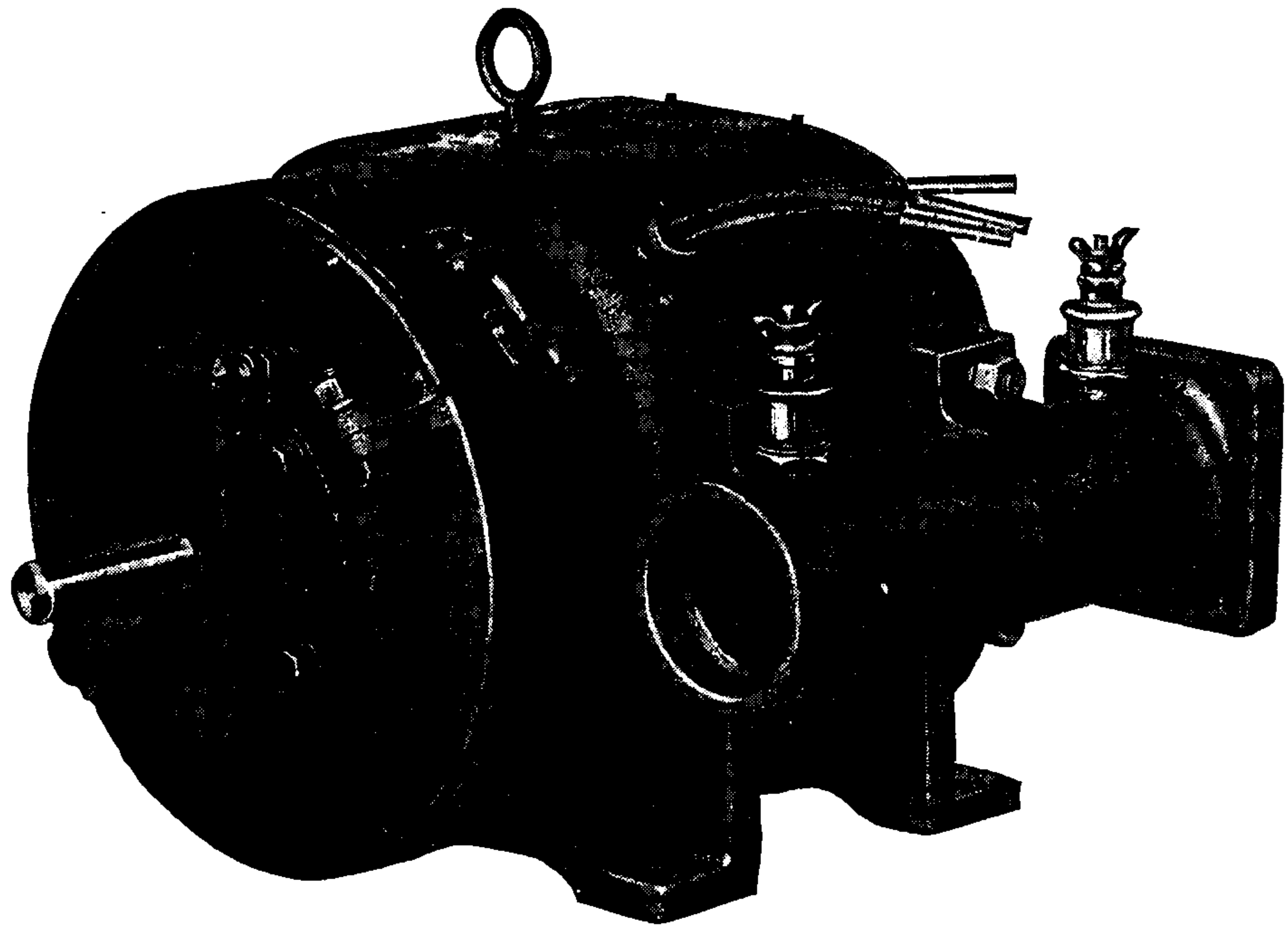


Fig. 107. Westinghouse Hoisting Motor with Provision for Back Gear Arrangement

The latest types have the main poles centered at 45 degrees from the horizontal plane and employ interpoles, as shown in Fig. 106. The field windings are of flat copper strap with the turns separated by asbestos ribbon. Westinghouse mill motors are of very similar design, in nine sizes from 5 to 150 horsepower, but wound for 220 volts. They are series- or compound-wound as desired; in the latter case, the shunt winding is so designed as to keep the no-load speed down to about twice full-load speed. This company's hoisting motors consist of 10 frames, wound for 110, 220, or 500 volts, ranging from 2 to 52 horsepower. They are 4-pole, series-wound, full enclosed. Fig. 107 shows a type K direct-current crane motor arranged with back shaft and gear.

## DYNAMOTORS, MOTOR-GENERATORS, BOOSTERS

**Dynamotor.** *Characteristics.* A dynamotor is a transforming device combining both motor and generator action in one and the same magnetic field, with an armature having two separate windings and independent commutators. This class of machines has certain advantages resulting from both generator and motor windings being on the same core. The armature reactions of the two windings, being opposite, neutralize each other, since these windings are on the same armature core. There is, therefore, no shifting of the brushes required and no tendency to spark with varying loads, with resulting ability to stand heavier overloads. They are slightly more efficient than motor-generators, since energy is saved in magnetizing the fields and there is less loss in the bearings, because all torque strain upon the shaft is eliminated. They are also cheaper, of less weight, and more compact. On the other hand, the voltage of the generator can not be varied to any extent except by introducing ohmic resistance into either generator or motor armature circuits. Also the gener-

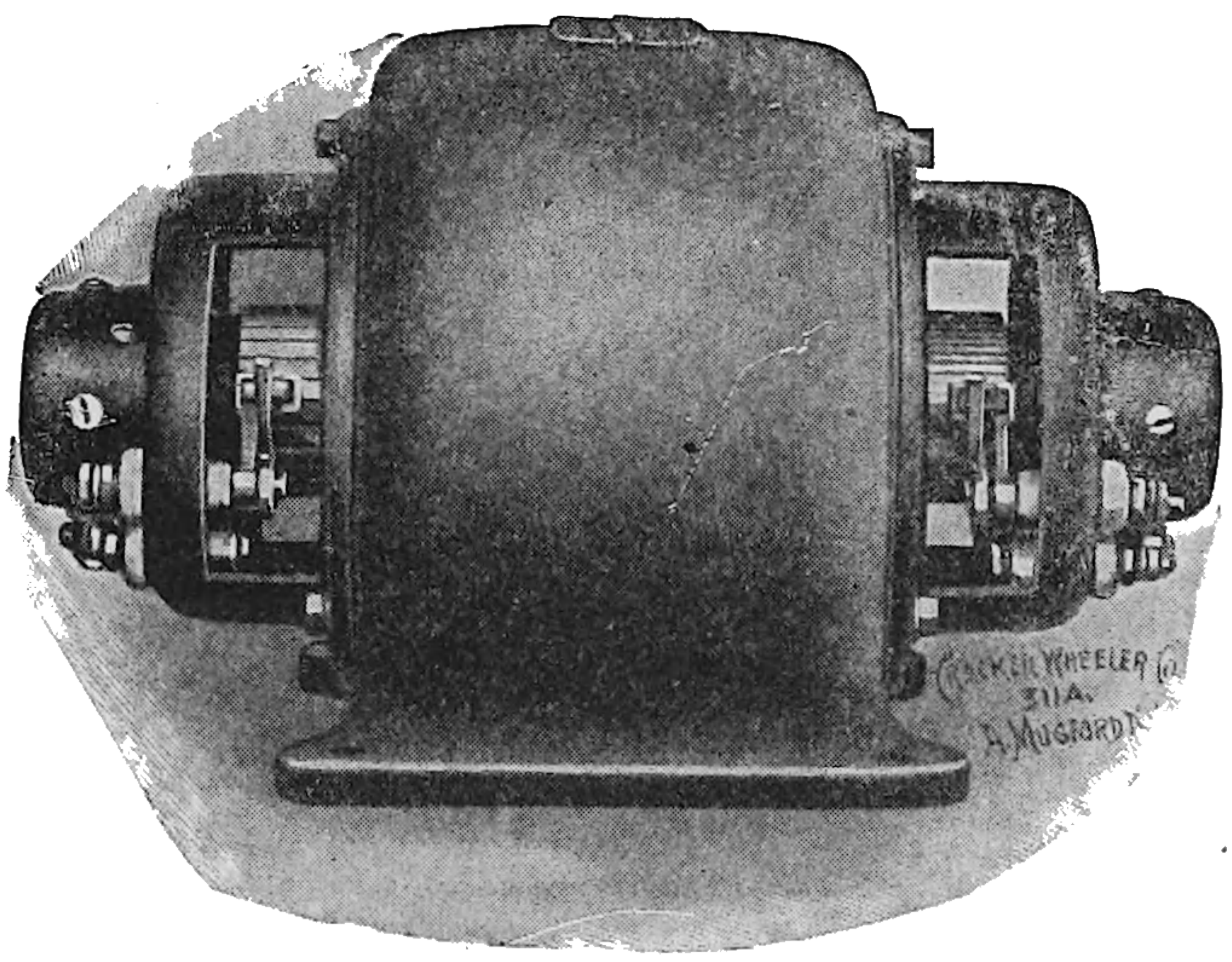


Fig. 108. Crocker-Wheeler Dynamotor

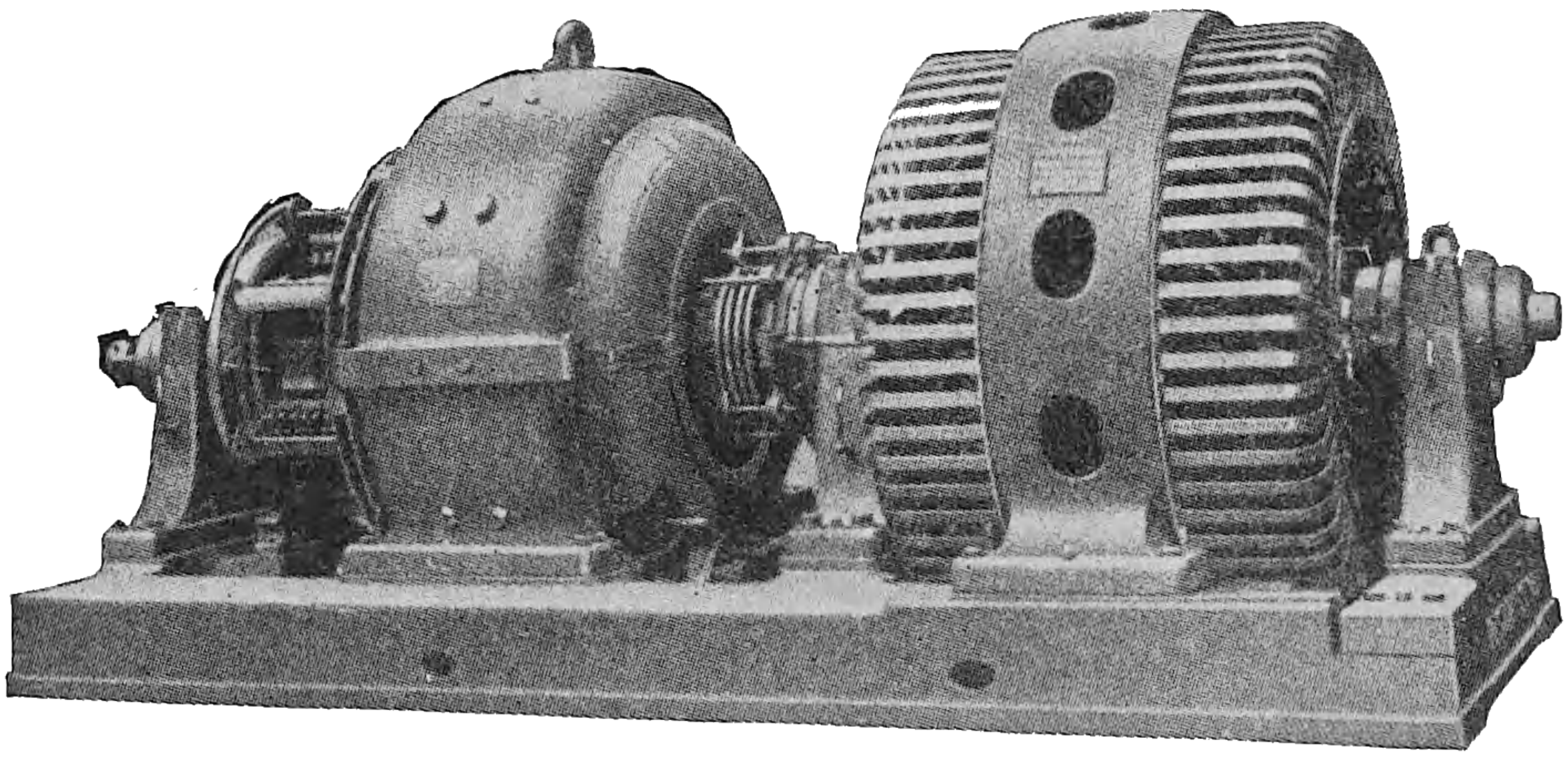


Fig. 109. Westinghouse Motor-Generator Set

an alternating-current one and the other is a direct-current one. It is only in the smaller sizes and in special applications that both machines are of the direct-current type. Fig. 109 shows a 500-kw.

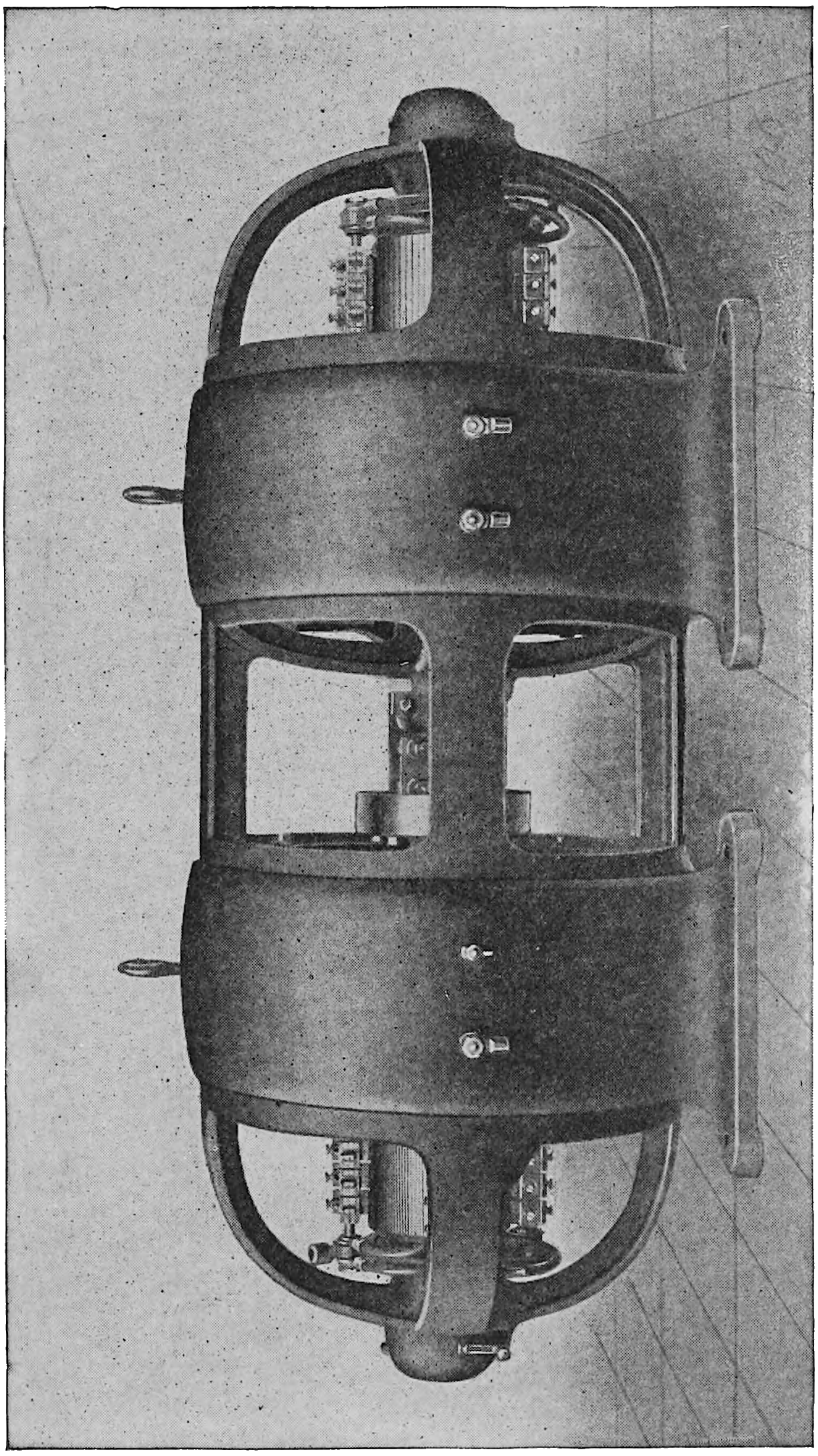


Fig. 111. Motor-Generator Set 500 Volts D. C. to 125 Volts D. C
*Courtesy of Crocker-Wheeler Company*

motor-generator set, consisting of a 3-wire direct-current generator, driven by a 3-phase synchronous motor.

*Use as a Welding Set.* A special adaptation of the device is illustrated in Fig. 110, which shows a rather unique C & C welding set with switchboard attached. The outfit is of 300 amperes capacity, and is arranged for double-circuit operation, that is, it supplies two separate welding circuits, the voltage of which may be adjusted independently. It thus permits of having one operator weld with

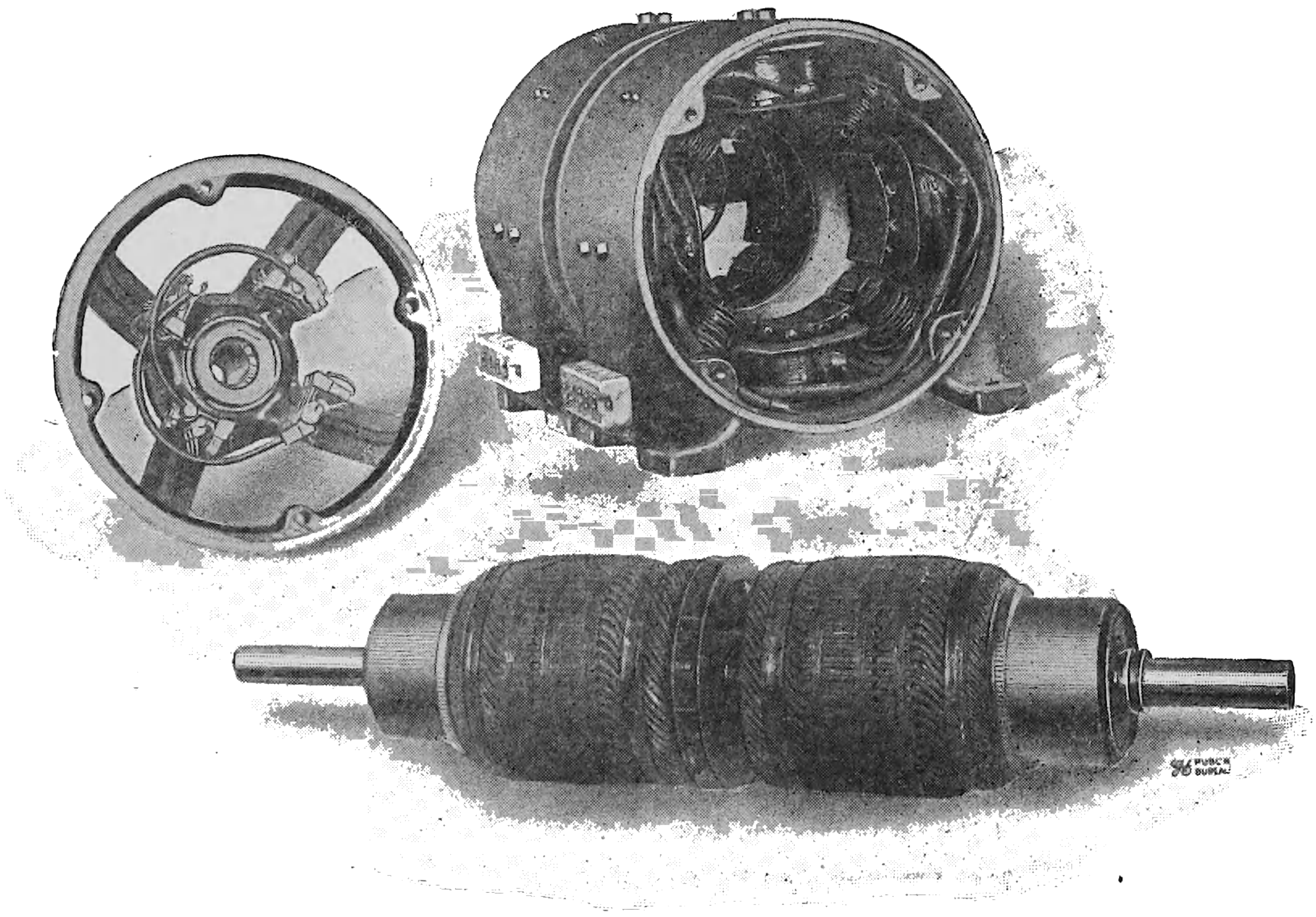


Fig. 112. View of Disassembled General Electric Balancer set with Single Shaft

metallic electrodes, which require a voltage of only 10 to 30 volts at the arc, while another operator may be using graphite electrodes which require from 40 to 60 volts at the arc. Each circuit is provided with an automatic relay, which, as soon as the circuit is closed, automatically inserts a resistance in series, and thus prevents a

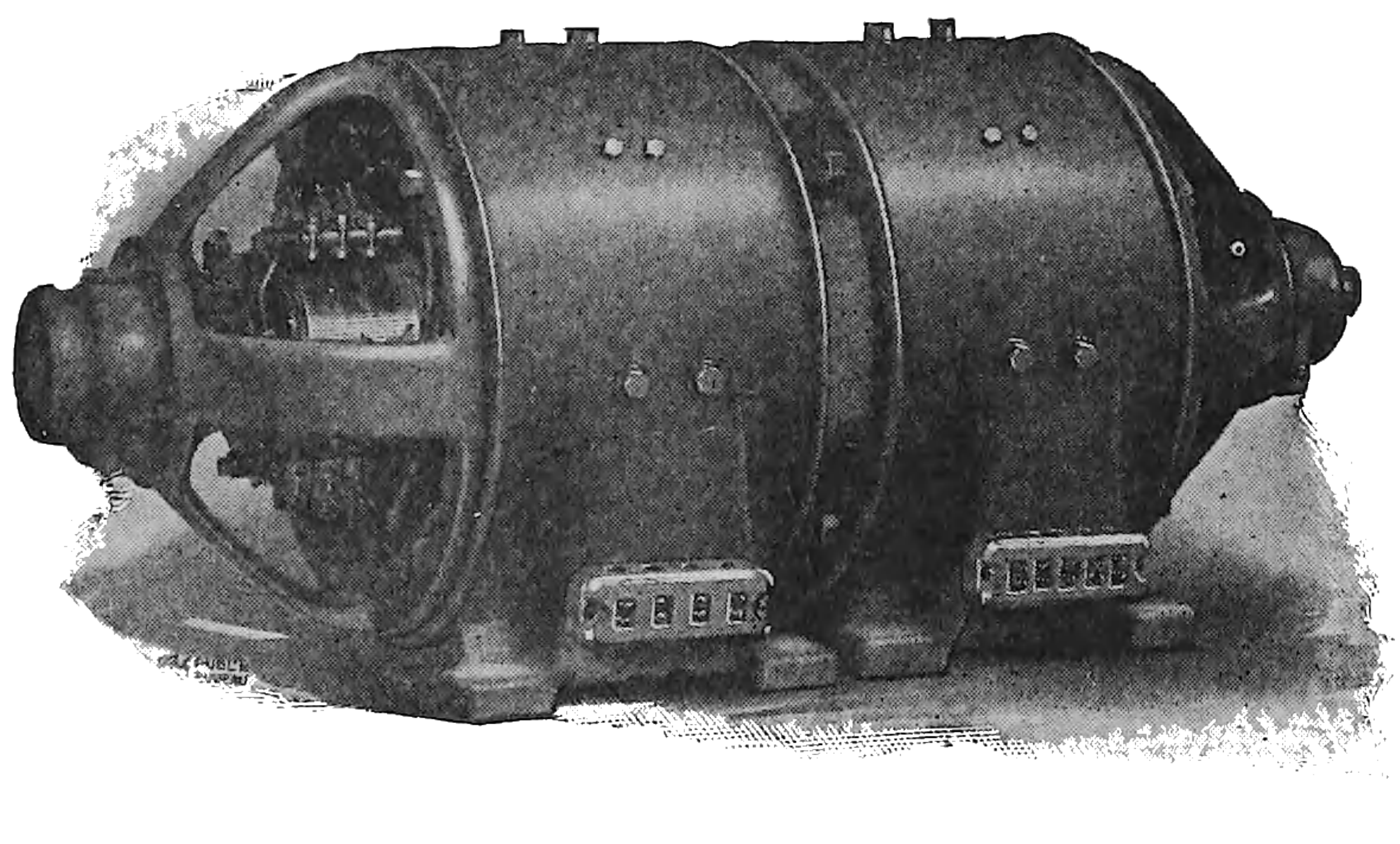


Fig. 113. General Electric Balancer Set

short circuit on the machine. Another set for obtaining 500 volts from a 120-volt circuit, or the reverse, is the Crocker-Wheeler set illustrated in Fig. 111. In the smaller sizes the set is very often arranged with continuous shaft and only two bearings. Fig. 112 shows a General Electric Balancer set disassembled.

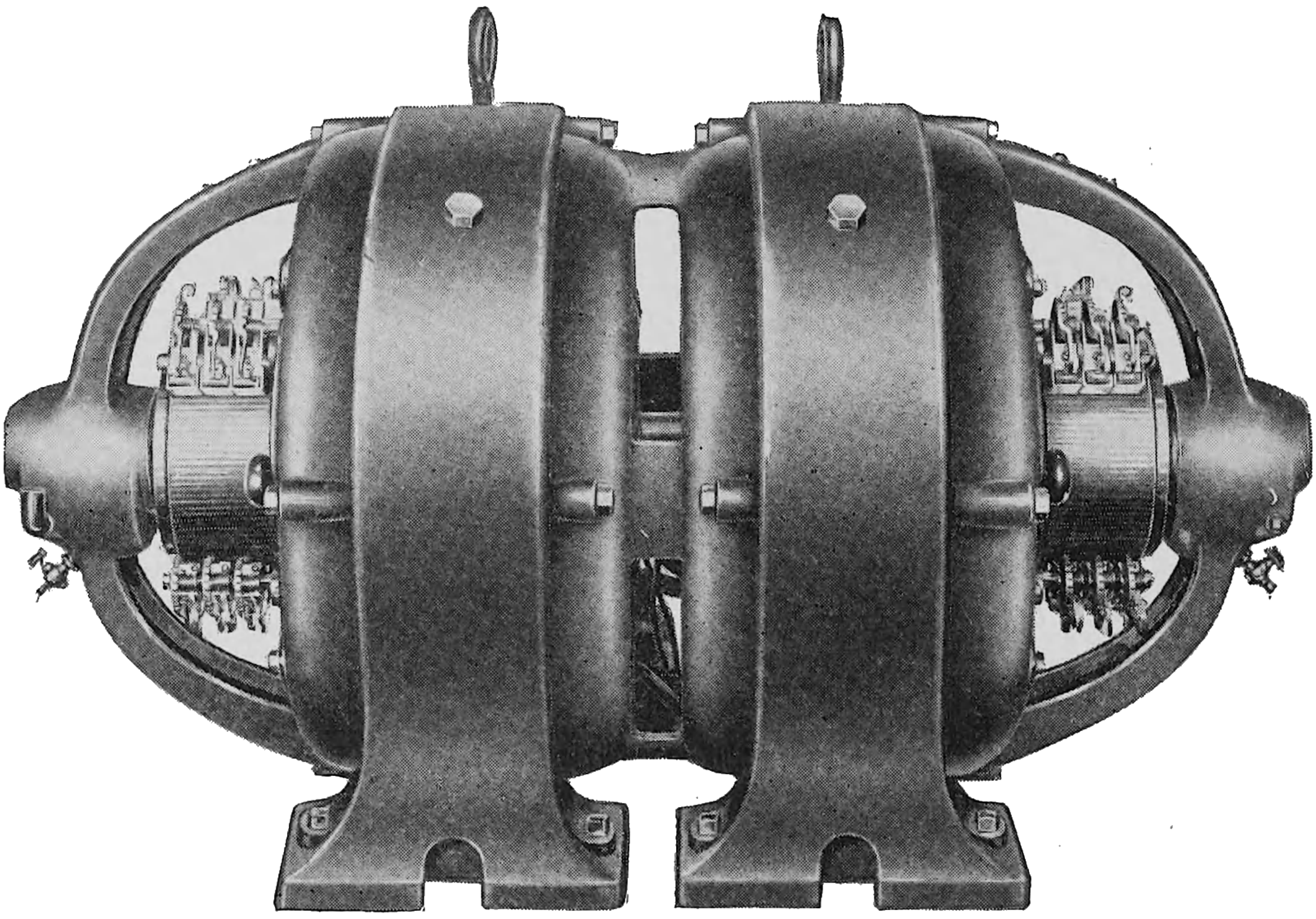


Fig. 114. C & C Balancer Set

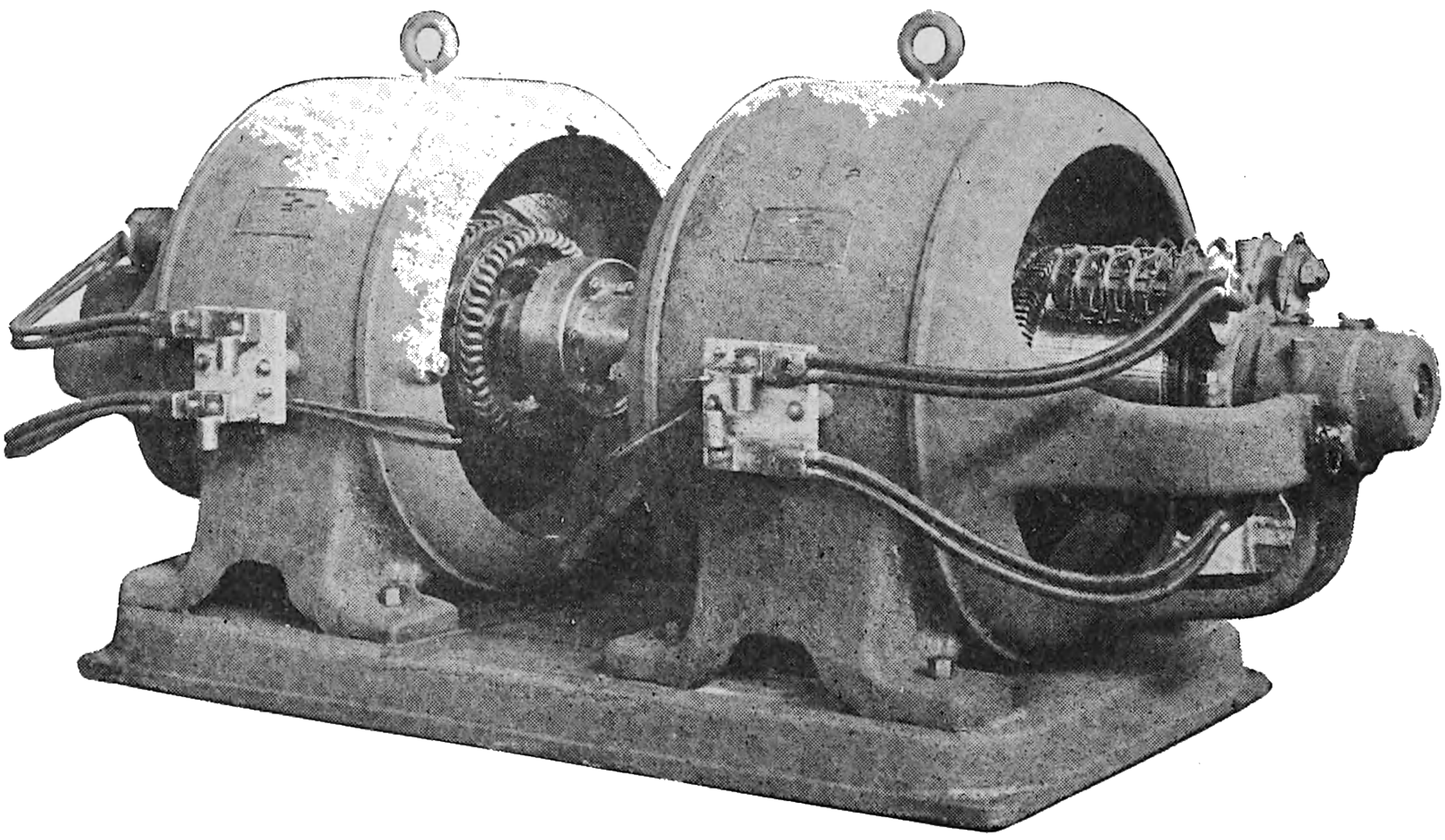


Fig. 115. Allis-Chalmers Balancer Set

*Use as Balancer.* Motor-generators having both machines direct-current and of the same voltage find their greatest application in connection with the three-wire system for furnishing the neutral point for connection to the neutral wire. the two outside wires being

current of the two machines compensating for increased load on the generator side. Balancer sets are generally flat compounded so as to keep the voltage on each side equal, irrespective of the load. An adaptation of this kind of the smaller line of belted generators

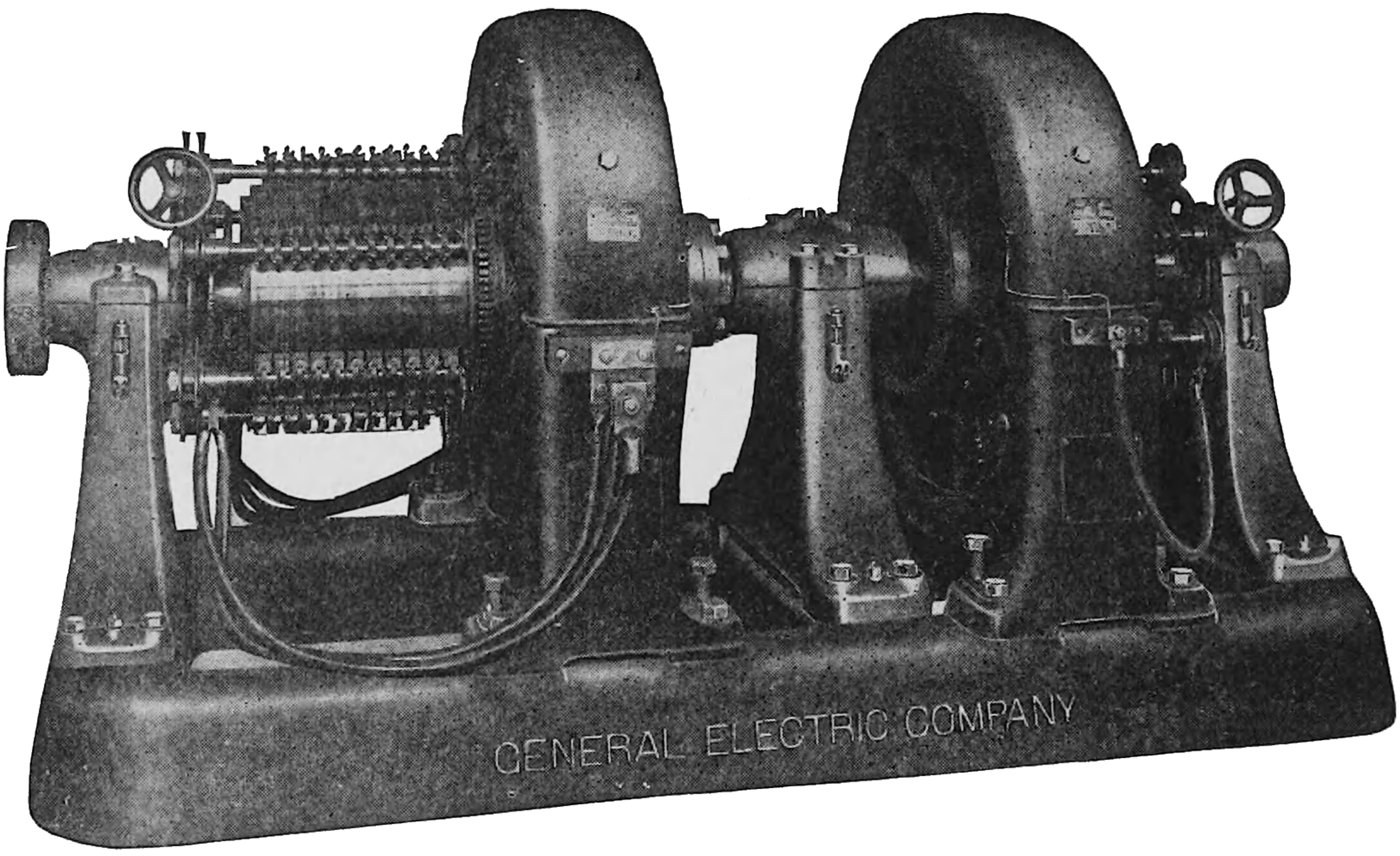



Fig. 117. General Electric Shunt-Wound Booster 40 to 65 Volts, Direct-Connected to 250-Volt Motor, Electric Storage Battery Company

brought out by the General Electric Company is shown in Fig. 113. Since the sets are somewhat enclosed in the middle, a fan is provided

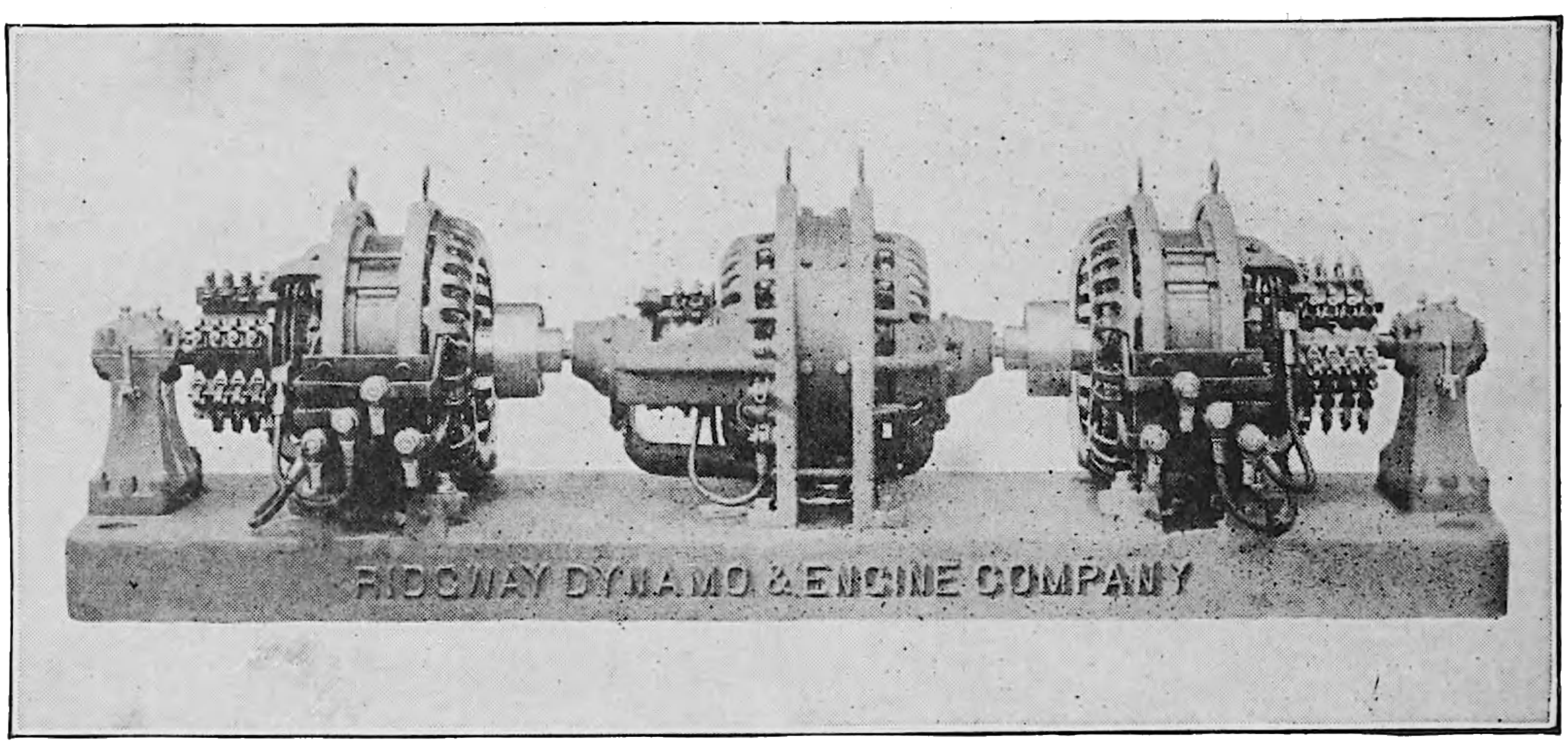


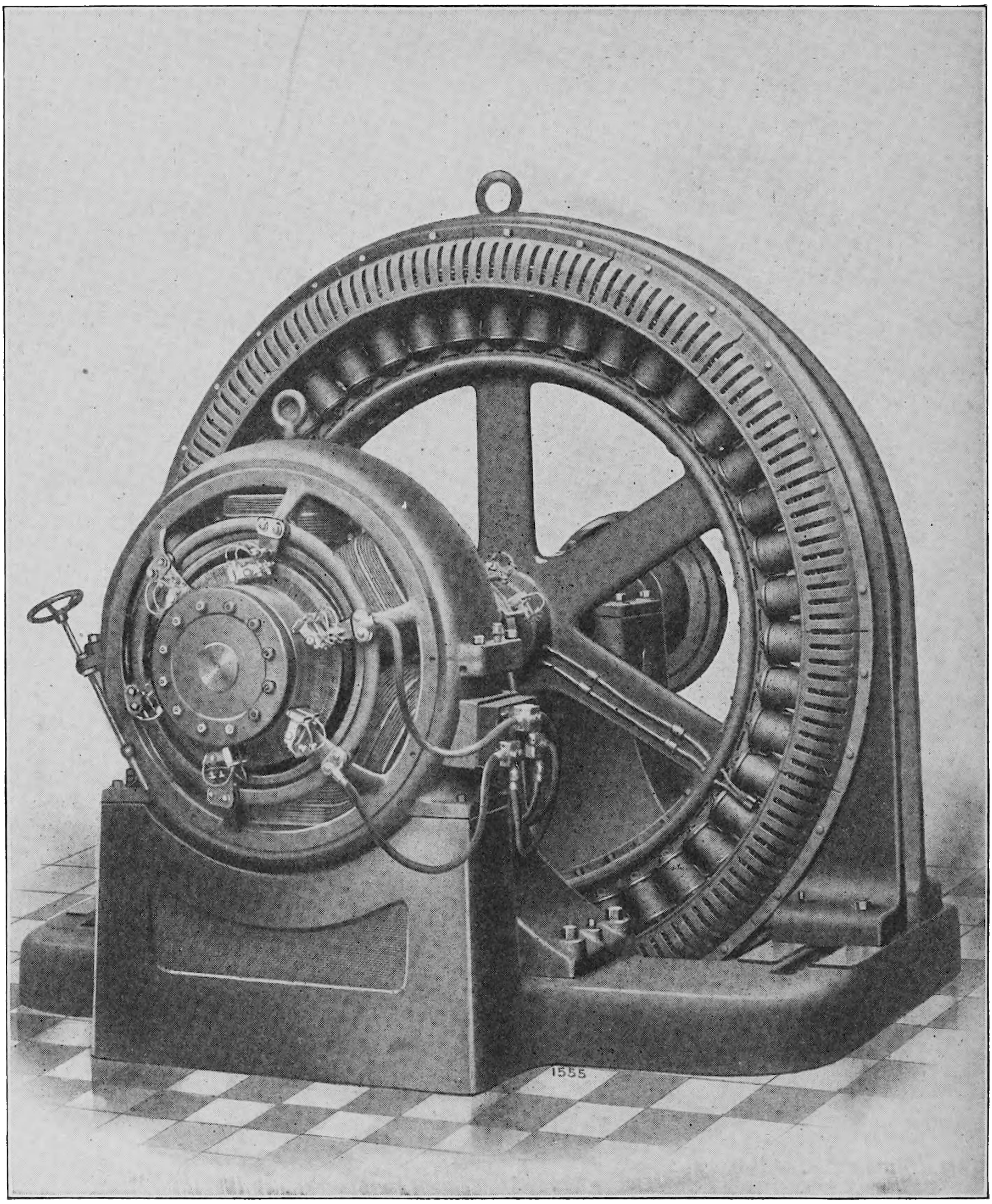

Fig. 118. Ridgway Booster Set

and mounted between the armatures. Fig. 114 shows a C & C balancer set composed of their type SL machines. For various systems of multiple voltage motor control, the two armatures may be of different voltages, usually 90 and 160 on a 250-volt main circuit. A three-wire Allis-Chalmers balancer set is shown in Fig. 115. In connection with four-wire systems the set is composed of three machines like the Crocker-Wheeler one shown in Fig. 116, with each machine giving a different voltage, so that six different voltages can be impressed on the armature of the motor run from the four-wire system by selecting the voltages of machines 1, 2, 3, 1 and 2, 2 and 3, and all three.

**Booster.** A booster is a machine inserted in series in a circuit to change its voltage. It may be driven by an electric motor (in which case it is termed a motor booster), or otherwise. These machines are employed for purposes of voltage regulation in connection with direct-current electric lighting, power, and railway circuits, and with storage battery applications. The voltage of these circuits falls off considerably at points distant from the station with increase of load, and the booster is connected with the circuit in such a way that its voltage is added to that of the circuit, keeping the voltage at the distant points constant. In nearly all cases they are motor-driven, the motor being a shunt-wound machine and the generator a series-, shunt-, or differential-wound type.

Fig. 117 shows a booster of General Electric manufacture composed of a shunt-wound generator and a shunt-wound motor used for storage battery charging and regulation. This requires adjustment to keep the charging of the battery at the proper rate. The whole operation becomes automatic by employing on the generator differential windings properly proportioned so that, up to a certain load, the line voltage is raised by the booster sufficiently to charge the battery, while at higher loads the battery assisted by the booster will discharge into the line.

Fig. 118 shows a booster set manufactured by the Ridgway Dynamo and Engine Company, consisting of a shunt motor and two series generators. Each generator is connected into one of the outside wires of a three-wire system supplying light and power to a distant point.



ENGINE-DRIVEN MULTIPHASE ALTERNATOR WITH DIRECT CONNECTED EXCITER

*Courtesy of Fort Wayne Electric Works*

as to give a certain frequency. The standard frequencies today are 60 and 25 in this country. For 60 cycles, the number of poles multiplied by the speed in revolutions per minute must equal 7200, while for 25 cycles their product must always equal 3000.

In belted alternators the speeds usually fall between 1800 and 600 r. p. m., while their number of poles are from 4 to 12. Alternators direct driven by steam engines, gas engines, or water wheels run from 900 to 72 r. p. m., and carry from 8 to 72 poles. Turbo-

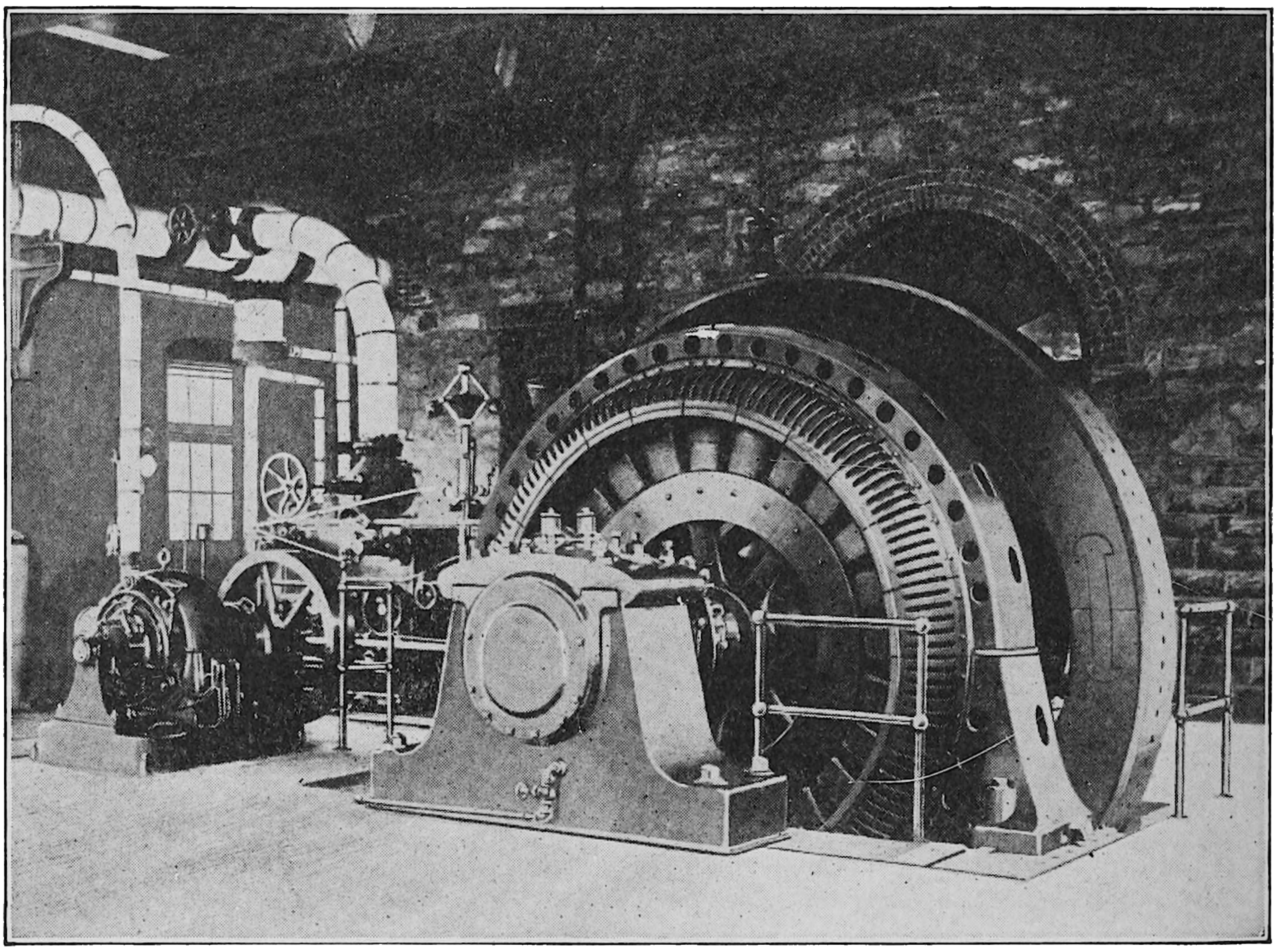


Fig. 119. Engine-Driven, Revolving-Field, Alternating-Current Generator
*Courtesy of Allis-Chalmers Manufacturing Company*

alternators, or alternators that are direct driven by steam turbines, run from 3600 to 500 r. p. m., and have from 2 to 12 poles.

**Classifications.** Alternators may be divided into three types, depending upon the mechanical arrangement of the armature and the field:

(1) Alternators with revolving armatures and stationary fields.

(2) Alternators with stationary armatures and revolving fields.

(3) Alternators in which both armature and field windings are stationary. A revolving part called the inductor causes the flux from the field windings to sweep across the armature conductors.

The revolving-field type is practically the only one manufactured today, the inductor type having been discontinued, and the revolving armature being restricted to the smaller sizes and lower voltages.

## DESCRIPTIONS OF TYPES

**Allis-Chalmers Manufacturing Company.** The alternators put upon the market by this company include five different types:

(1) Standard engine type, in which the rotor is separate from the engine flywheel, as shown in Fig. 119.

(2) Flywheel type, Fig. 120, in which the field poles are mounted directly

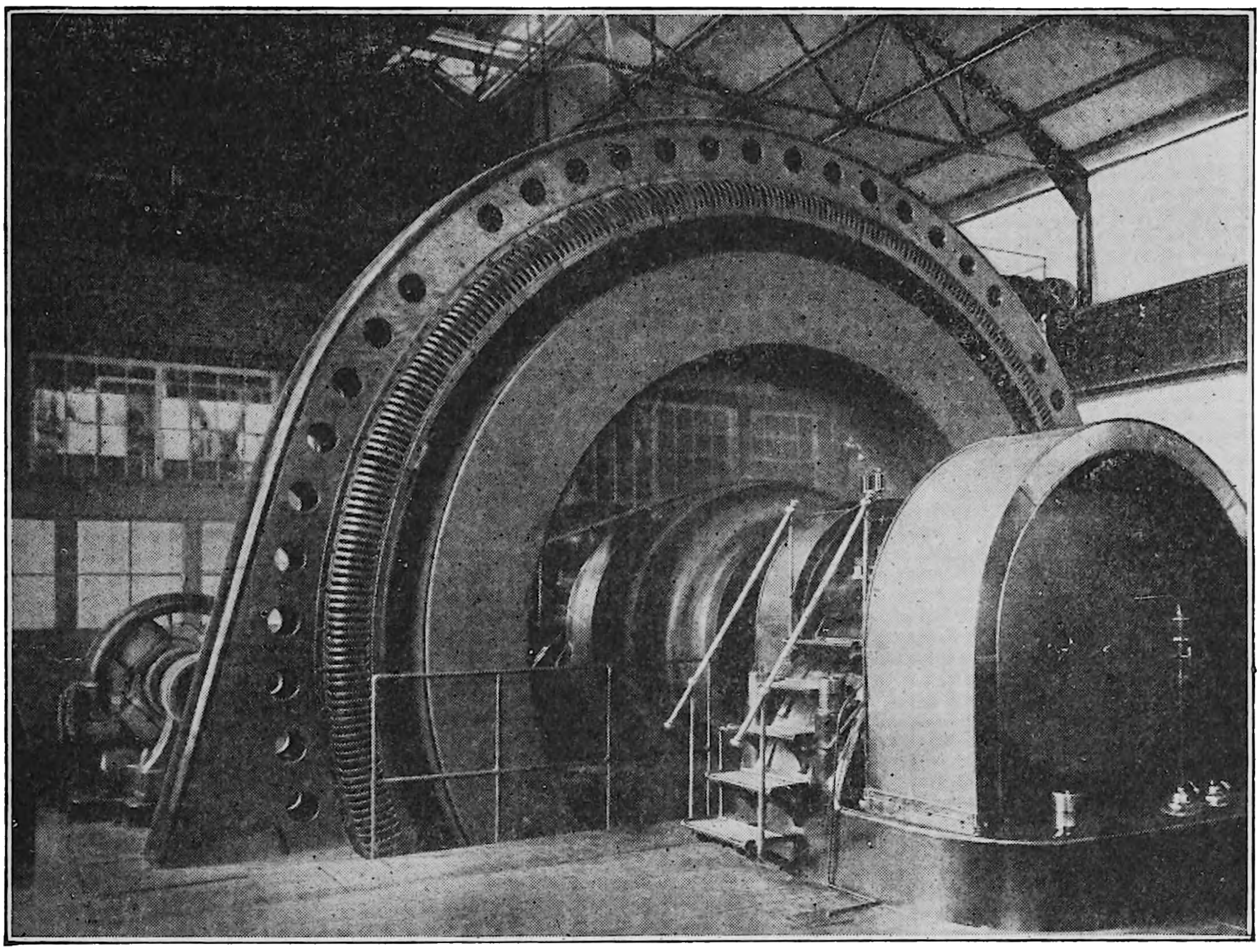


Fig. 120. 1500 K. V. A. Alternator Installed for the Mutual Electric Company, San Francisco, California.
*Courtesy of Allis-Chalmers Manufacturing Company*

on the face of the engine flywheel which then serves the double purpose of flywheel and rotor spider. This is only built in the largest sizes, so that the rotor can give the necessary flywheel effect.

(3) Water-wheel type, having a horizontal shaft, two bearings and flange coupling, as shown in Fig. 121.

(4) Belted type, in sizes from 50 to 900 k. v. a. for use in smaller and industrial plants. This type is illustrated in Fig. 122.

(5) Turboalternators with horizontal shaft, being totally enclosed and employing forced ventilation, as shown in Fig. 123.

All of these types are built revolving field, 60 or 25 cycles, two-phase or three-phase and employ 120 volt field excitation. The

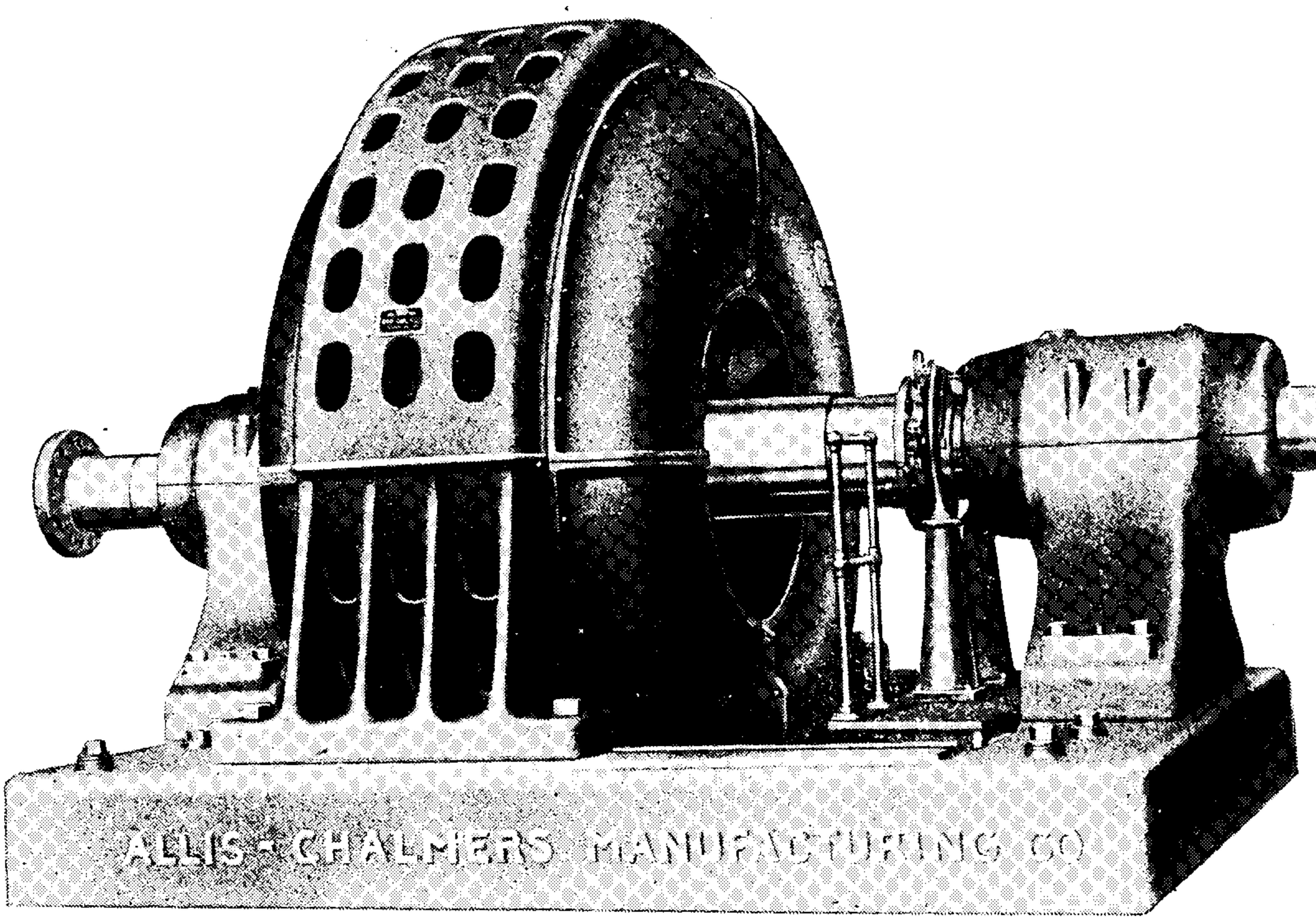



Fig. 121. 5000 K. V. A., 6600 Volt, Three-Phase Water-Wheel Type Alternator Built for Northern California Power Company

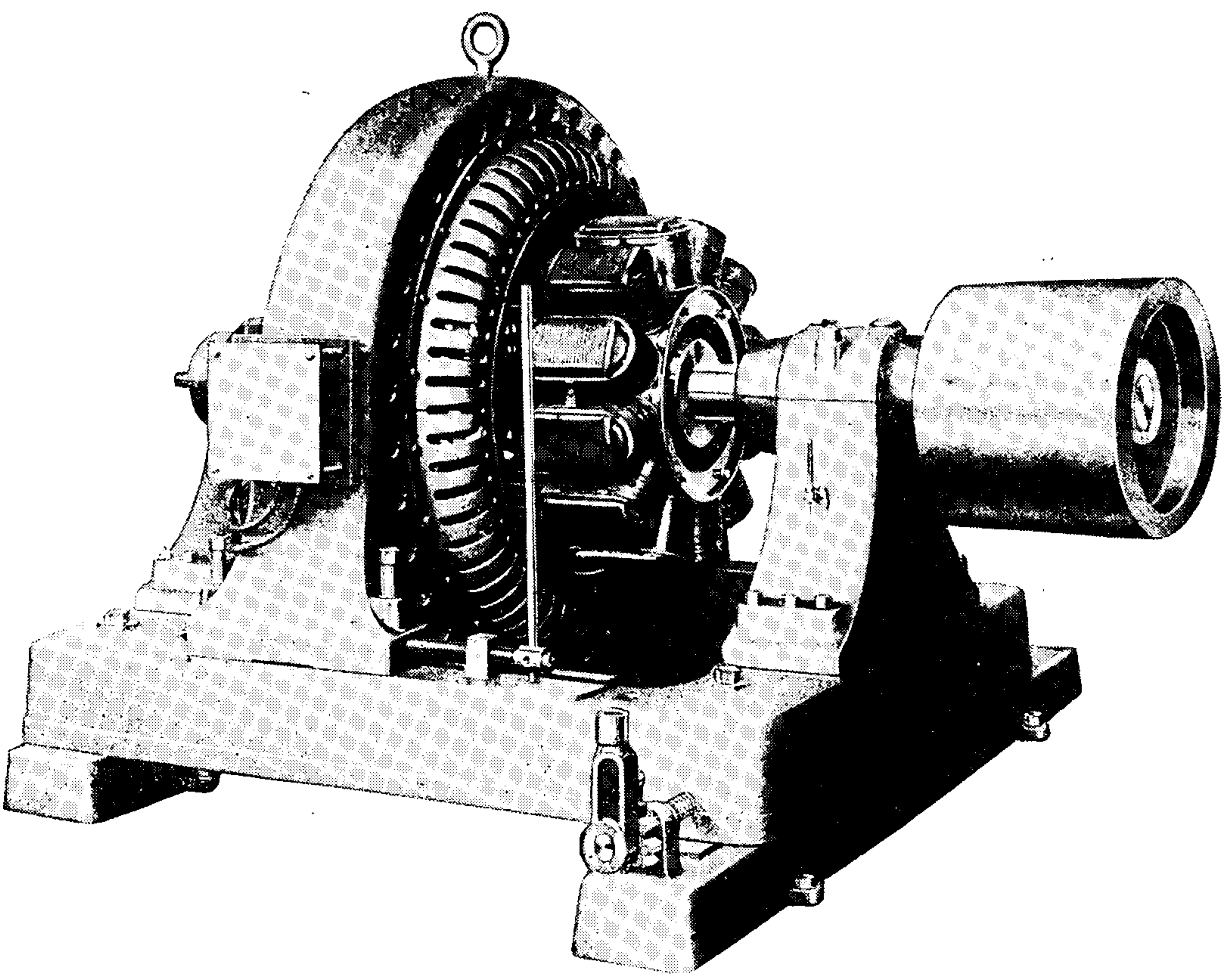


Fig. 122. Allis-Chalmers Type AN Belted Two-Bearing Alternator—Stator Moved Sideways

After the coils have been covered with insulating materials and treated with insulating compound, the parts that are to lie in the slots are pressed to exact size in steam-heated moulds. The ends

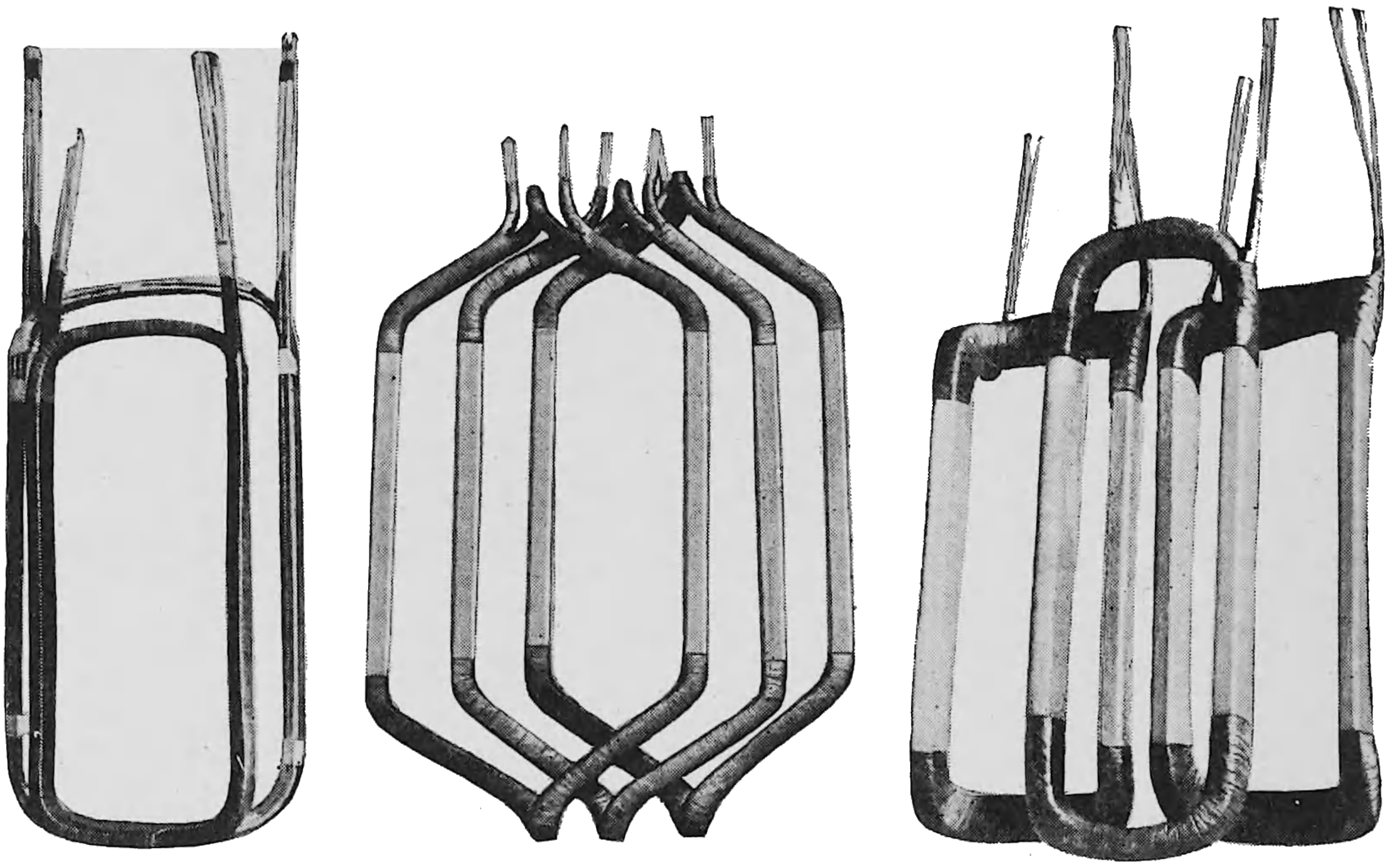


Fig. 124. Form-Wound Interchangeable Armature Coils

of the coils where they project beyond the slots are heavily taped and, when necessary to withstand the stresses due to short circuits, suitable supports are provided. The details of the coils and windings are shown in Figs. 124, 125, and 126.

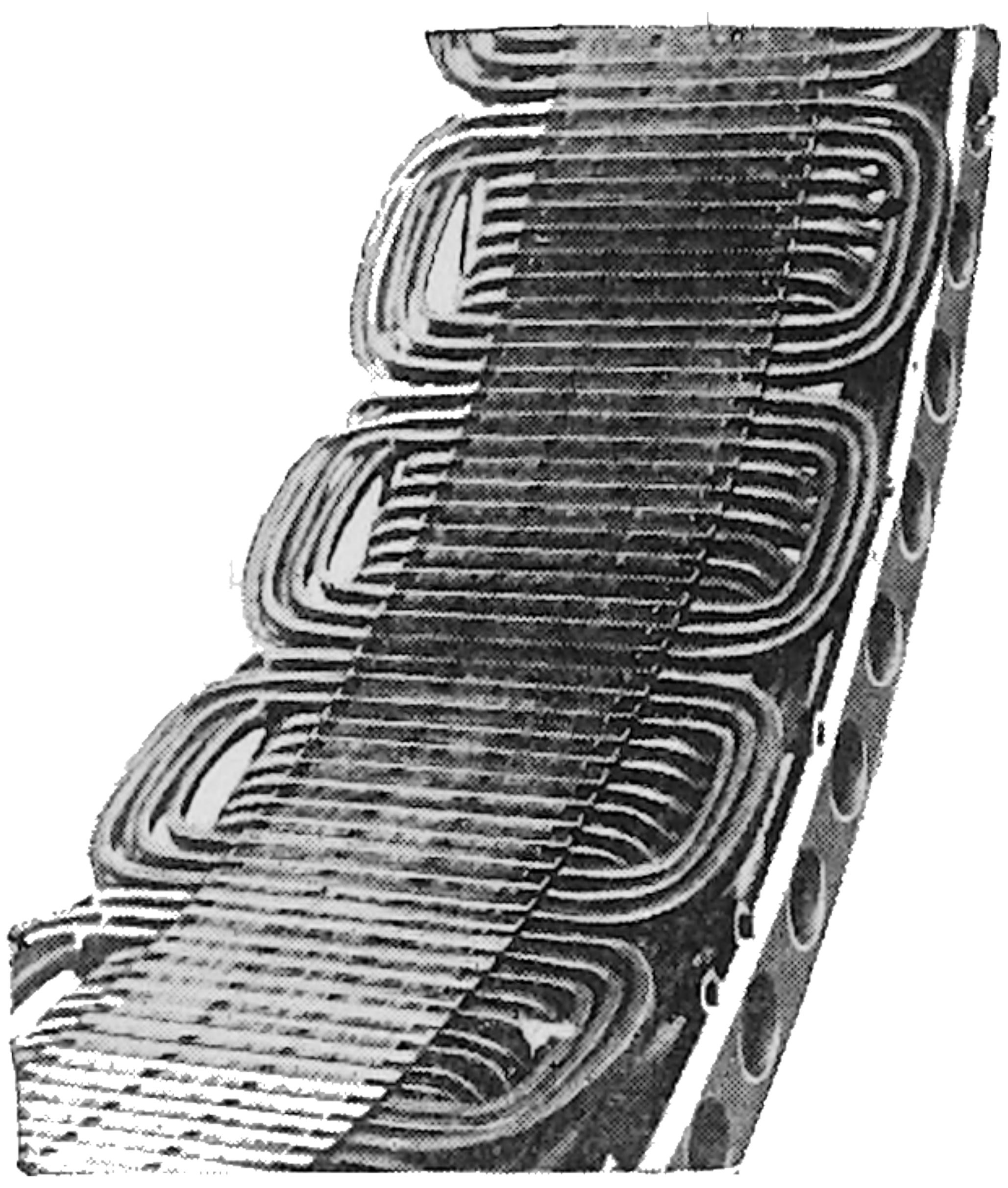


Fig. 125. Allis-Chalmers Chain Winding

In the engine type, water-wheel driven, and belted machines, the field structure consists of laminated pole pieces mounted on the rim of the cast-steel spider; in the flywheel machines the poles are mounted directly on the flywheel face. In some of the large machines the rim of the revolving field is built up of steel laminations. In most machines the pole pieces are provided with dovetail projections that fit into corresponding slots milled in the spider rim and are securely held in place by tapered steel keys. The poles are usually built up of steel punchings clamped together between malleable-iron end plates securely held by rivets.

Each pole piece carries a magnetizing coil held firmly in place between the spider or flywheel rim and the projecting parts of the pole and end plates. The field coils are made of copper strip, edgewise-wound. The collector rings, through which exciting current is supplied to the field, are of cast copper. Current is led into the rings by means of carbon brushes, at least two per ring. Copper shunts or pigtails are attached to the brushes to prevent current from passing through the springs. With engine, flywheel, and water-wheel types the brush holder studs are mounted on a stand, as is shown in Fig. 121. In the belted type the brush holder studs are fastened to the cap of one of the bearing pedestals. The bearings on all machines are of the ring-oil type with ample oil reservoirs.

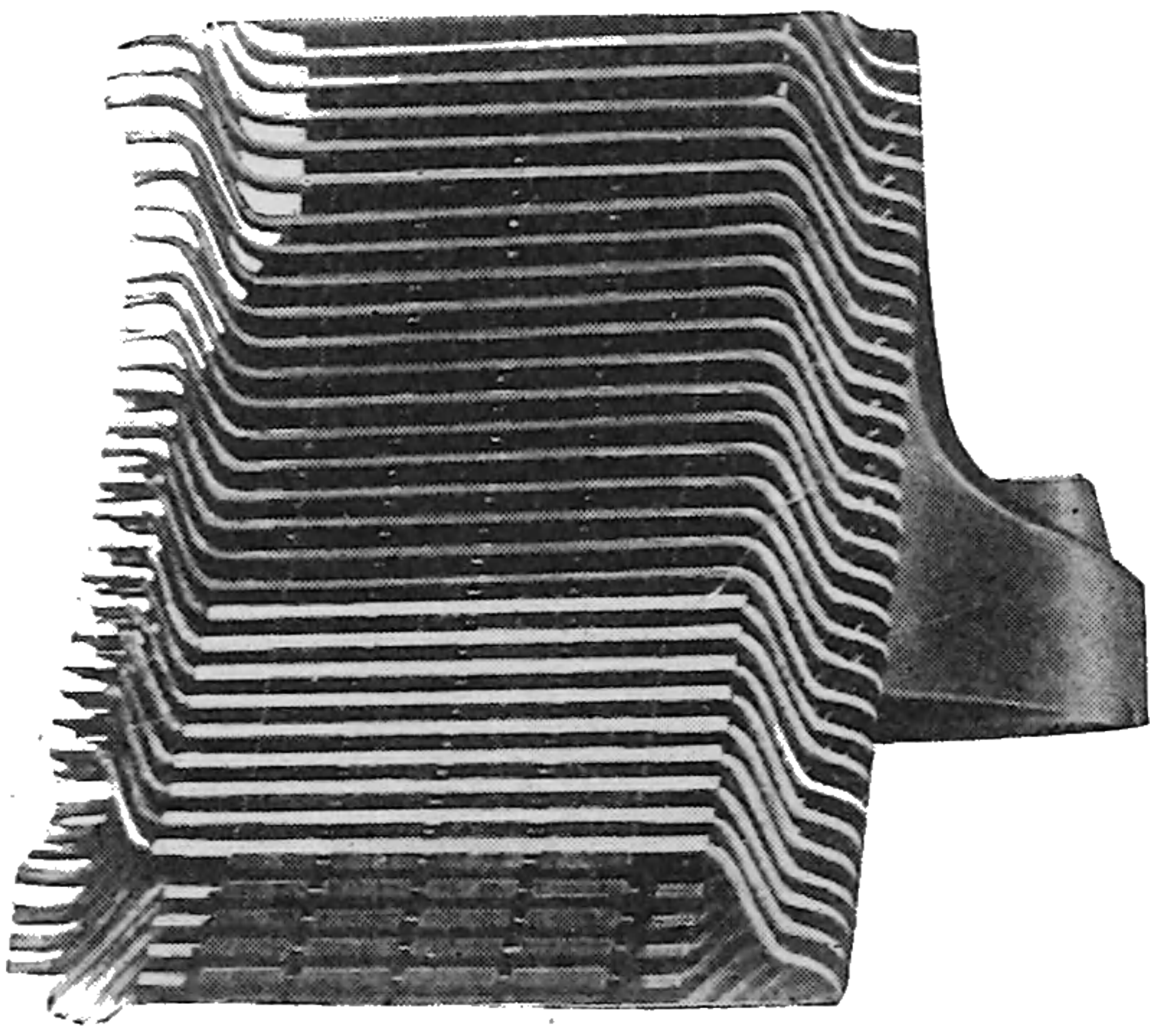


Fig. 126. Allis-Chalmers 2-Layer Winding

*Characteristics of Turboalternators.* In the turboalternators, the armature or stator construction is similar to that of the other types. The rotor or revolving field is built up of either steel laminations or of nickel-steel forgings. The slots formed in the core to receive the field coils are radial. The field winding is made of carefully insulated coils of flat strap copper firmly held in the slots by means of bronze wedges. The ventilation of the ends of the coils

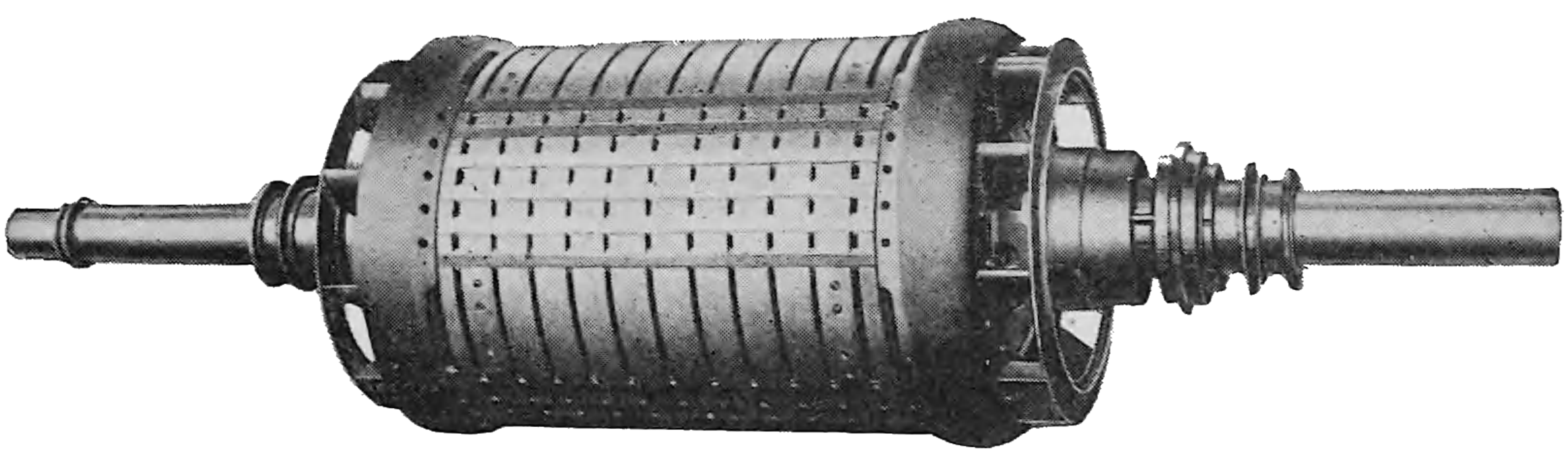


Fig. 127. Rotor of a 5625 K. V. A. Allis-Chalmers Turbogenerator

is attained by having them project beyond the ends of the core. At this point they are firmly held by means of nickel-steel rings. For the purpose of obtaining proper ventilation and for muffling the noise produced by the circulation of the air the machines are totally enclosed and the air is taken in at the ends, passing through fans that discharge it over the end connections of the armature coils and through ventilating ducts of the core to the outlets. Fig. 127 shows an assembled revolving field with protecting nickel-steel rings and ventilating fans in place.

**Crocker-Wheeler Company.** This company manufactures alternators of the engine, coupled, and belted types as well as turbo-alternators. The coupled type of alternator has its own bearings and a shaft which is connected by a coupling to the shaft of an engine, water wheel, or other source of power. All four types are built revolving field, for two-phase or three-phase at 25 or 60 cycles and for the following standard voltages: 240, 480, 600, and 2300. The field excitation is at 125 volts, allowing the standard C.-W. compound-wound direct-current generators to be used as belted, geared, or direct-connected exciters. In their engine, coupled, and belted types, shown in Figs. 128, 129, and 130, the stator consists of a cast-

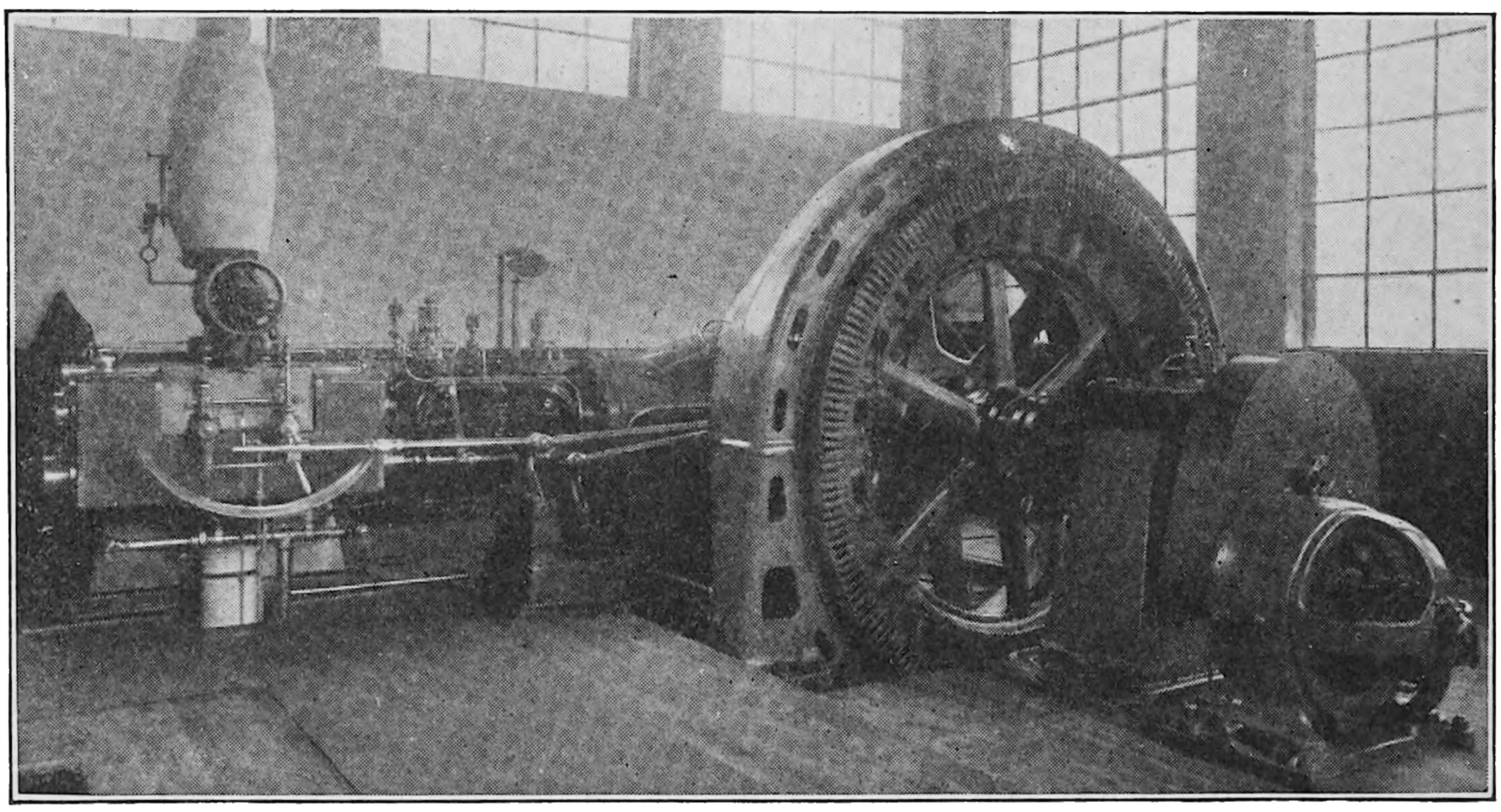


Fig. 128. 165 K. V. A. Alternating-Current Generator
*Courtesy of Crocker-Wheeler Company*

iron frame supporting a laminated core of sheet steel, in the slots of which are placed the stator windings.

*General Types.* The frame is constructed to allow for the proper circulation of air around the stator coils and core, and out through holes in the external surface of the cast-iron frame. This circulation of air over the windings, around the core, and through

For the smaller sizes of alternators, the rotor is a solid steel casting consisting of hub, spokes or web, rim, and poles. Steel pole shoes are bolted to the projecting ends of the poles. For the larger sizes of generators the rotor is like those for the smaller sizes except for the fact that the poles and pole shoes are cast in one piece and bolted to the machined surface of the rotor rim. The rotor or field coils, with the exception of a few sizes that are wound with wire, consist of strips of copper wound on edge. Each turn is properly insulated from the next, and the whole coil is compressed and baked into a compact unit. The coils are well insulated from the neighboring metal and securely held in position by the pole shoes. The exciting current is fed into the field winding through carbon brushes and cast-iron collector rings. These rings are supported on a cast-iron hub from which they are suitably insulated. In the belted type, however, one collector ring is placed on each side of the rotor. The brush holders are of the radial type, with adjustable tension, and the brushes are self-feeding. The entire brush rigging and yoke

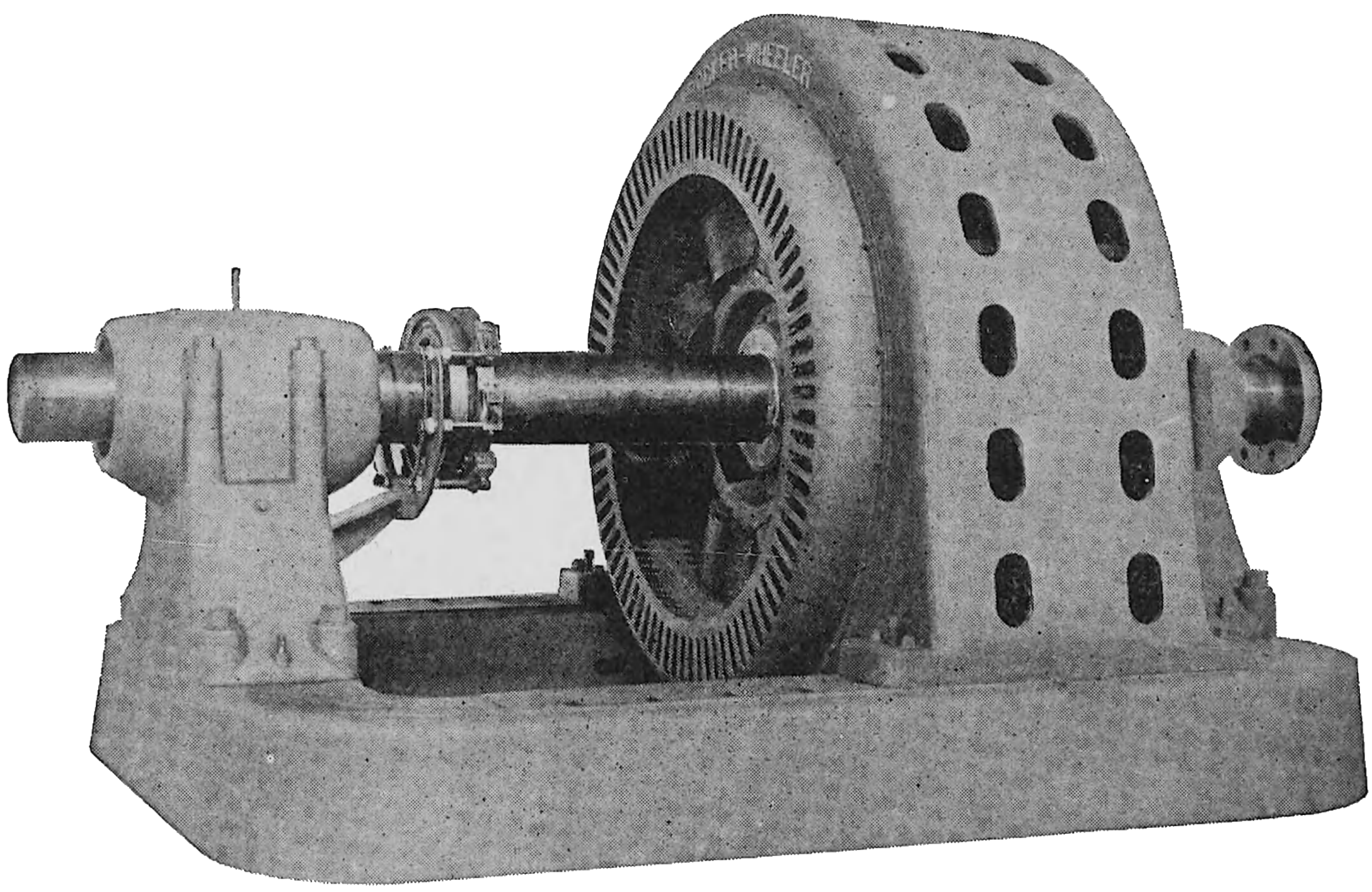


Fig. 130. 2000 K. V. A. Coupled-Type Alternator
*Courtesy of Crocker-Wheeler Company*

are mounted on the bearing or bearing bracket. All bearings are ring-oiling, with caps that are easily taken off to permit the removal of the journal boxes. In the larger sizes the stator frame and bearing pedestals are bolted to the cast-iron base. In the smaller sizes the bearings are carried by three arm brackets bolted fast to the ends of the stator housing.

*Turboalternators.* Crocker-Wheeler turboalternators range from 500 to 6000 k. v. a. They have a frame forming the housing for

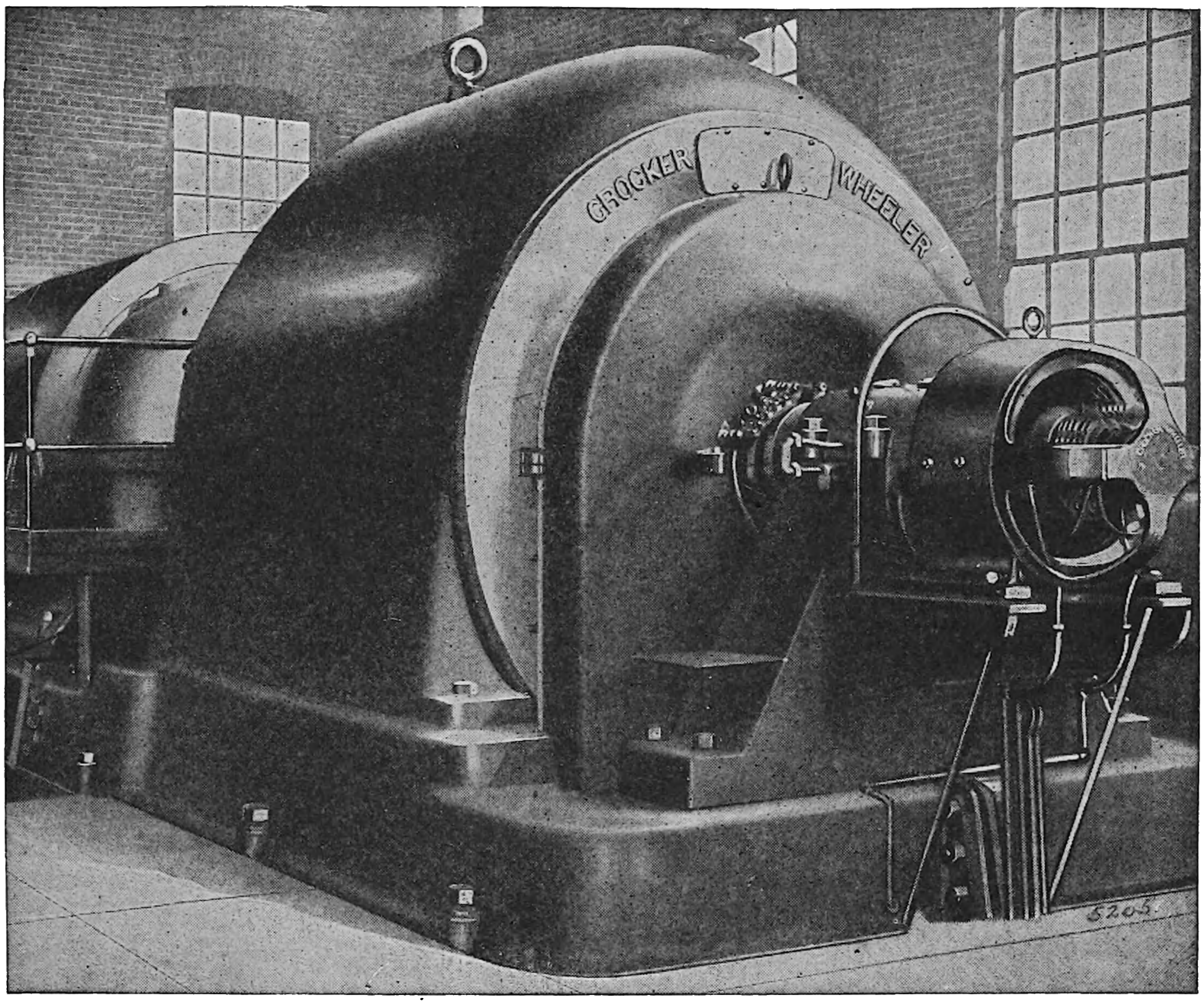



Fig. 131. 3750 K. V A. 2200 Volt, Three-Phase Crocker-Wheeler Alternator

the stator punched laminations that is ribbed and braced on the inside to obtain strength and rigidity. Both ends of the stator housing are closed by means of shields bolted fast to it. The shields serve as passage ways to carry the incoming ventilating air where it is needed, protect the windings of the stator from injury, and prevent the admission of oil, dust, or dirt. These enclosing shields also reduce the noise made by the rapidly-revolving rotor.

The method of ventilation in these machines provides for drawing the air in through horizontal openings on the under side of each end shield and discharging it through openings in the lower central part of the frame. The absence of other openings and of any projecting lugs or ribs results in a frame of smooth exterior surface and of compact and symmetrical shape as shown in Fig. 131.

The laminations of the stator are of sheet steel securely clamped together by end flanges and provided with ventilating ducts to secure uniform and low temperature throughout the core. The insulated,

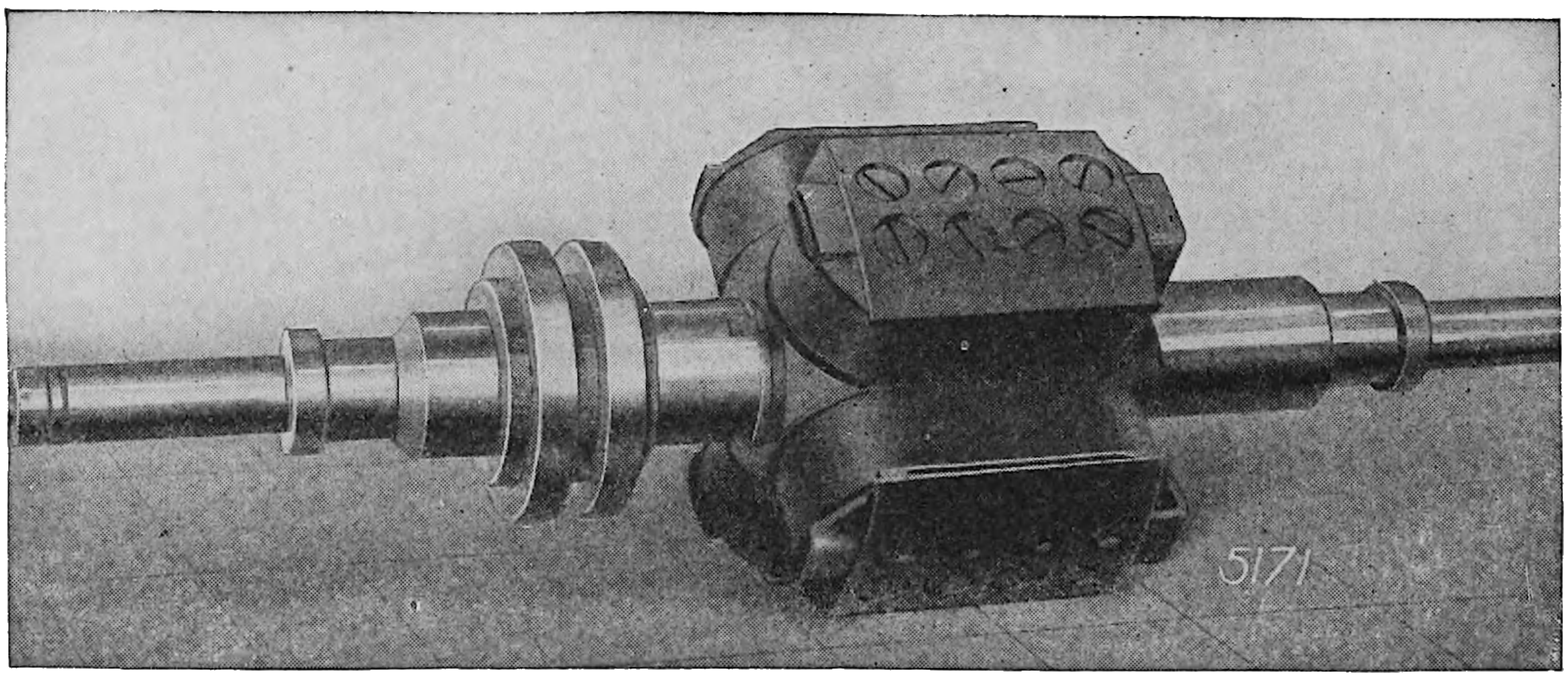


Fig 132. Rotor of 250 K. V. A. Two-Phase Crocker-Wheeler Turboalternator

form-wound stator coils are held in the open slots of the stator by wooden wedges fitted into the grooves in the teeth. The projecting ends of the windings are heavily insulated and varnished and are further protected by the extended portion of the stator housing and the end shields.

In some cases the rotor core is a solid steel casting with pro-

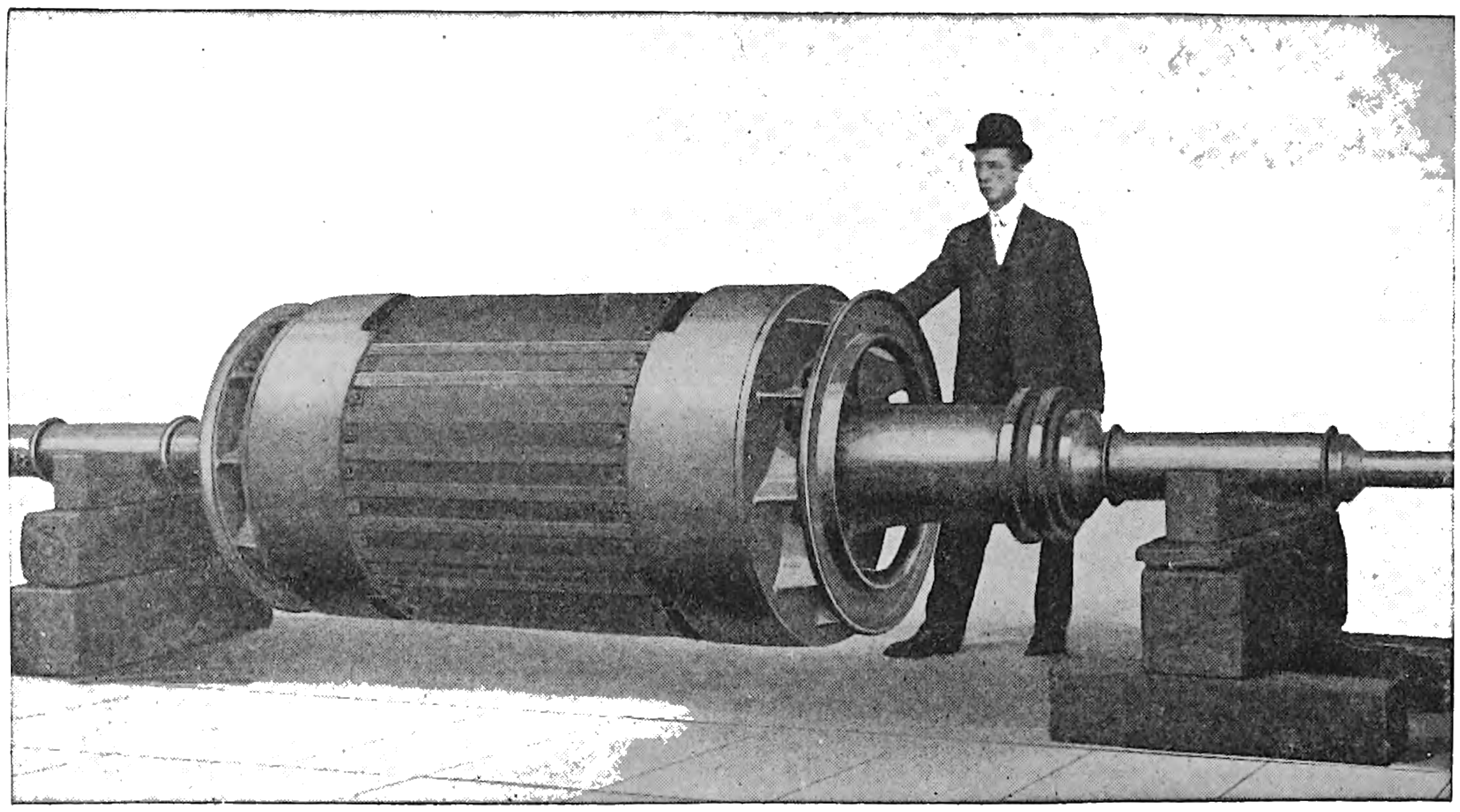


Fig. 133. Rotor of 3500 K. V. A. Three-Phase Crocker-Wheeler Turboalternator

jecting poles to which the pole shoes are bolted, as shown in Fig. 132. These pole shoes provide proper distribution of the magnetic

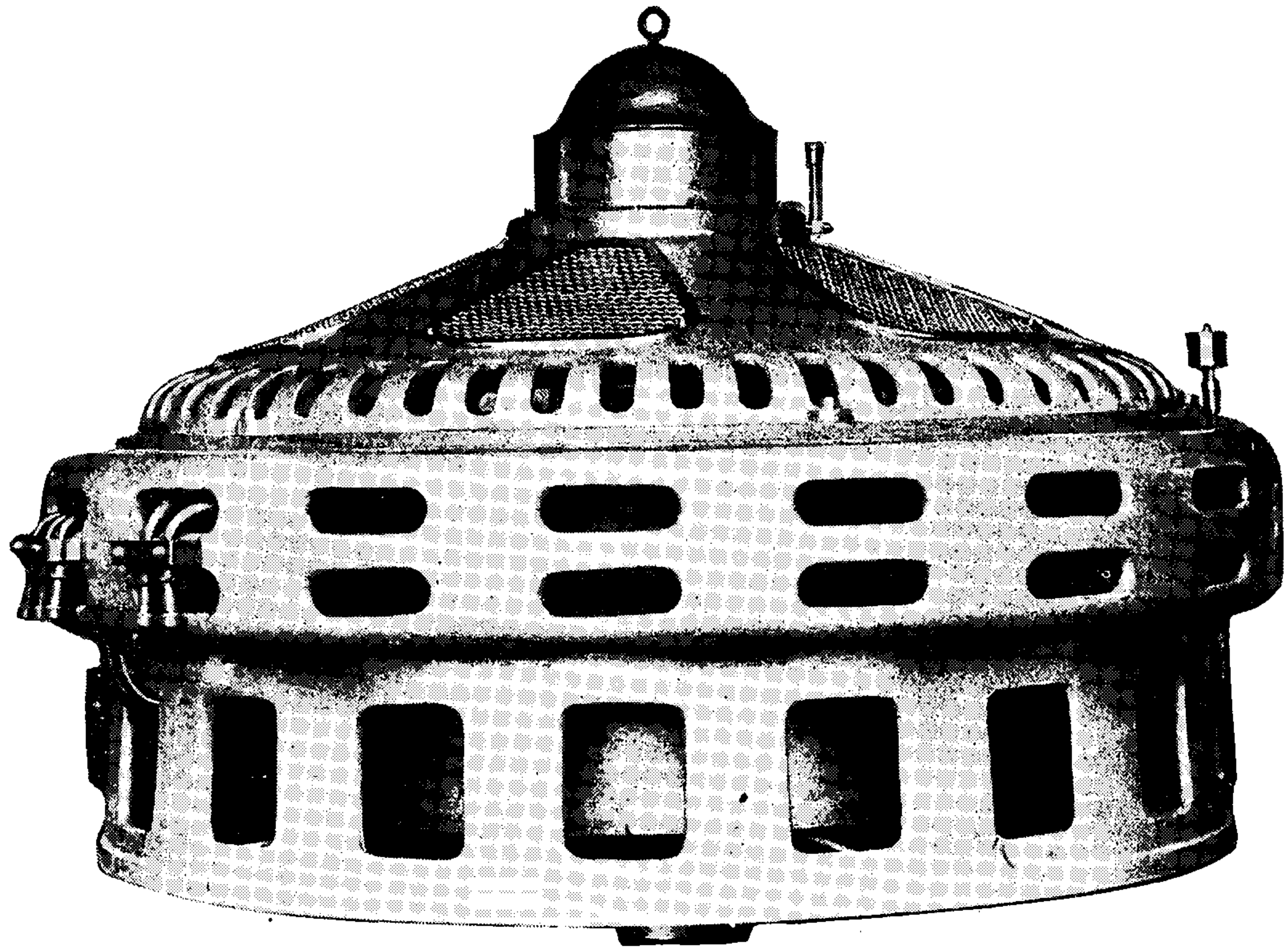


Fig. 135. Vertical Type of Electric Machinery Company Alternator

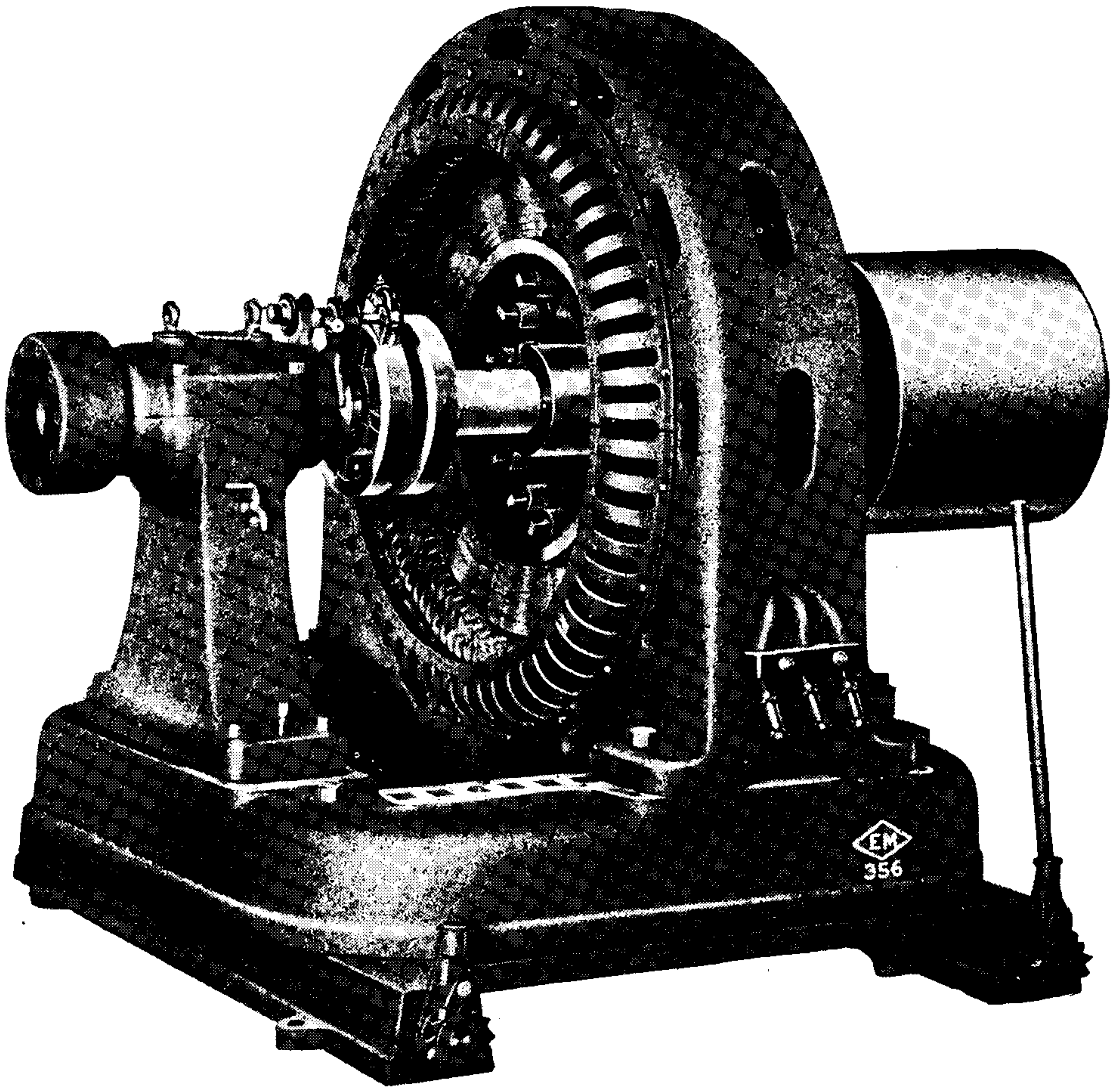



Fig. 136. 100 K. V. A. Two-Bearing Pedestal-Type Alternator
*Courtesy of Electric Machinery Company*

belted types. They are all revolving-field, two-phase or three-phase, 25 or 60 cycles, employ 125 volt exciters and are wound for 240, 480, 600, 1200, or 2400 volts. One of their engine-type alternators is shown in Fig. 134. Their coupled machines are of two types, horizontal shaft, and vertical shaft, for direct coupling to vertical water-wheel shafts. This latter style is shown in Fig. 135, while Fig. 136 is an illustration of one of their belted types. Their belted machines in the larger sizes are three-bearing and in the smaller sizes have the bearings supported by end brackets instead of separate pedestals.

*General Characteristics.* Except in the largest sizes, where it is

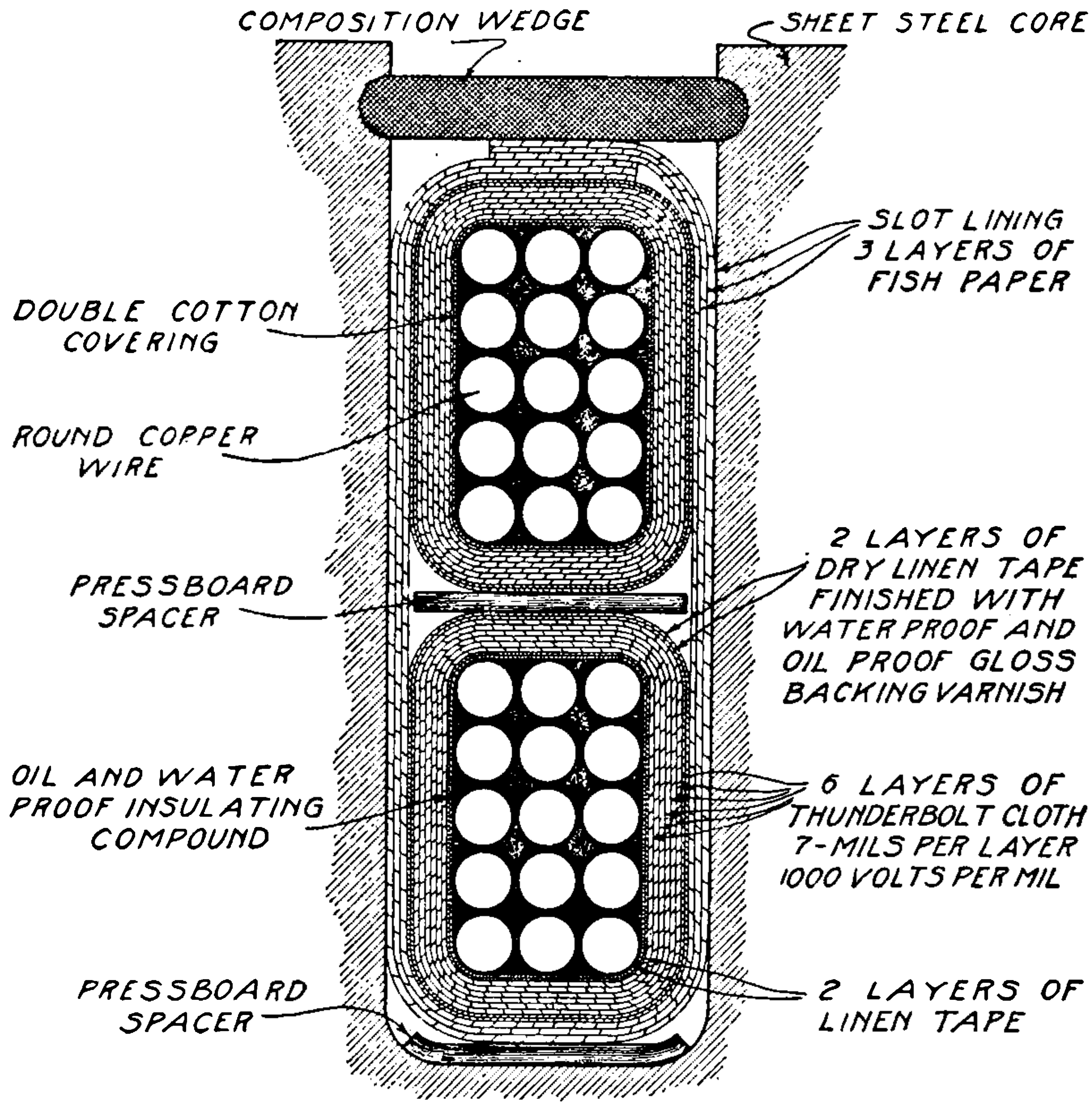



Fig. 137. Details of Electric Machinery Company Armature Coil and Slot Insulation

split horizontally, the circular cast-iron armature ring is one piece. The sheet-steel armature core is built up of laminations assembled with staggered joints and clamped between rigid cast-iron retaining rings. Ventilating spaces are provided at short intervals by means of box-shaped spacers near the ends of the teeth and through the depth of the core. Open-type armature slots carry the form-wound interchangeable coils rigidly held in place by composition wedges, as shown in Fig. 137. At both ends of the armature core, tooth supports reinforce the teeth and prevent humming and chafing of the coils. These are punched steel strips, V-shaped, and riveted to each other at the open ends so as to form a continuous chain of loops, each one supporting one tooth. The revolving field consists of a spider very much like a thick-rimmed pulley. It is made of cast iron for slow speeds but of cast steel for high speeds. This spider carries the pole pieces with their field windings. Square holes are

Fig. 138. Box-Frame Type of Armature
*Courtesy of General Electric Company*

formed in the rim for receiving the anchors of the pole pieces. The pole pieces are built up of steel laminations held between end plates. The field coils are edgewise-wound copper ribbon. Cast-iron collector rings and carbon brushes allow the exciting current to pass through the field windings.

**General Electric Company.** *General Characteristics.* The alternators manufactured by this company include complete lines of

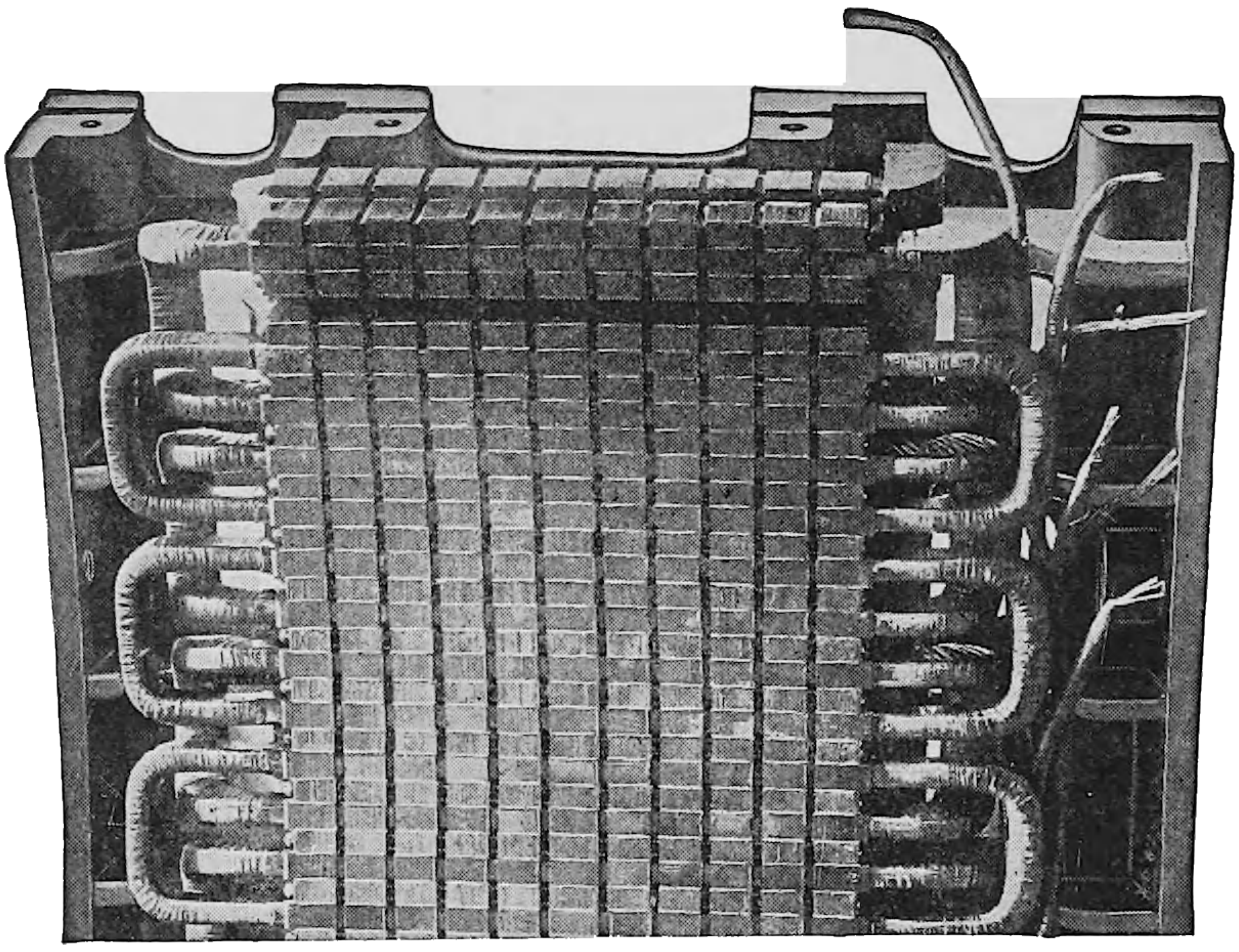


Fig. 141. Section of G. E. Stator Sh wing Ventilating Ducts

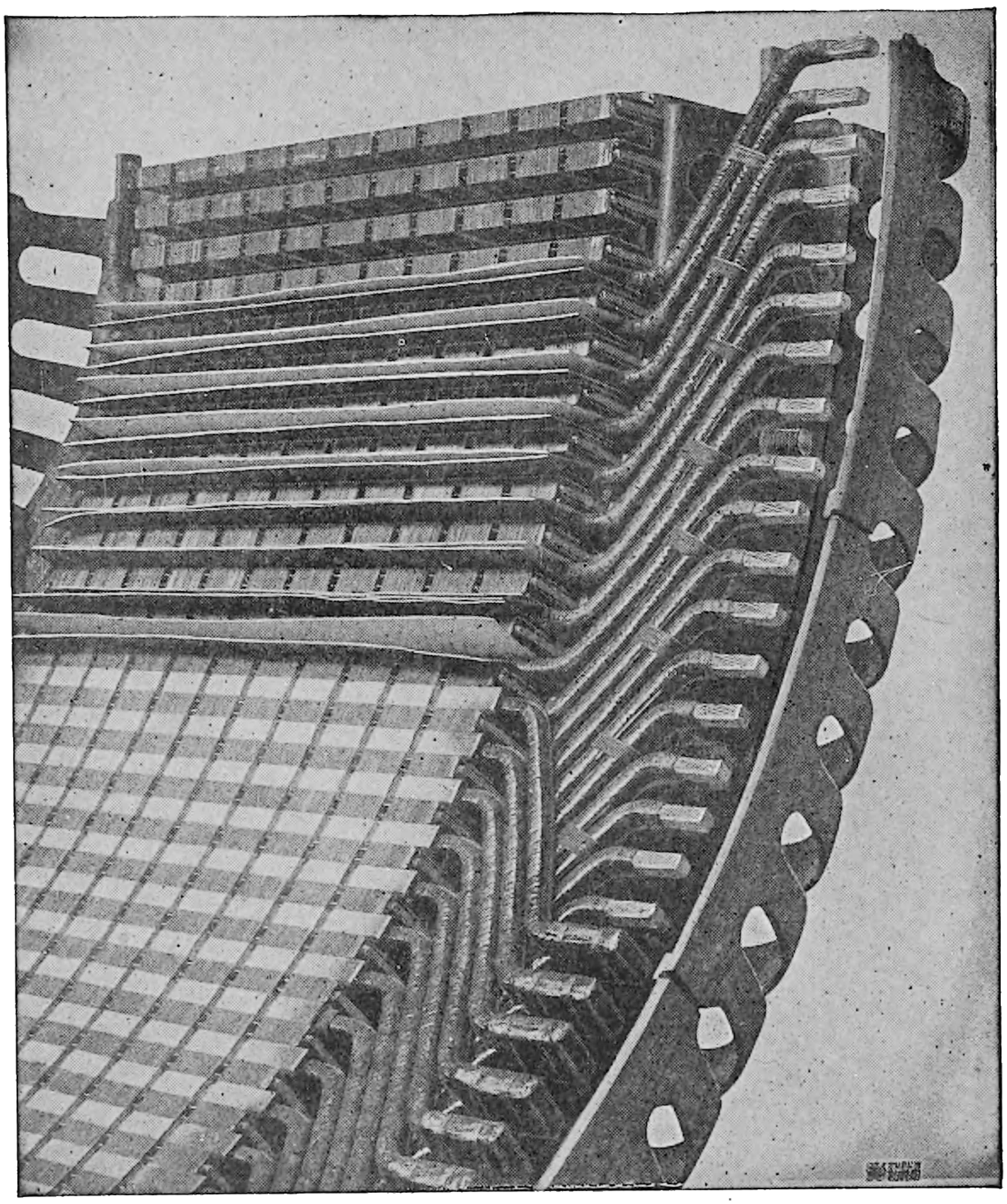


Fig. 142. Section of G. E. Stator Showing Air Ducts and Supporting Fingers Along Slot Projections

laminations is dovetailed for fastening to the frame and the inner circumference is slotted to receive the windings (see Figs. 140, 141, 142, and 143). The armature windings consist of carefully insulated form-wound coils held in open slots by suitable wedges. The coils and windings are clearly shown in Figs. 141, 142, and 143. The revolving-field structure, Fig. 144, consists of laminated pole pieces bolted to a cast-steel or iron ring, which is connected to the hub by arms of ample section, as shown in Fig. 145. The pole pieces, Fig. 146, are built up of laminated iron sheets, spreading at the pole face so as to secure

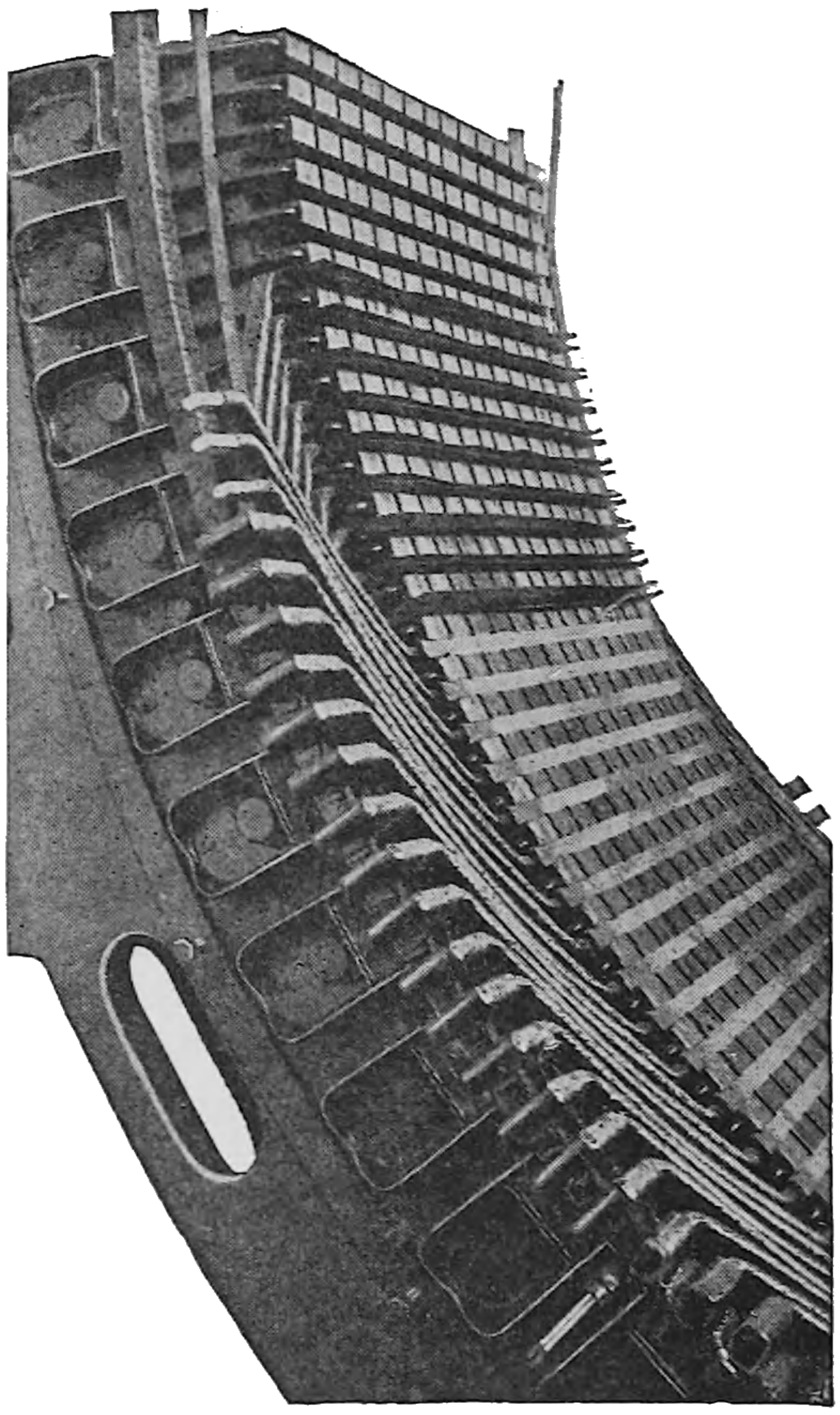


Fig. 143. Section of Stator Showing Method of Assembling Coils

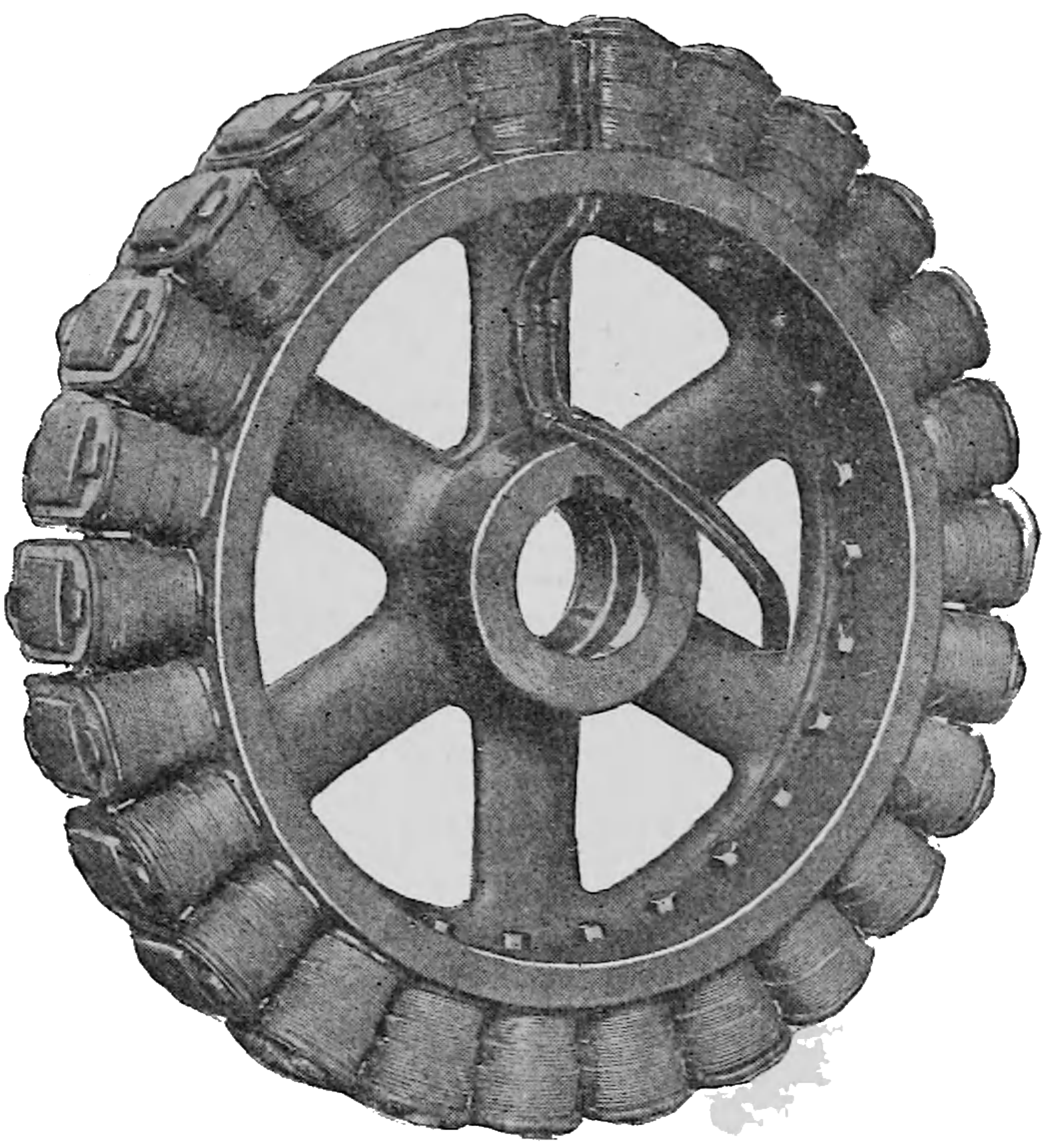


Fig. 144. Revolving Field with Wire-Wound Coils
*Courtesy of General Electric Company*

not only a wide polar arc for the proper distribution of the magnetic flux, but also to hold the field windings in place. The laminations are either riveted or bolted together and reinforced by

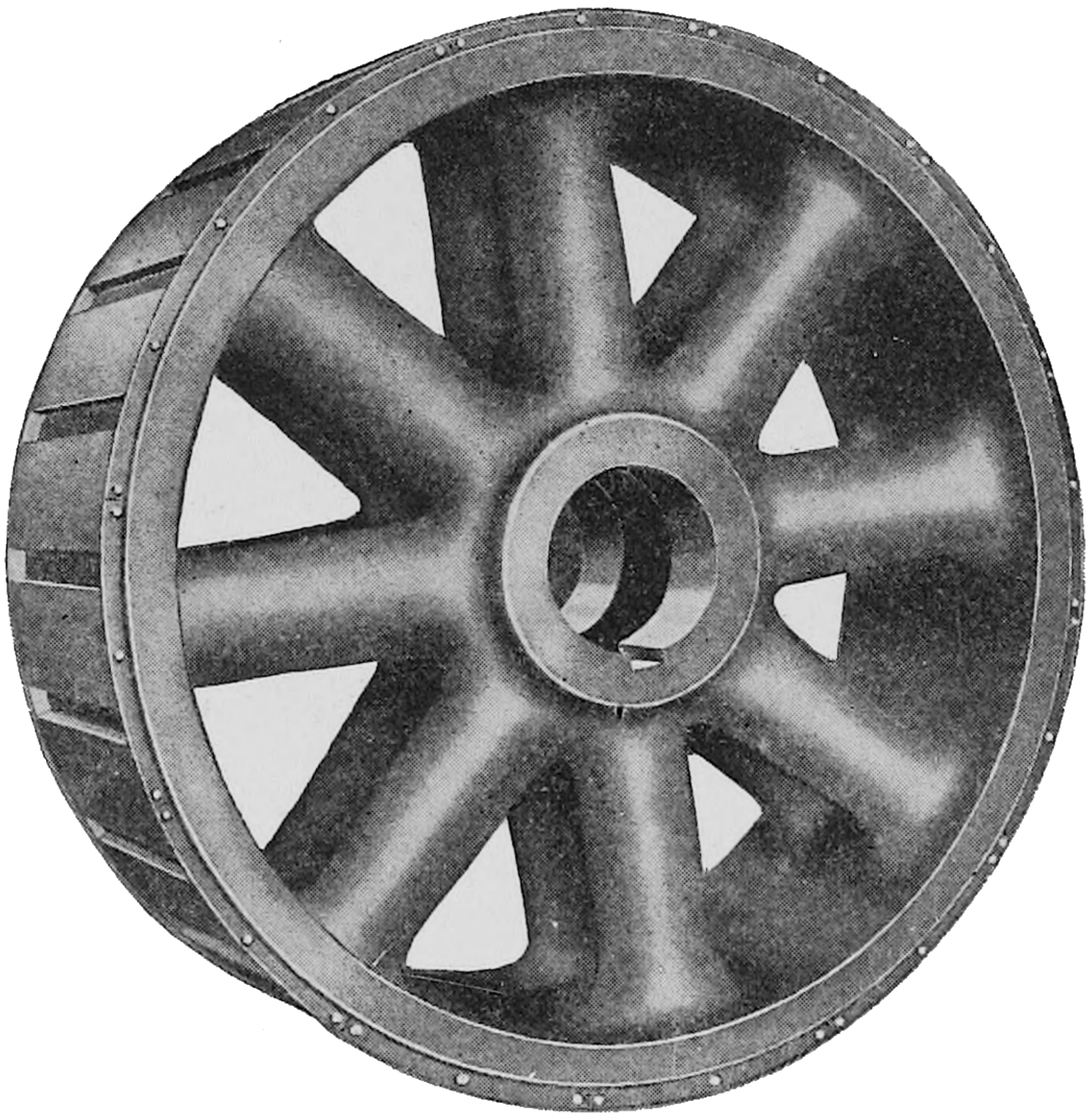


Fig. 145. General Electric Rotor Spider

two stiff end plates. They are either bolted to the spider or solidly mounted by means of dovetail slots in the rim, Fig. 145, the steel wedges being guarded by two bolted end rings. In the smaller

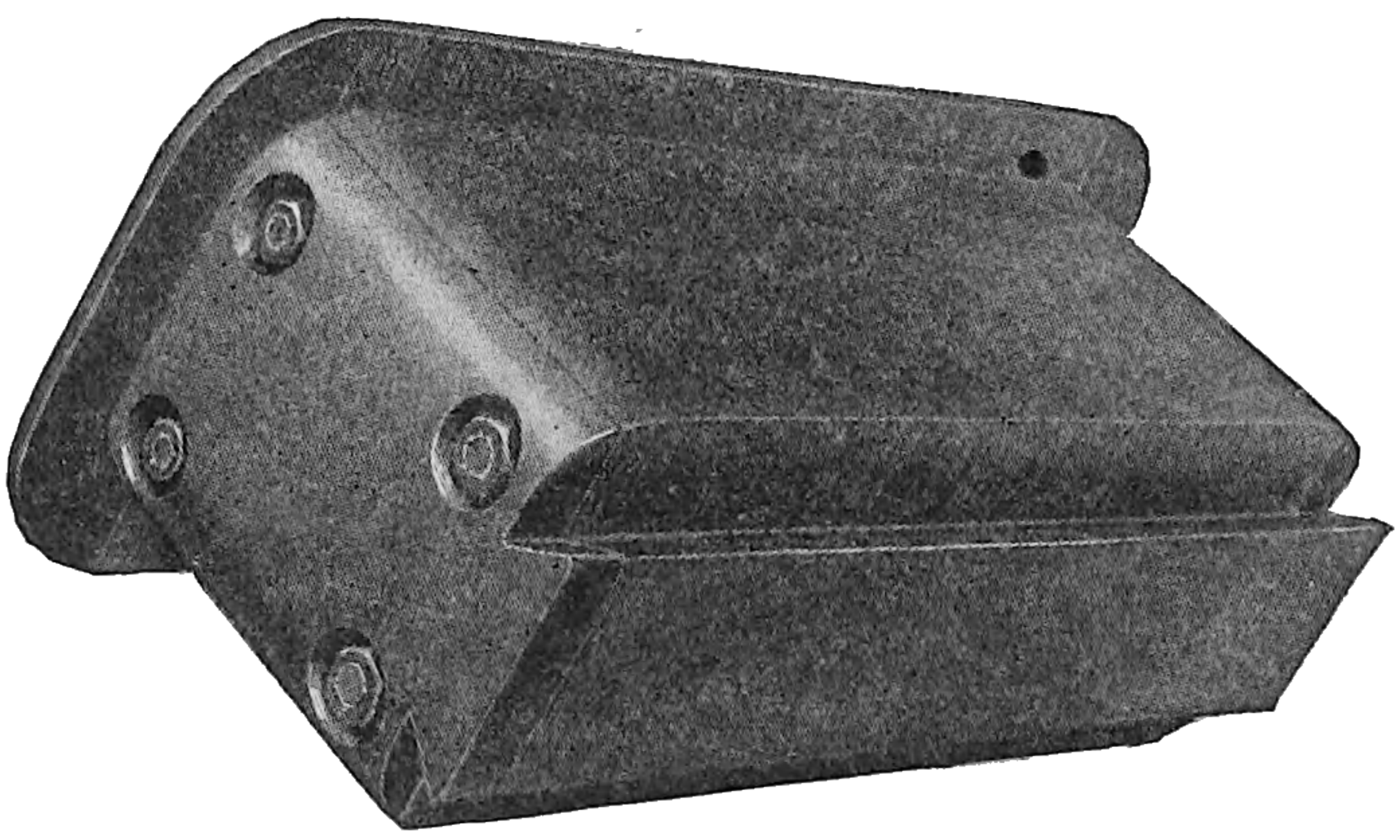


Fig. 146. General Electric Pole Piece Showing Dovetailing

machines the wire is wound on spools which are slipped over the pole piece and held in place by the large tips. The field coils on the larger machines consist of a single strip of flat copper, wound on edge so that every turn has a surface exposed to the air for cooling. The collector rings for the low potential field current are made of cast

amortisseur winding over the revolving field. This is done to decrease variations in angular velocity and improve parallel operation. Any tendency to pulsation or hunting between the engines that is accompanied by a sudden change in the angular velocity of the field, generates current in this short-circuited winding that resists the forces causing pulsation. The appearance of this short-circuited winding is shown in Fig. 148.

*Engine Types.* The engine-type machines are made in standard sizes from 50 to 2000 k. v. a. The water-wheel driven, arranged for either horizontal or vertical shaft, reach as high as 20,000 k. v. a. and a voltage of 13,200.

*Belted Alternators.* The standard belted machines manufactured by the G. E. Company are made in two lines. One is in 7 sizes from 7½ to 200 k.v.a. wound for 240, 480, 600, or 2300 volts, two-phase or three-phase. They are built revolving field and the usual methods of construction are employed. The second line differs radically in that the machines are of the revolving-armature type. They are built in three sizes, 7½, 15, and 25 k.v.a. rating wound for 120, 240, 480, or 600 volts, two-phase or three-phase, at 60 cycles. Their general appearance is shown by Fig. 149. The armature contains two distinct windings placed on the same core. The main generator armature winding is connected to the collector rings furnishing two-phase or three-phase alternating currents, while the other winding connected to the commutator furnishes direct current for the fields. These machines, therefore, require no separate or external exciter. The field structure consists of four laminated pole pieces cast into the yoke or frame.

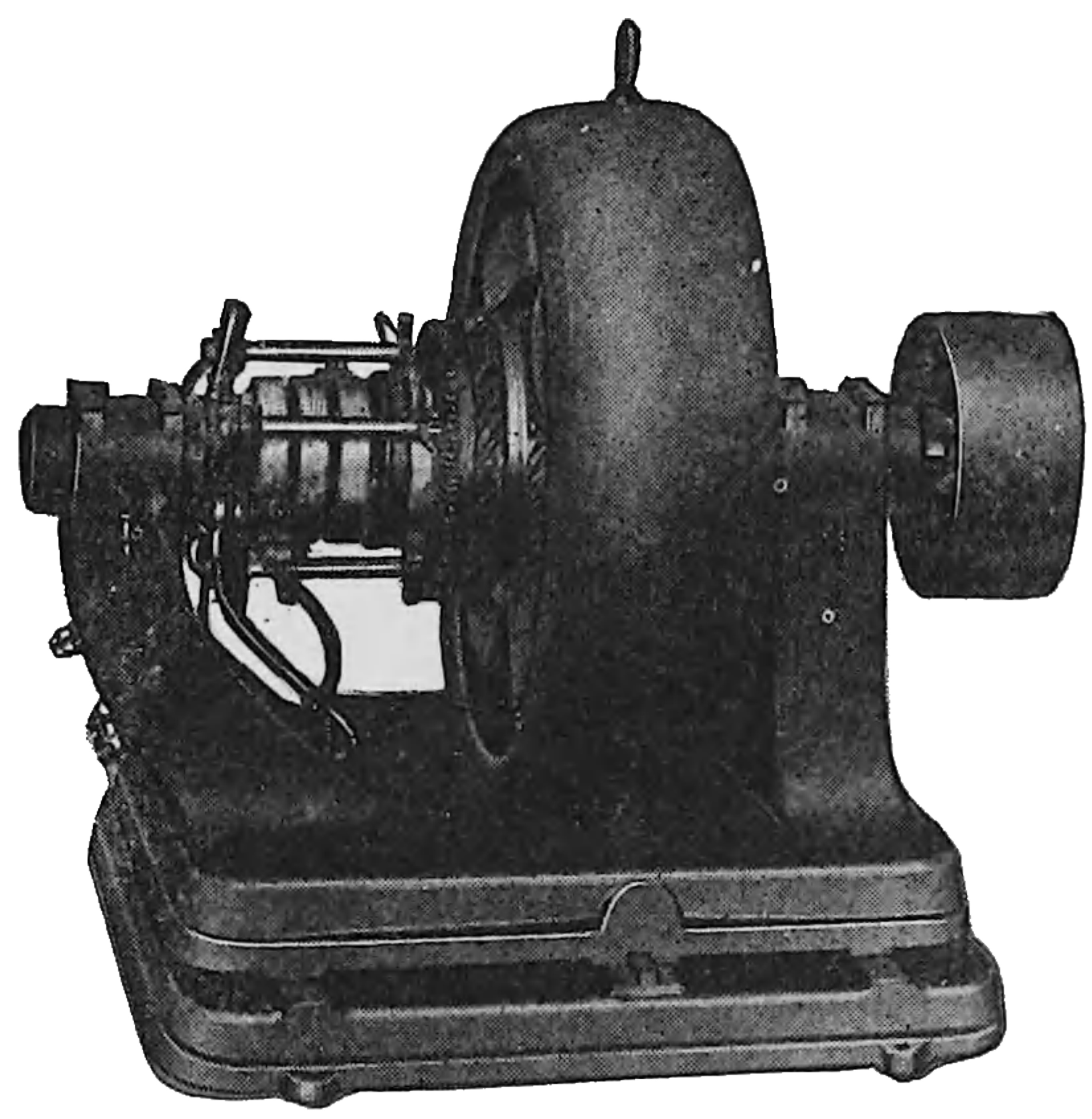


Fig. 149. General Electric 25 K.V.A. Alternator

*Turboalternators.* The turboalternators of this company are of the enclosed type and self-ventilated. In the larger sizes, a fan on each end of the rotating field draws in air through the ducts at either end of the generator and directly under the end shields which

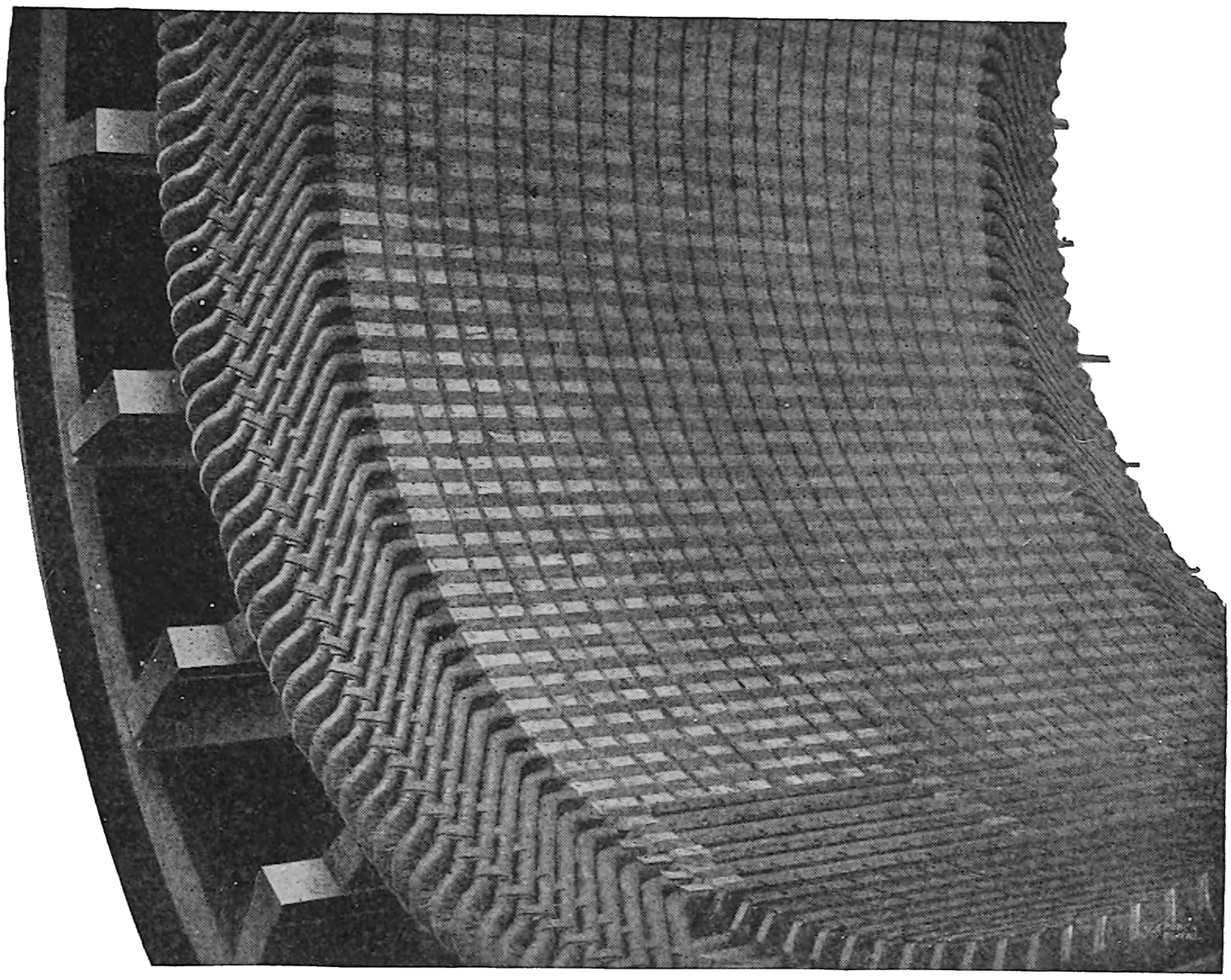


Fig. 150. Portion of Stator Showing Armature Coils Assembled in Slots for G. E. Turbo-alternator

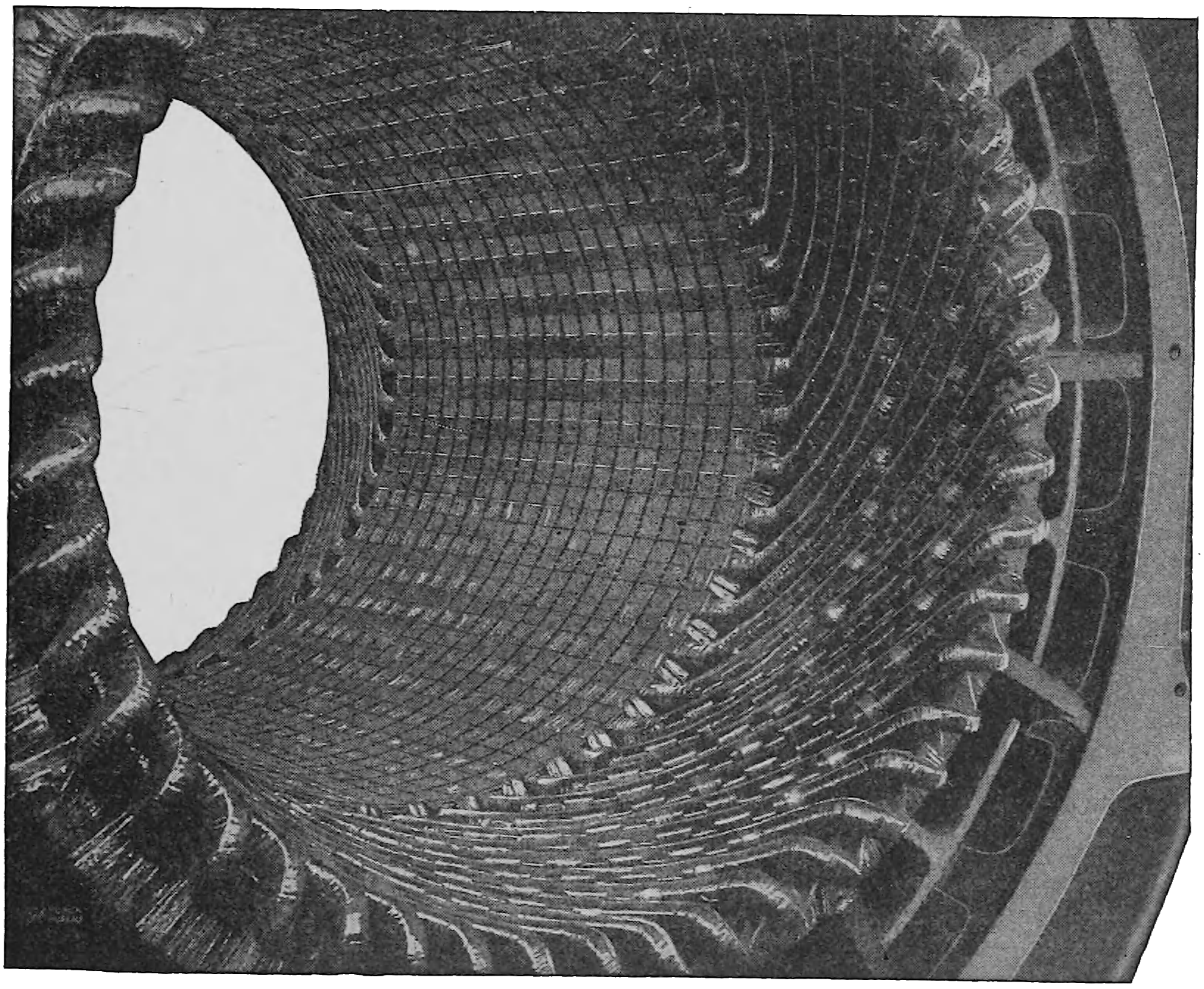


Fig. 151. G. E. Turboalternator Showing Armature Coils, Air Ducts, and Laminations

act as funnels. This air is forced through all parts of the generator, cooling the coils, and is then discharged directly downward through

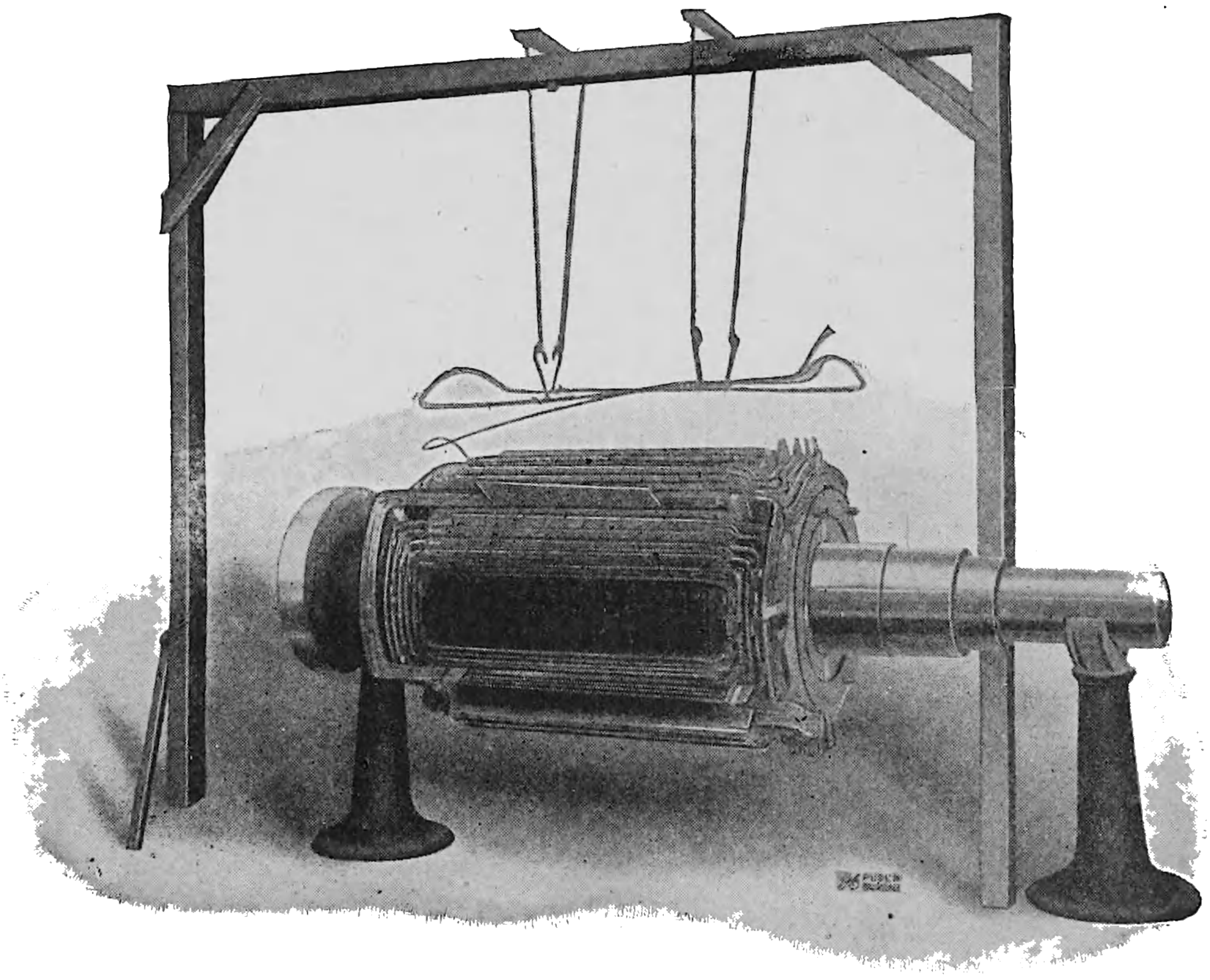


Fig. 152. Revolving Field of G. E. Turboalternator with Coils in Process of Assembly.

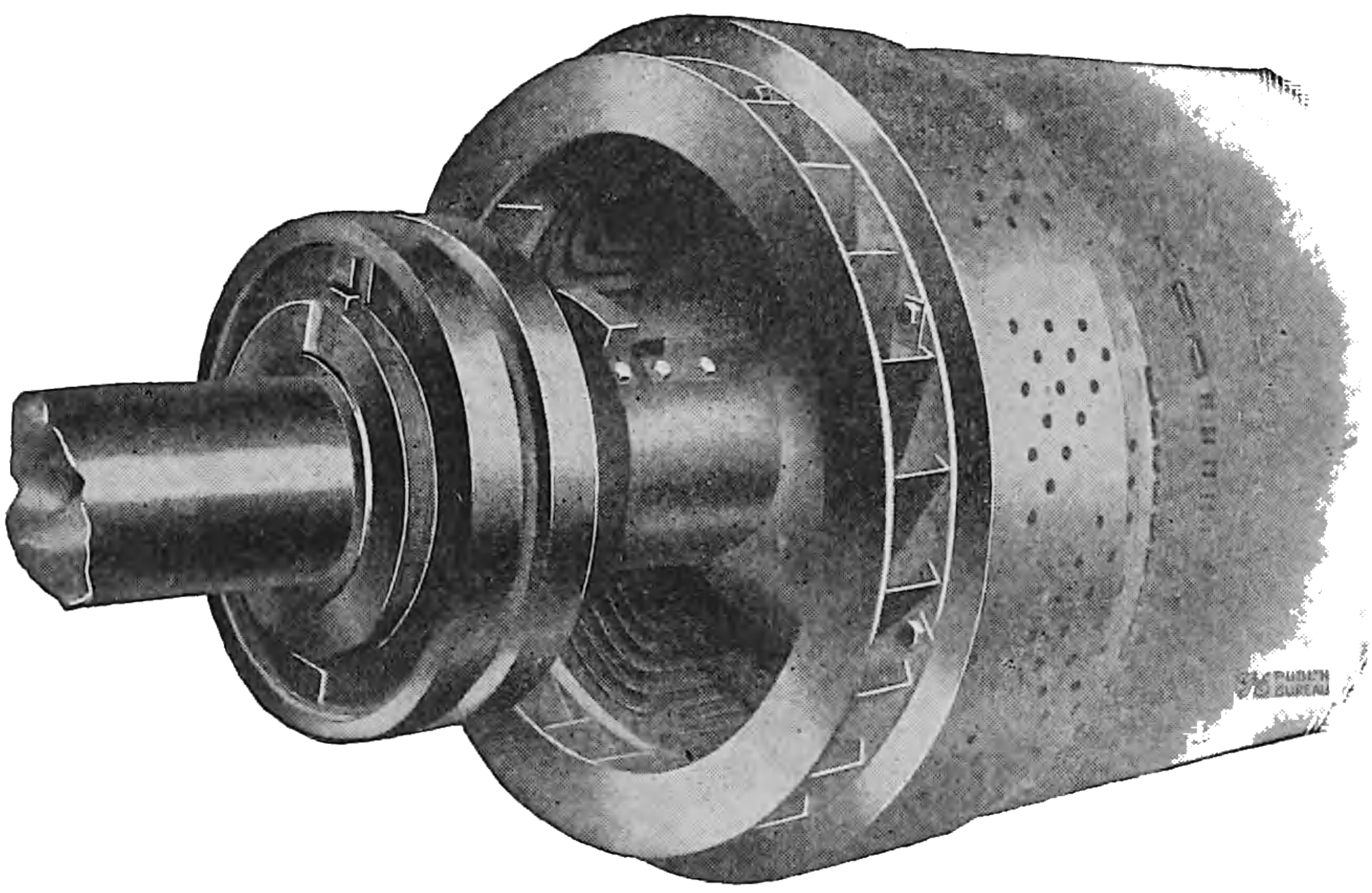


Fig. 153 Revolving Field o G. E. Turboalternator Showing Details of Construction

a large central duct. The collector rings and brushes are placed at the end of the generator where they are readily accessible. Fig. 150 shows a view of the stationary armature with part of the coils

The armature frame consists of two heavy cast-iron rings having an I beam section. The core is clamped securely in position between these rings by bolts that pass through the core but outside of the magnetic circuit. This method of construction, clearly illustrated in Figs. 155 and 156, has the advantage of securing splendid ventilation for the core. Neat and substantial guards bolted to the frame, and shown in Figs. 156 and 157, protect both ends of the windings from mechanical injury.

For 1100 volts and over, the winding is of formed coils, impregnated with insulating varnish, and baked into a solid mass. All such coils are wound on a single form and are, therefore, interchangeable. For lower voltages the winding consists of solid copper bars, carefully insulated with tape and varnish and baked before being placed in the slots. The use of bars avoids the necessity of connecting a number of circuits in parallel. Before the winding, whether of bars or formed coils, is placed in the core, the slots are lined with heavy insulating material of high, dielectric strength.

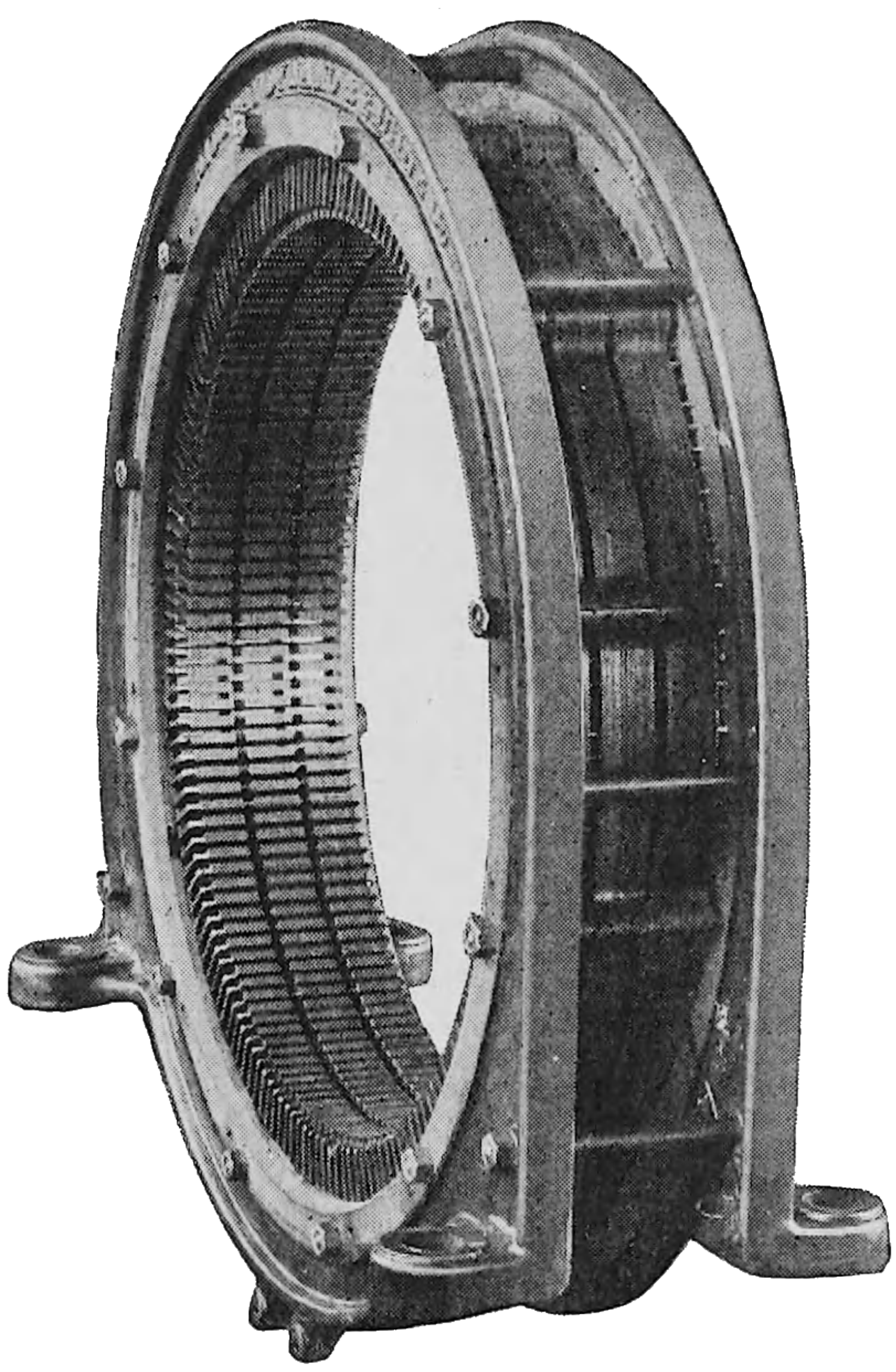


Fig. 155. Ridgway Armature Core Completed

The field spider of small engine-type generators is a single steel casting. In larger machines it is of cast iron, onto which is shrunk a heavy rim of cast steel. The pole pieces are built up of laminated steel punchings, held between heavy brass end pieces and are bolted to the spider by stud bolts which screw into the poles and pass through the rim of the spider. The field of a belted machine consists of a laminated steel core mounted on a heavy cast-iron hub and clamped between substantial end plates. In the periphery of this core are punched T-shaped slots, corresponding to similarly shaped projections on the laminated pole pieces. A small space is allowed between the projections on the pole pieces, and two sides of the

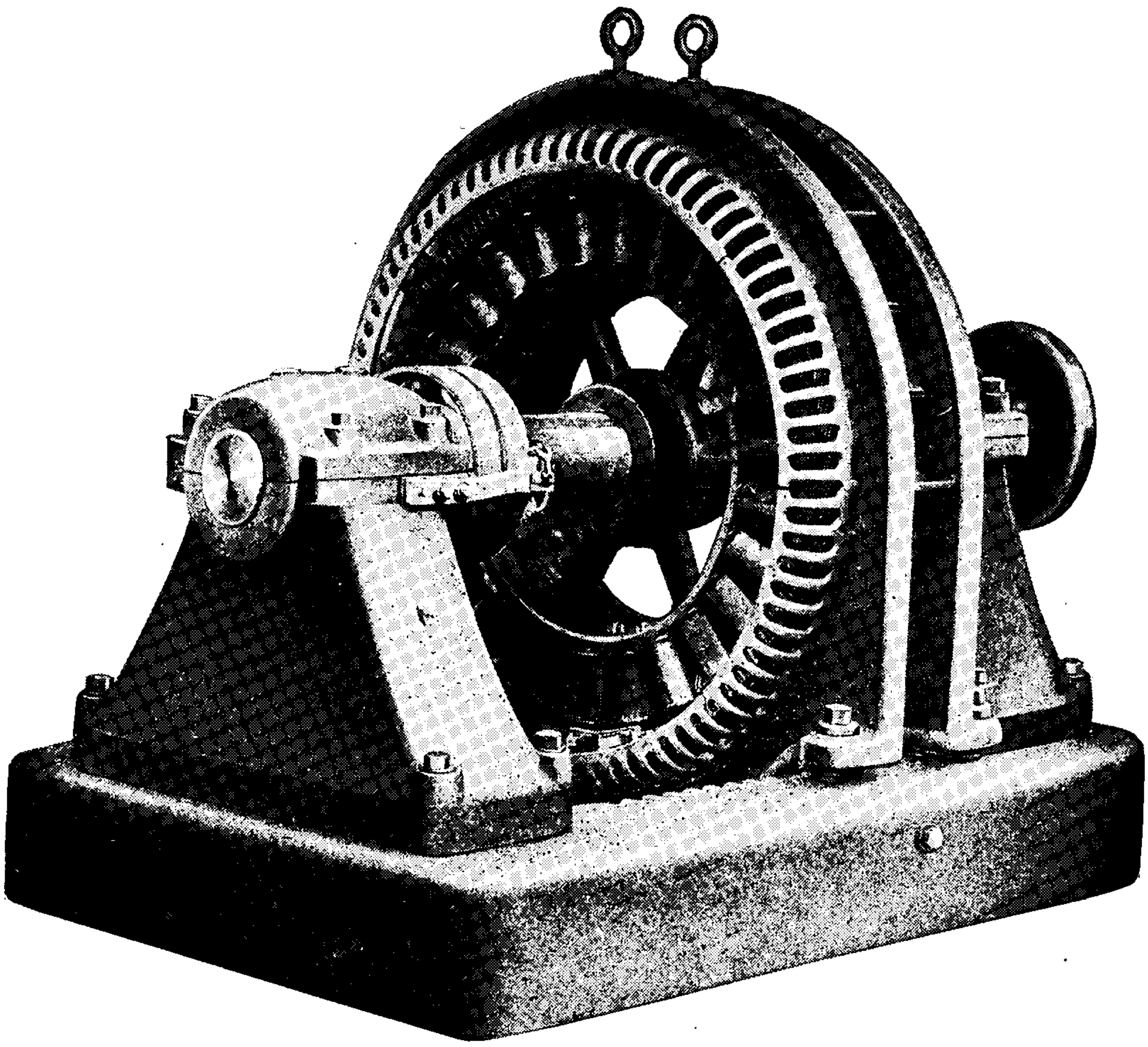


Fig. 156. Ridgway Water-Wheel-Type Alternator

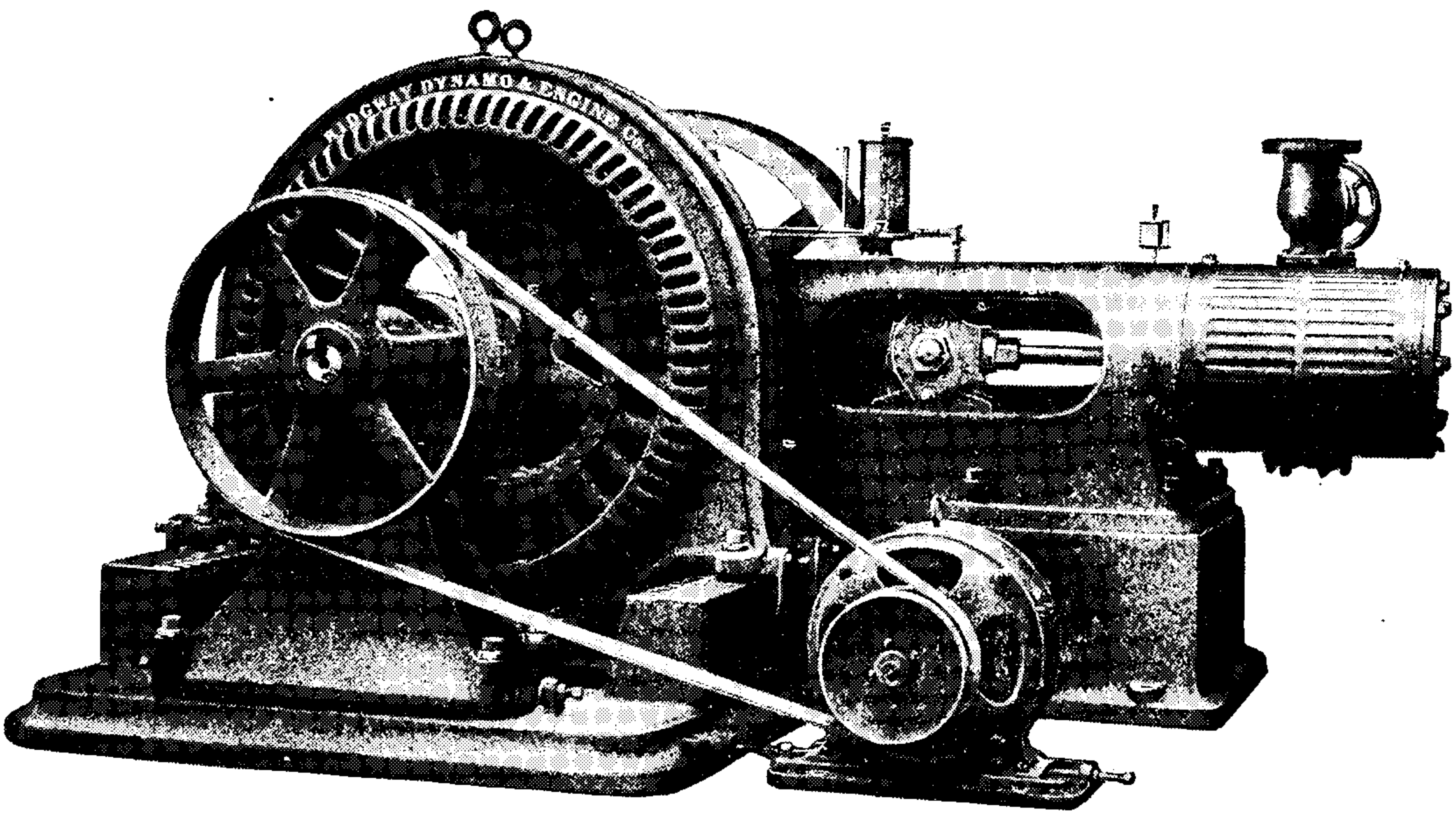


Fig. 157. Engine-Type Alternator Connected to Center-Crank Engine
*Courtesy of Ridgway Dynamo and Engine Company*

slots, and into these spaces are driven square keys that hold the pole pieces securely in place.

The field coils of small engine-type and belted-type machines are wound with square copper wire, having rounded edges and insulated with a double layer of cotton. On larger machines of both types the field coils consist of copper strip wound on edge, and insulated with paper and insulating varnish. At one side of each coil, there is placed a thin metal blade which, when the rotor is in motion, produces a strong current of air past the coil and across the face of the armature coil. In addition to this fan, there is, in

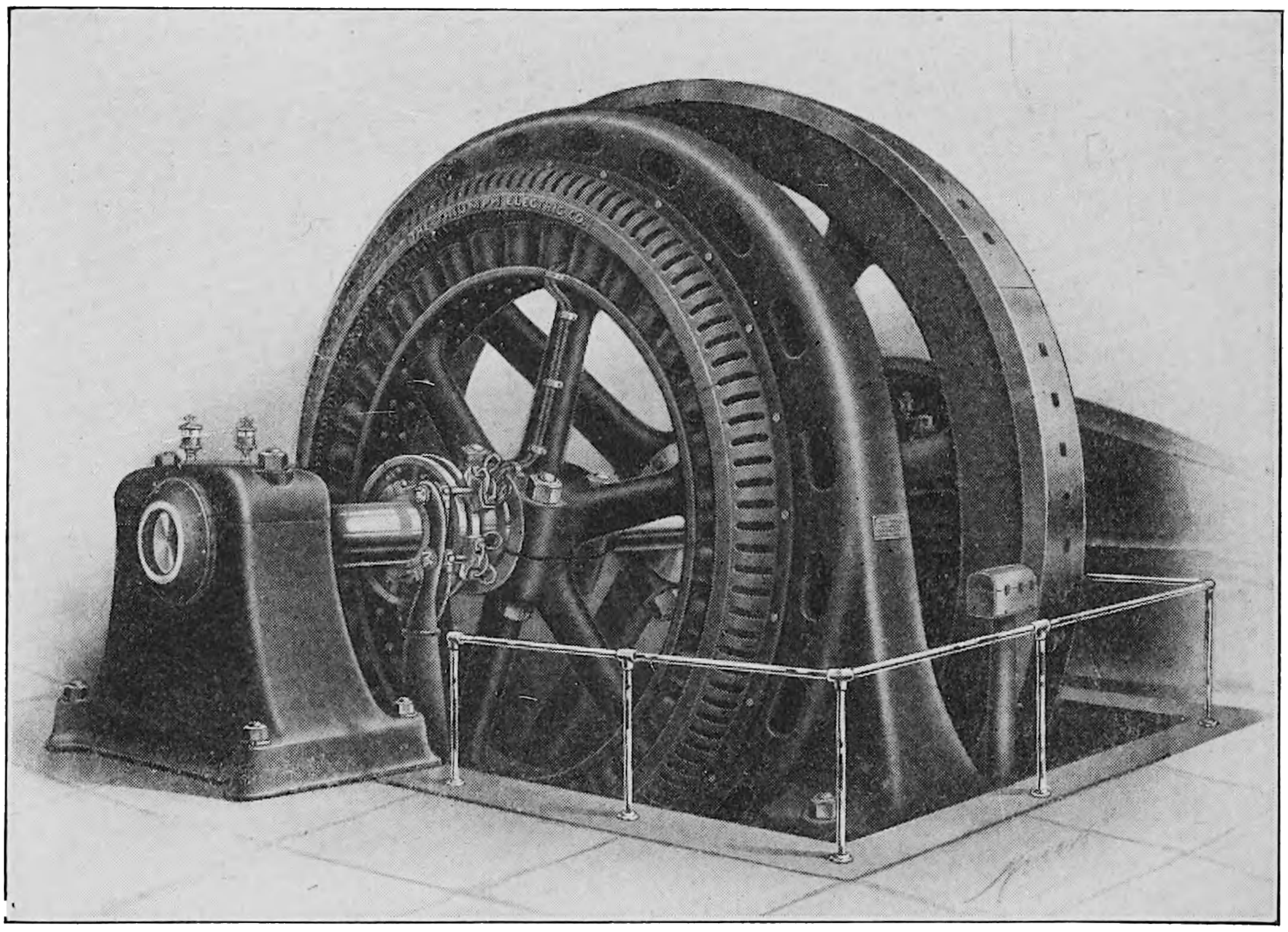


Fig. 158. 250 K. V. A., Three-Phase Triumph Alternator

belted generators, a ventilating duct passing through the middle of the coil. The collector rings for conducting the exciting current to the field coils are of cast iron, mounted on a separate spider and well insulated therefrom. The brush holders are of the box type, each carrying two carbon brushes, and are usually mounted on the adjacent bearing.

**Triumph Electric Company.** Triumph alternators may be of the engine, coupled, or belted type, are wound single, two-phase or three-phase for 25 or 60 cycles and for the standard voltages of 240,

larger ones being split horizontally. Feet with ample bearing surfaces are cast upon the frame; shoes and slide rails permit adjustment of position as shown in Fig. 161. The armature core is built up of punchings or laminations of thin sheet steel of high permeability, thoroughly annealed and japanned. These laminations are assembled under pressure in dovetail slots in the interior transverse ribs and securely held in place by finger plates and end plates.

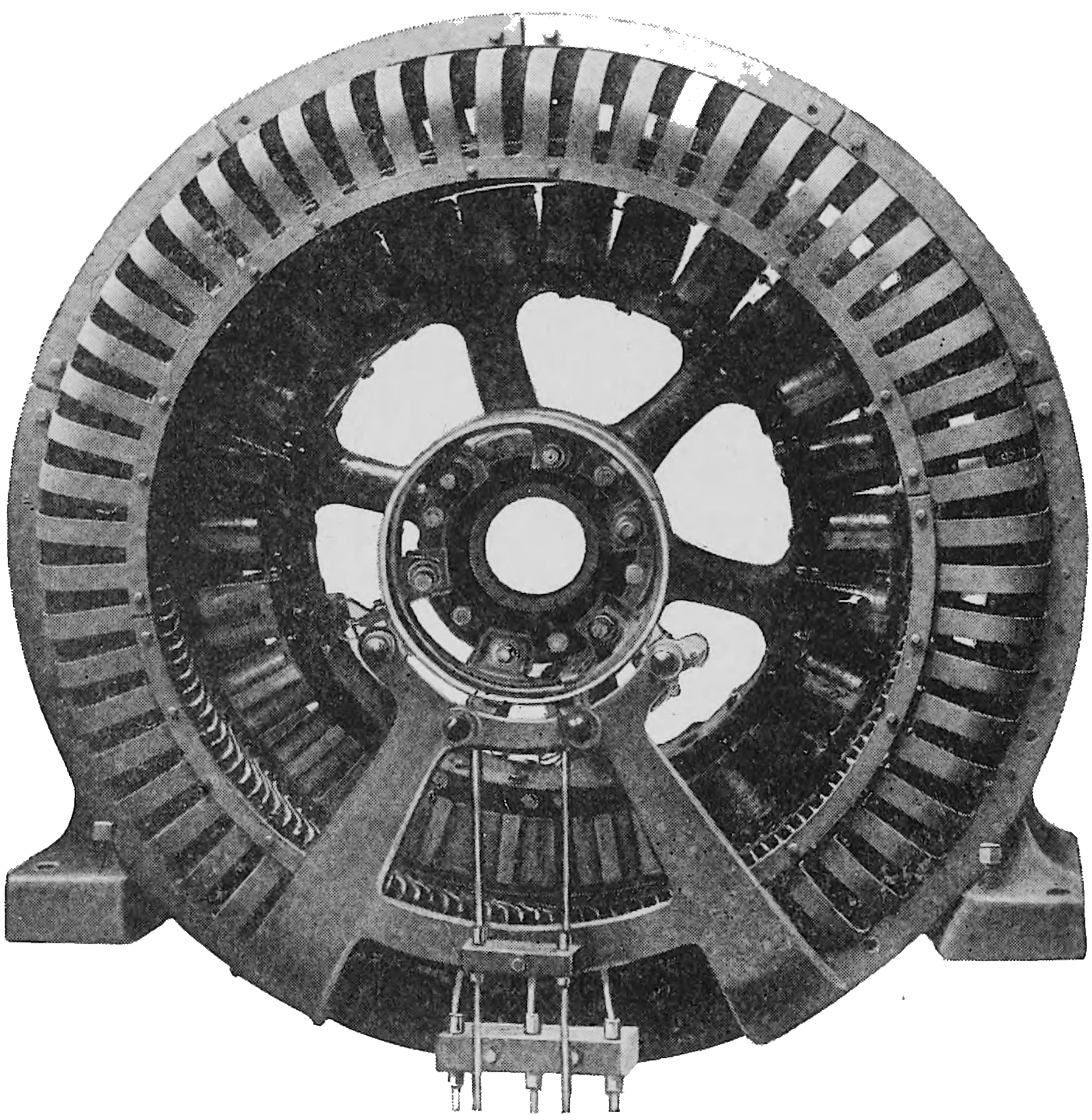


Fig. 160. Westinghouse Type E, 75 K. V. A. Generator Showing Collector End

Ventilating finger plates of sheet steel are assembled with the laminations to form suitable air ducts. Finger plates of malleable iron are used at each end of the core for supporting the teeth. These plates are of greater depth than would be necessary for strength alone, in order to provide generous ventilating ducts along the outer sides of the core between the laminations and the end plates. End plates of cast iron, assembled under heavy pressure outside the finger plates, complete the assembly of the core as a rigid unit, free from all possibility of internal vibrations. In the smaller machines these end plates are keyed to the frames. In the other frames, in which the end plates are segmental, they are held in place by through bolts between the ends, clear of active iron. The armature slots are open and the armature coils are held in place by hard fibre wedges firmly secured in slots of the teeth, effectually preventing vibration. The armature coils are machine-wound of double cotton-covered copper wire or strap. After winding and forming, the coil is dried out in vacuum and filled with an insulating compound under pressure. An outer insulation is then applied, consisting of layers of flexible sheet mica for that portion of the coil within the slots and of treated tape for the ends. The entire coil is then given a further protection of cotton tape and finally treated a number of times with an insulating varnish that protects the insulation and gives a finished appearance. The end bells attached to the frame are sheet-steel segments built up into circular form. They are of light weight and open construction yet rigid and practically indestructible, full protection being afforded by them to the end connections without in any way interfering with perfect ventilation.

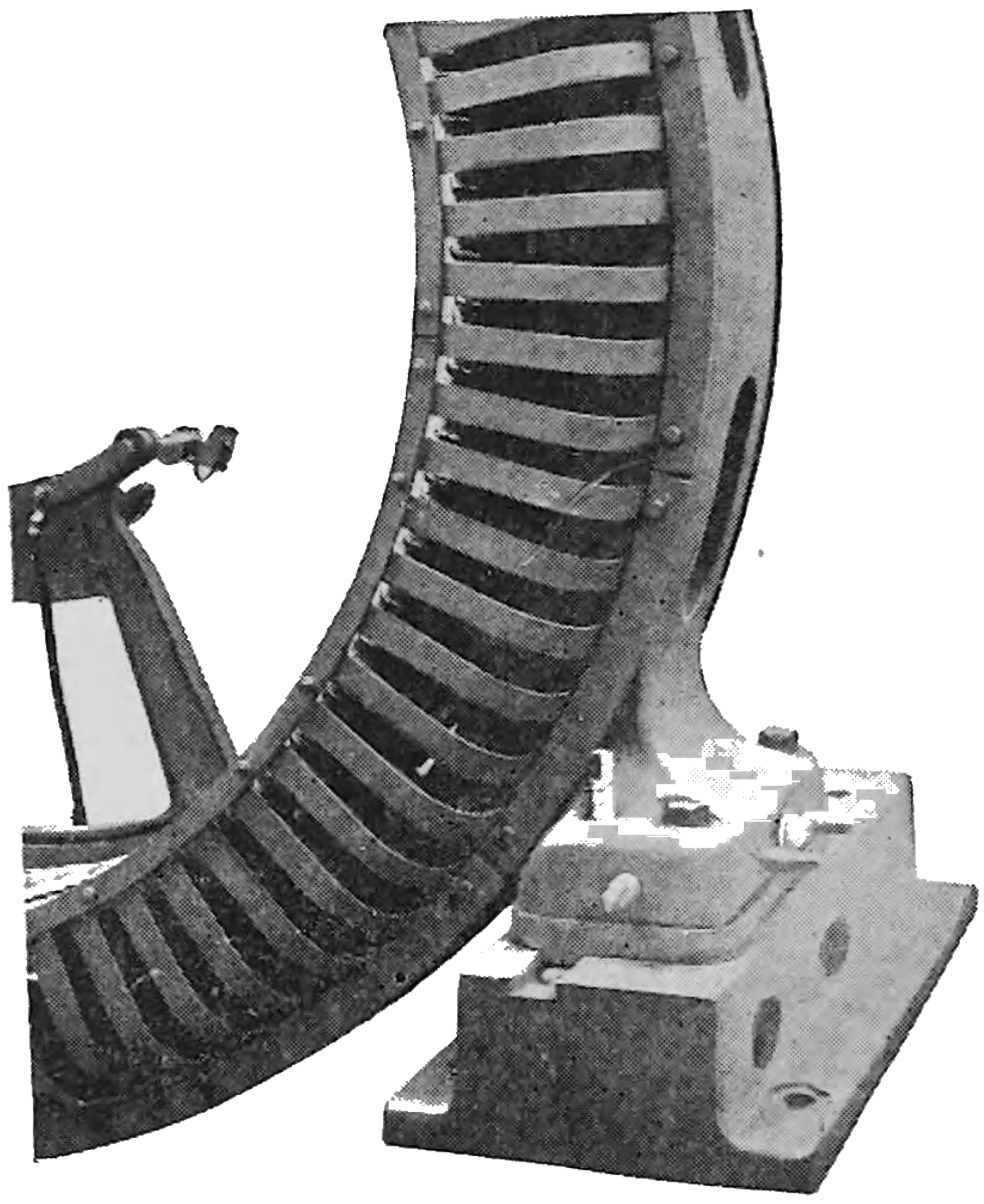


Fig. 161. Westinghouse Shoe and Slide Rail for Type E Generator

The brush holders are of the standard sliding shunt type and are supported by cast-iron brackets. On the smaller sizes the brackets are bolted to the armature frame (see Fig. 160). On the larger sizes the brush holders are carried on one or two separate bracket stands, as shown in Fig. 162, supported on the foundation or engine-

Fig. 162. Westinghouse Brush Holder Bracket Stand for Large Size Alternators

bearing pedestal. The spider of the type E alternator rotor is a single steel casting, carefully proportioned with reference to cooling strains. As the rim of the spider forms a part of the magnetic circuit, better magnetic conditions are obtained at the joint between pole and rim with cast steel than would be the case if cast iron were employed. The pole pieces are built up of sheet-steel punchings riveted together and bolted to the spider rim. As an additional means of creating air currents and regulating the temperature of the alternator, small radial steel plates with surfaces at right angles to the direction of rotation are bolted at intervals on each side of the spider rim. Edgewise-wound strap coils are used for the field coils. This construction is preferred, every turn being exposed to the air

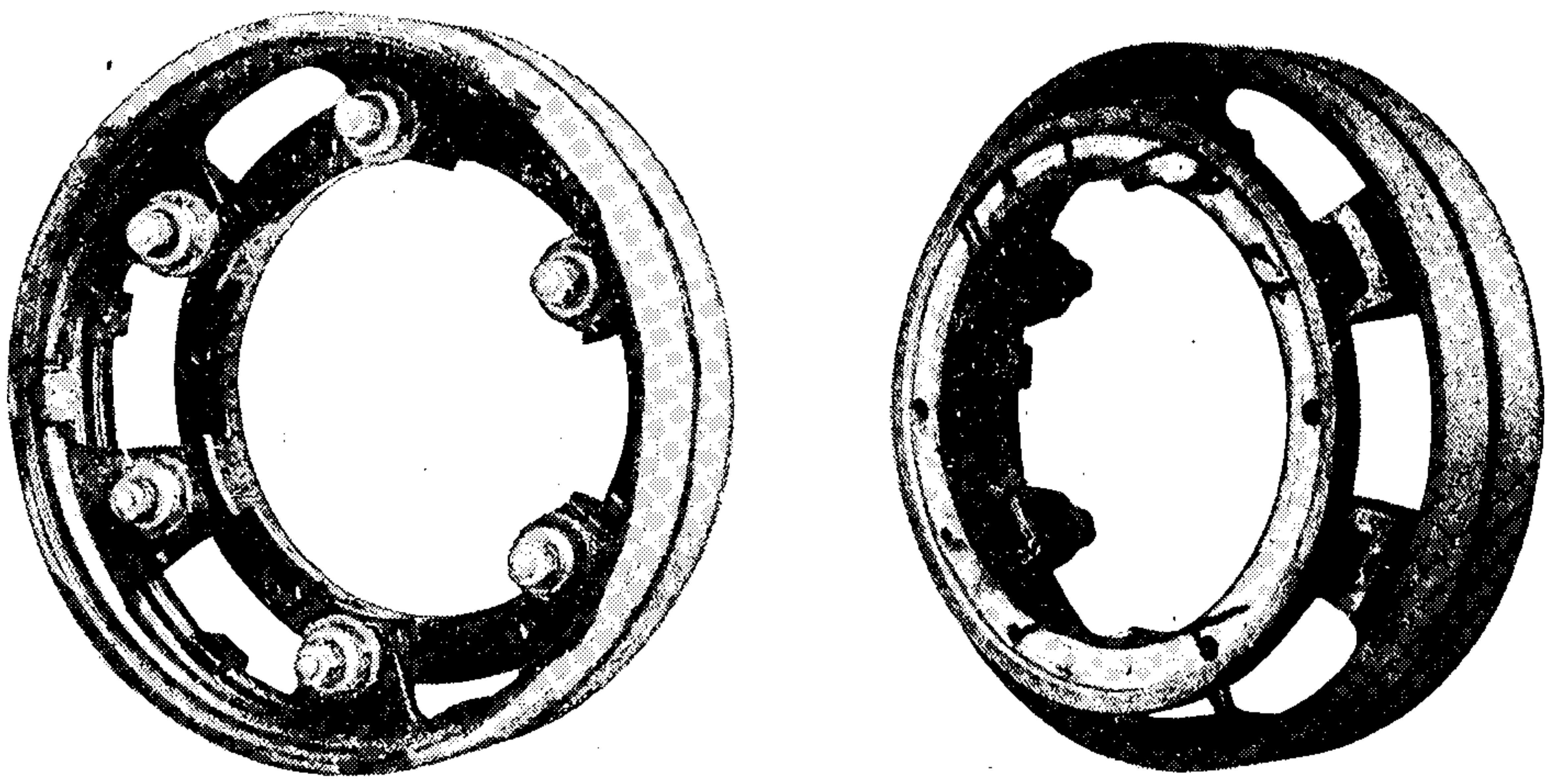


Fig. 163. Front and Rear Views of Type E Collector Rings
*Courtesy Westinghouse Electric & Manufacturing Company*

so that the heat of the coils is readily conducted to the surface and so dissipated. Between adjacent surfaces of the turns of the strap, layers of flexible fireproof insulating material are inserted and the entire coil is treated with an insulating varnish, making the coils practically fireproof and indestructible.

The collectors, Fig. 163, are of the spider type, consisting of two accurately machined cast-iron rings, mounted on a cast-iron hub from which they are insulated by V-shaped moulded mica bushings, and micarta bushings and washers on the supporting bolts. The assembled collector is bolted to the hub of the spider. Two brushes, at least, are provided for each ring, to deliver current at 125 volts to the field winding. With internal combustion engines as prime movers, a cage-damper winding is provided on the field poles.

cast spider and the poles are dovetailed to the rim. For the very highest speeds the construction shown in Fig. 167 is employed.

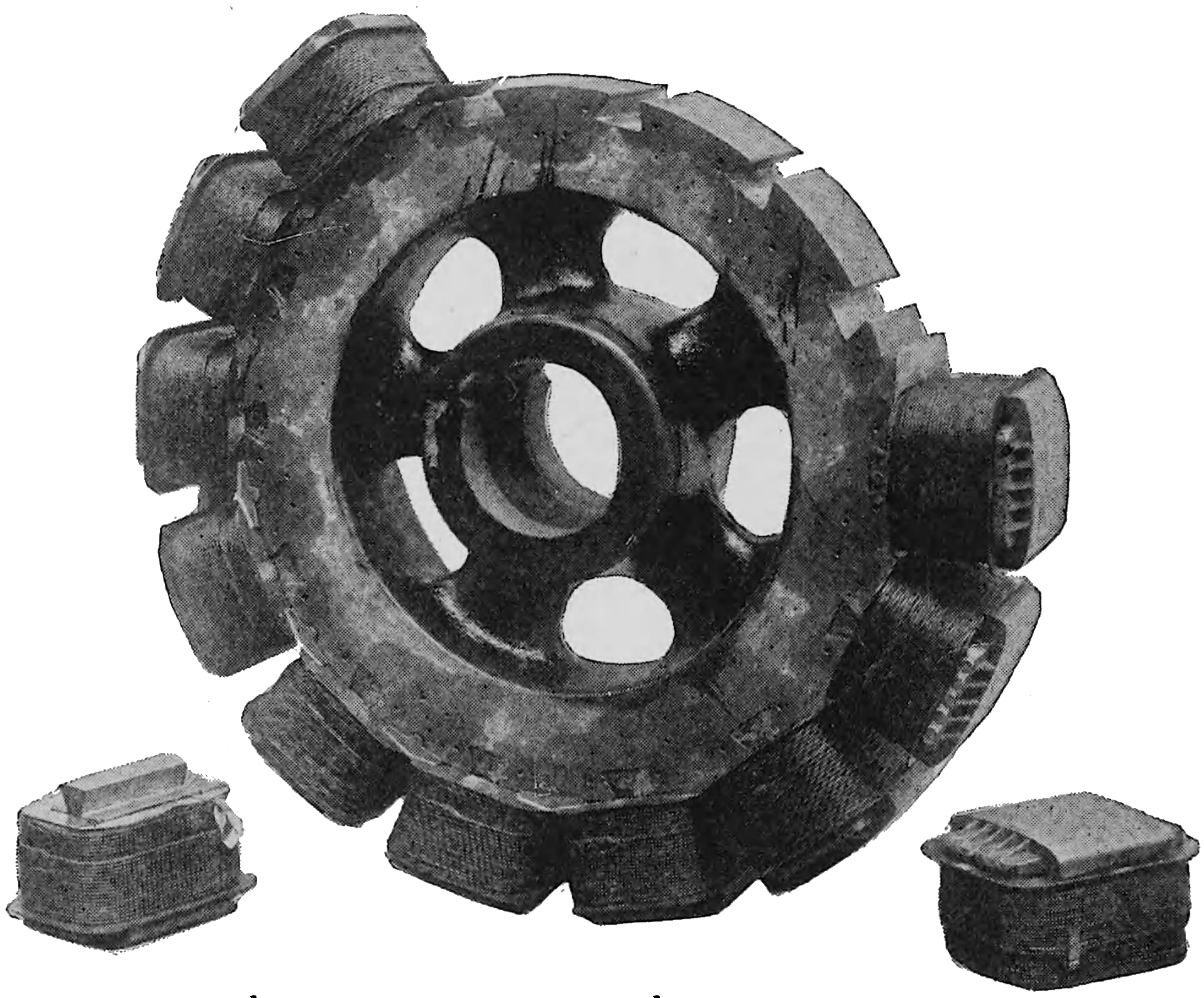


Fig. 165. Westinghouse Rotor Construction Showing Cast Spider and DoVetailed Pole Pieces

Fig. 166. Westinghouse Rotor Construction Showing Cast Spider, Laminated Rim, and Dovetailed Slots

Rolled-steel plates form the spider and the poles are dovetailed to the spider.

The stator and armature constructions of these machines are similar to the engine type. The water-wheel alternators are designed with either horizontal or vertical shafts.

*Belted Types.* The line of belted machines cover sizes from 30 to 200 k. v. a. at 60 cycles from 240 to 2400 volts, two-phase or three-phase. The three smaller sizes are provided with bracket-bearing housings, while the other sizes have pedestal bearings. In these machines the rotors consist of a laminated spider, as shown in

Fig. 168, built up of thin steel plates assembled upon a mandrel and firmly riveted together under hydraulic power. The poles are built

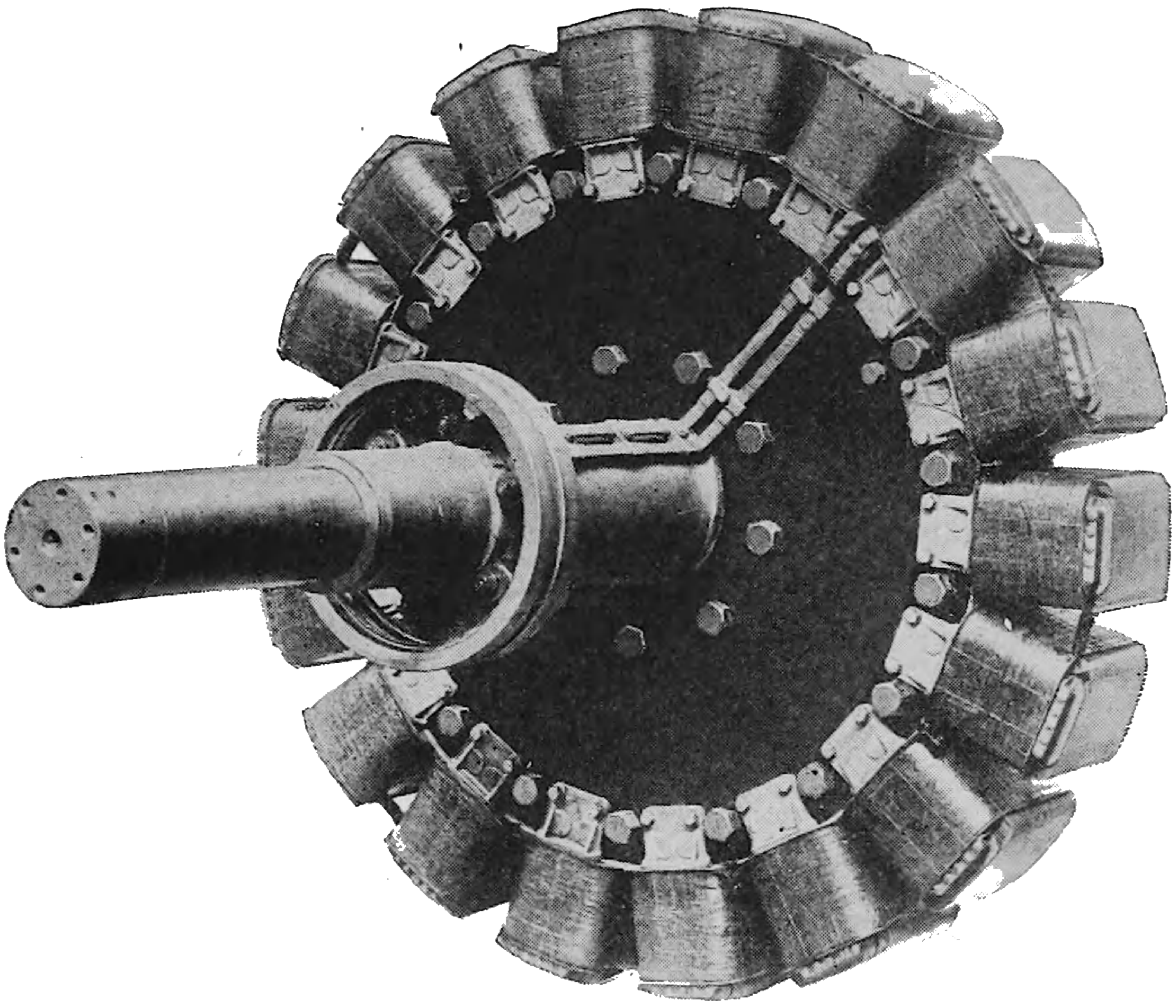


Fig. 167. Westinghouse Rotor Construction Showing Rolled-Steel Plate Spider and Dovetailed Pole Pieces in Position

up of steel laminations of the same thickness as those of the spider and riveted together. Each pole is dovetailed into the spider and retained by two taper steel keys. The field coils are wound with wire. The stator and armature constructions are practically the same as in the other lines.

*Turboalternators.* Westinghouse turboalternators are also of the revolving-field type. This construction avoids all moving contacts between the generator and the main circuit to which it is connected and is of especial advantage in dealing with large currents and high voltages. These generators can be wound to supply

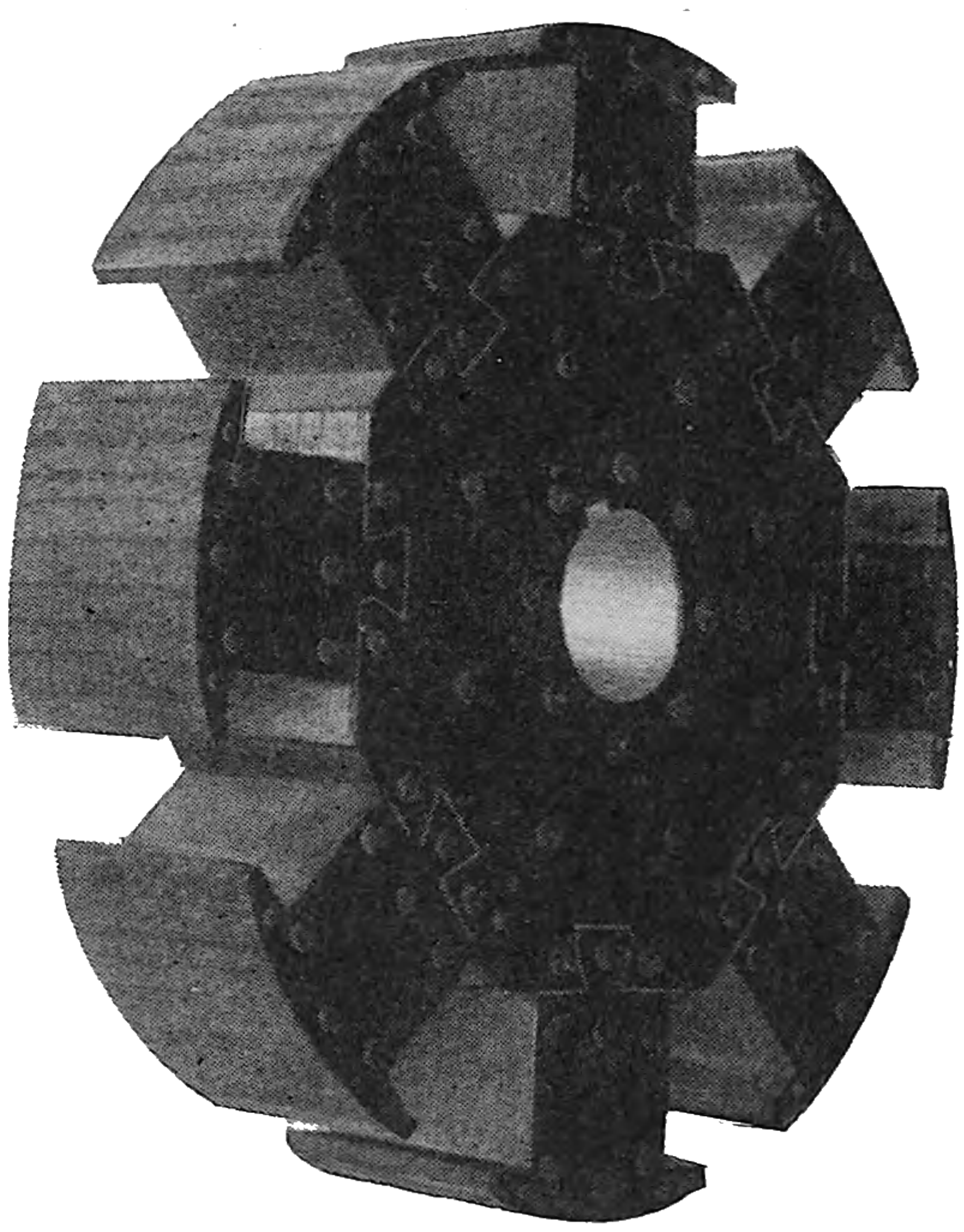


Fig. 168. Westinghouse Laminated Spider with Pole Pieces Dovetailed to It

single-phase, two-phase, or three-phase circuits of any commercial frequency or voltage. Standard generators are wound to supply two-phase or three-phase circuits of 240, 480, 1200, 2400, 6600, 11000, or 13200 volts at 25 or 60 cycles in capacities up to 15000 k. v. a. They are designed for separate excitation at a standard voltage of 125. Except in the largest sizes the frames are made in one piece. In the large machines the frames are divided horizontally, the two parts having faced joints and being bolted and keyed together so that they form practically a single piece.

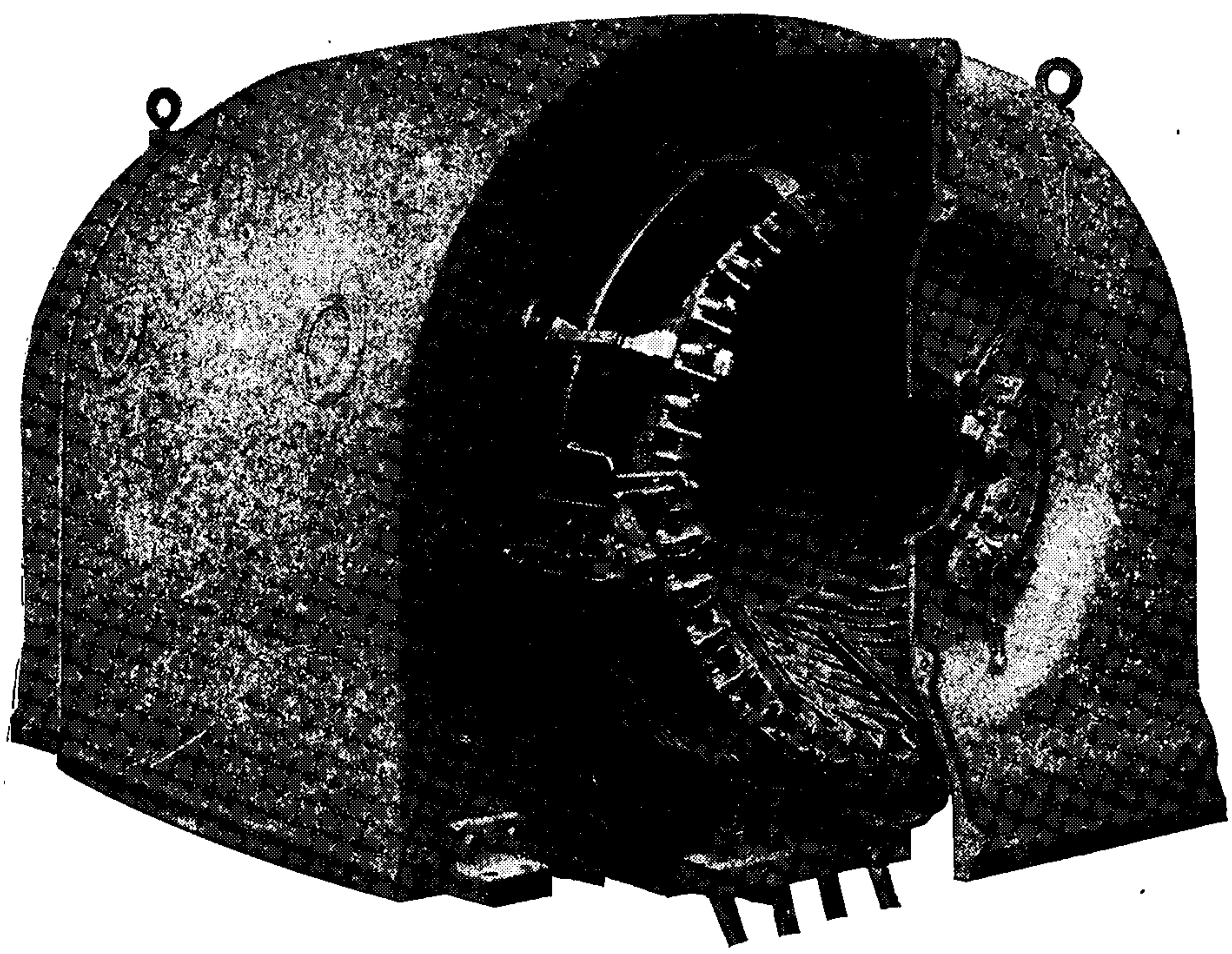


Fig. 169. Turboalternator with Rotating Field Dismounted and Half of End Bell Removed
*Courtesy of Westinghouse Electric & Manufacturing Company*

The armature or stator is built up of punchings of soft sheet steel. Ventilating plates are provided at suitable intervals, forming air ducts in the core. The core is slotted to receive the armature windings, the shape of the slot depending upon the capacity of the machine and the character of the windings. Either open or partly closed slots are used, the edges of the former being grooved at the top to receive the retaining wedges holding the coils in place. At the ends, the teeth are supported by finger plates and heavy iron retaining plates that are pressed into place and keyed. Form-wound armature coils are used and the winding is of wire, strap, or bar

constructed with two, four, or six poles, according to the frequency and capacity of the machine. The fields are of small diameter and are designed with special care to avoid windage losses and to facilitate ventilation. The poles of the two-and four-pole rotors, Fig. 171, are machined from disks forming the central body, and the slots to receive the field coils and the grooves for the binding wedges are milled. The six-pole rotors are built up by bolting poles to a central body. The rotors are carefully balanced after they are wound. In some designs, the rotor is pressed and keyed onto the shaft; in others, the shaft is formed of steel, cast or forged integral with the rotor core. For two-pole machines the rotor is generally made from a solid cylinder and the shaft is made in two portions and secured to each end of the rotor by heavy bronze flanges and suitable bolts.

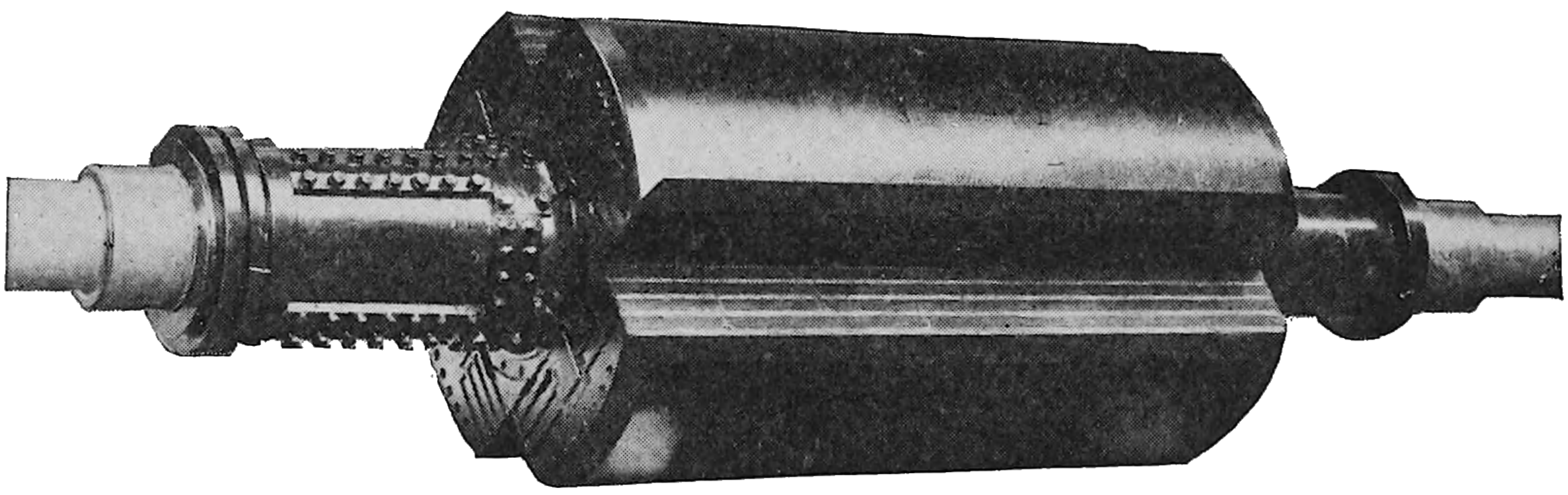


Fig. 171. Westinghouse Four-Pole Rotor

The field winding consists of copper strap embedded in slots cut in the poles. The coils are wound directly in place under a heavy tension. A groove is cut in each side of the slots and brass wedges are driven in to hold the coils in place. The coils are heavily insulated with material of high dielectric and mechanical strength. This material is applied in several layers. The winding and insulation are tightly wedged in place. The exciting current is delivered to the field or rotor winding by means of a pair of collector rings and suitable brushes. The collector rings are made in one piece, with no joints, and are shrunk on the shaft. Either carbon or copper brushes are used.

## MOTORS

**Classification.** The various alternating-current motors used on commercial circuits belong to one of the following classes:

(1) *Synchronous.* This type is really nothing more than an inverted alternator, it being possible to use identically the same

machine for either purpose. As a motor, however, it is practically not self-starting and also must be separately excited from some source of direct-current supply. It may be, of course, either single-phase, two-phase or three-phase.

(2) *Polyphase Induction.* This type has its field windings fed from the alternating-current supply which then produces a rotating magnetic field that makes the machine self-starting. It has no commutator and its armature circuit is not connected to the supply circuit. It may be either two-phase or three-phase.

(3) *Single-Phase Induction.* This type has its field windings but not its armature connected to the supply circuit. It has no commutator and it is not self-starting. It can be brought up to speed by one of the following methods: Hand starting, shading-coil or creeping-field starting, split-phase starting, or repulsion-motor starting.

(4) *Repulsion.* This type is single-phase, with its field windings connected to the supply circuit. It has its armature, commutator, and brushes connected to a local circuit, and whatever current flows in this circuit is entirely induced therein. It has practically the same characteristics as the direct-current series motor, and needs a load to keep it from attaining a dangerous speed. It is not used commercially to any extent although the principles underlying its action are employed in getting many single-phase motors up to speed.

When a second set of brushes and an auxiliary field winding are added, the machine becomes a compensated repulsion motor and has characteristics similar to a compound-wound direct-current motor. In this form it is used for small power motors.

(5) *Single-Phase Series.* This is a machine having its armature and commutator connected in series with its field windings. It has all of the characteristics of the direct-current series motor, and is applicable to the same classes of work. This type of motor is not in general use.

## DESCRIPTION OF TYPES

**Allis-Chalmers Manufacturing Company.** *Induction Motors.* The induction motors of the Allis-Chalmers Company are built in many sizes, from 1 to 300 h. p., wound for two-phase or three-phase, 25 or 60 cycles, and wound for the standard voltages of 110, 220, 440, 550, and 2200. They are divided into two classes: Type AN, or constant speed type, illustrated in Fig. 172, which has a squirrel-cage secondary winding; and type ANY, or the variable-speed type, which has a phase-wound secondary. The stators of the two types of motors are identical. The frame of these motors is of the box type, with large cored openings that permit of the passage of a large amount of air and make the motors cool running. Lugs are cast on the interior surface of the frame to support the stator core, leaving a large air space between the two. Supporting feet are cast in one piece with the frame. The stator core is built up of high grade electrical steel punchings that have been carefully

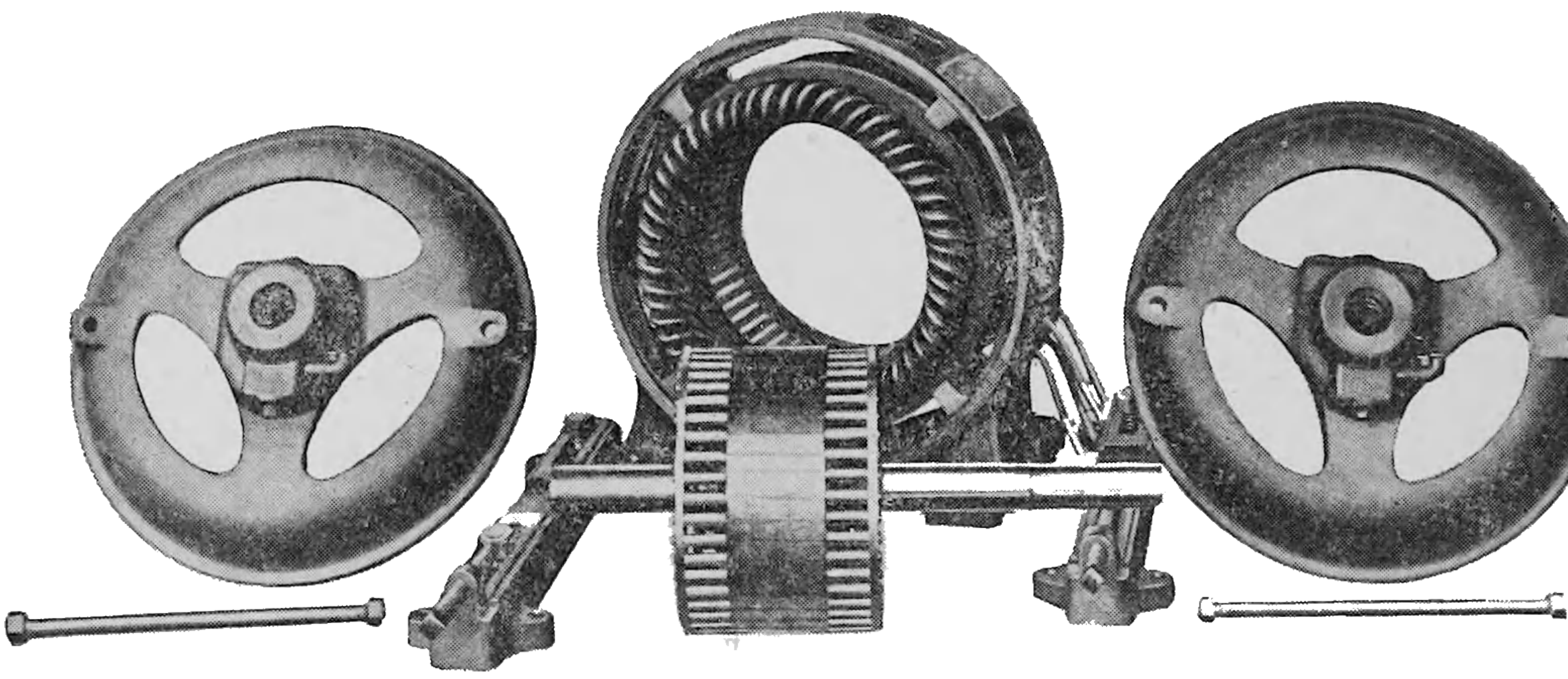


Fig. 172. Exploded View of Small AN Allis-Chalmers Motor

annealed and coated with insulating varnish. In the large motors these punchings are assembled in the frame with spacers introduced at intervals to form ventilating ducts through which currents of air are forced by the rotating element, thereby carrying off the heat from the interior of the machine. The inner periphery of the punchings is slotted to receive the coils.

The stator coils composing the field windings are form-wound and interchangeable. They are carefully insulated with the best obtainable insulating materials and, after they are wound, are impregnated with an insulating and waterproof compound. The straight portions of the coils are pressed to gauge in moulds so that they fit the slots exactly. Except in some of the smaller sizes below 5 h. p., the coils are placed in open slots. The ends of the coils,

ers having several taps each and a controller for making the necessary changes in the connections.

The A N Y motors use the same stators as the A N. The rotor,

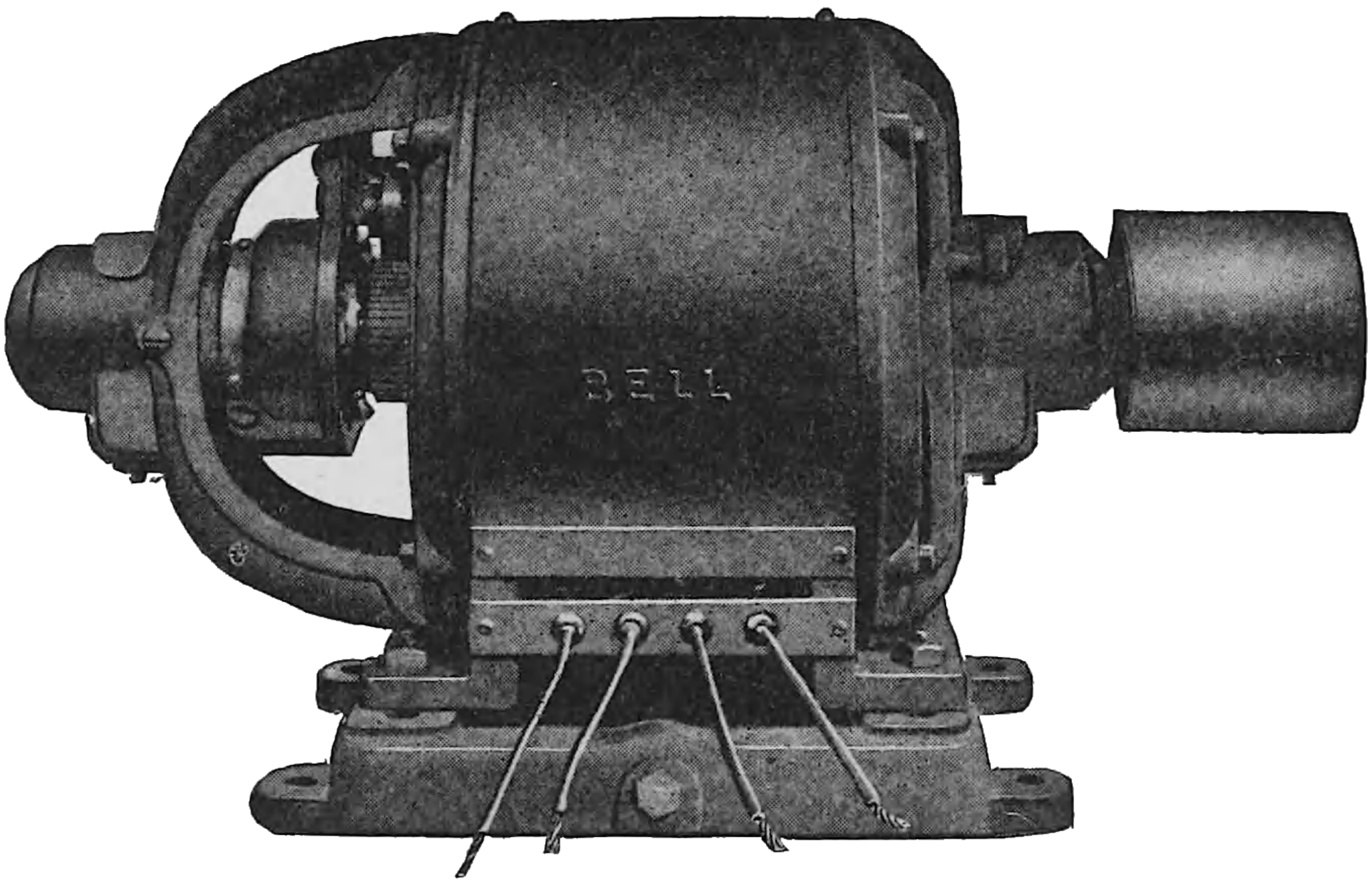



Fig. 174. Single-Phase Induction Motor
*Courtesy of Bell Electric Motor Company*

however, is wound for three-phases and the terminals brought out to three slip rings, as shown in Fig. 173. The front bearing bracket is slightly modified to make room for these rings on the inside. High grade, low resistance brushes, accurately fitted to the rings, are used. This type of motor is, therefore, controlled by inserting in the secondary circuit an external resistance adjusted by means of a suitable controller connected to the slip rings. It may be designed for starting duty only, or for both starting and speed regulation. This controller is non-reversing and is designed to control the secondary circuit only. A separate switch must be provided for the primary.

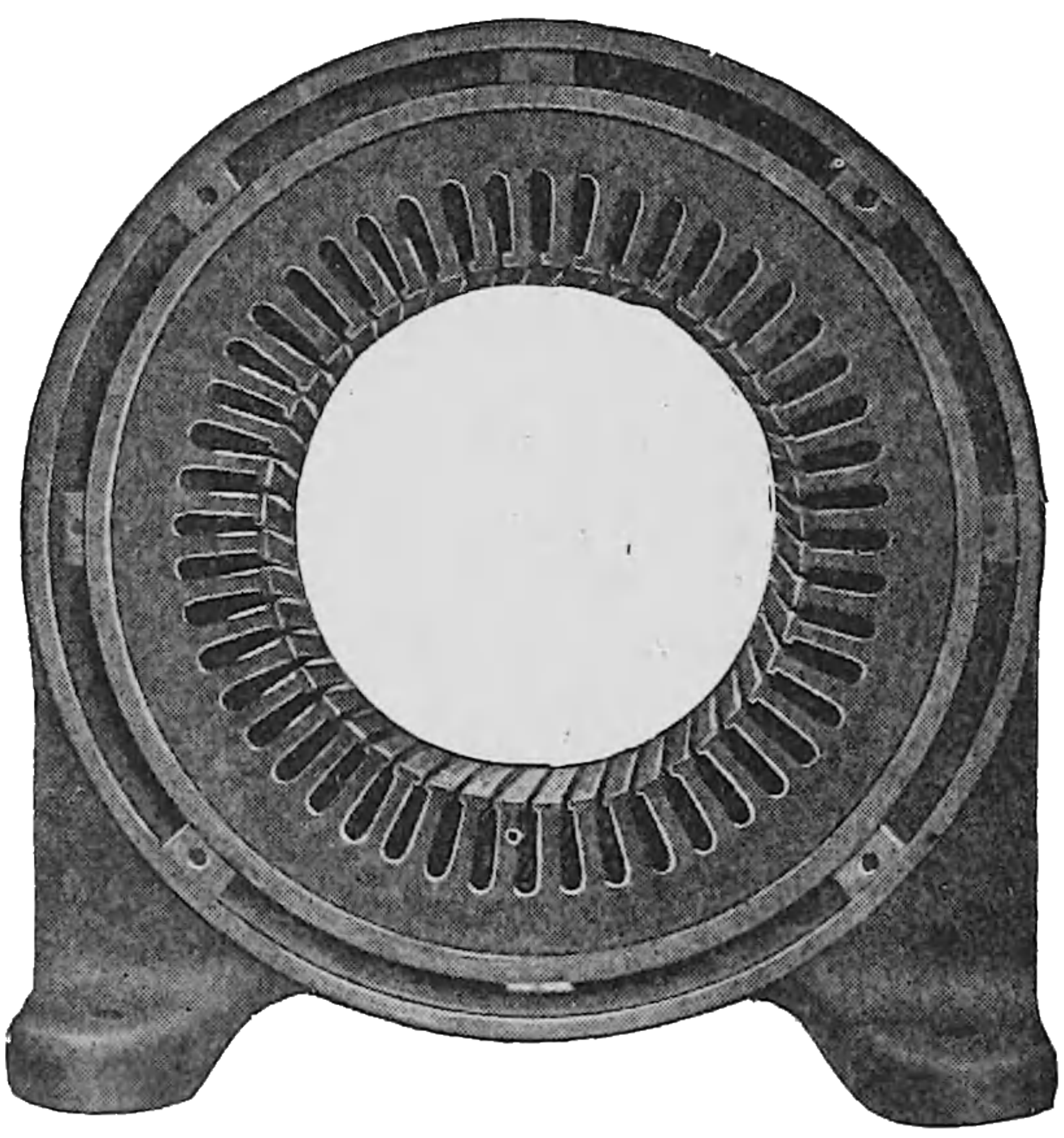


Fig. 175. Stator of Bell Automatic Single-Phase Motor

**Bell Electric Motor Company.** *Single-Phase Induction Motors.* The Bell Company makes a line of single-phase induction motors from $\frac{1}{2}$ to 15 h. p. for 110 or 220 volts, 60 cycles. Their general appearance is shown by Fig. 174. The line current passes into the field or stator winding only, all currents in the armature being devel-

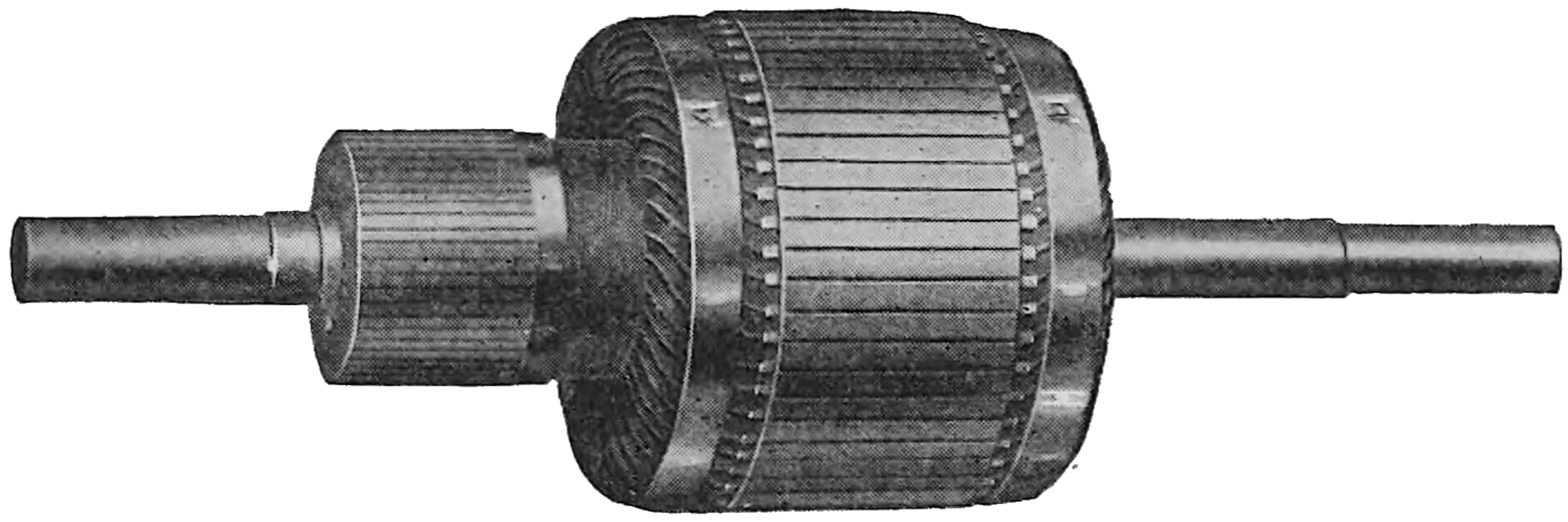


Fig. 176. Wound Armature of Bell Single-Phase Motor

oped by induction. The stator, Fig. 175, consists of punchings of the highest grade of laminated sheet iron, thoroughly annealed and slotted on the inner periphery to hold the field windings. These laminations are supported and protected by a light cast-iron frame carrying the feet of the motor. The bearings are of the best phosphor bronze and the shafts of high carbon steel. All shafts have oil slings so as to return to the reservoirs the oil distributed to them by revolving rings. By turning the end plates 90 or 180 degrees, these motors may be mounted on side wall or ceiling. The armature, Fig. 176, which is wound in a similar manner to those in direct-current motors, has a commutator and brushes which, being short-circuited

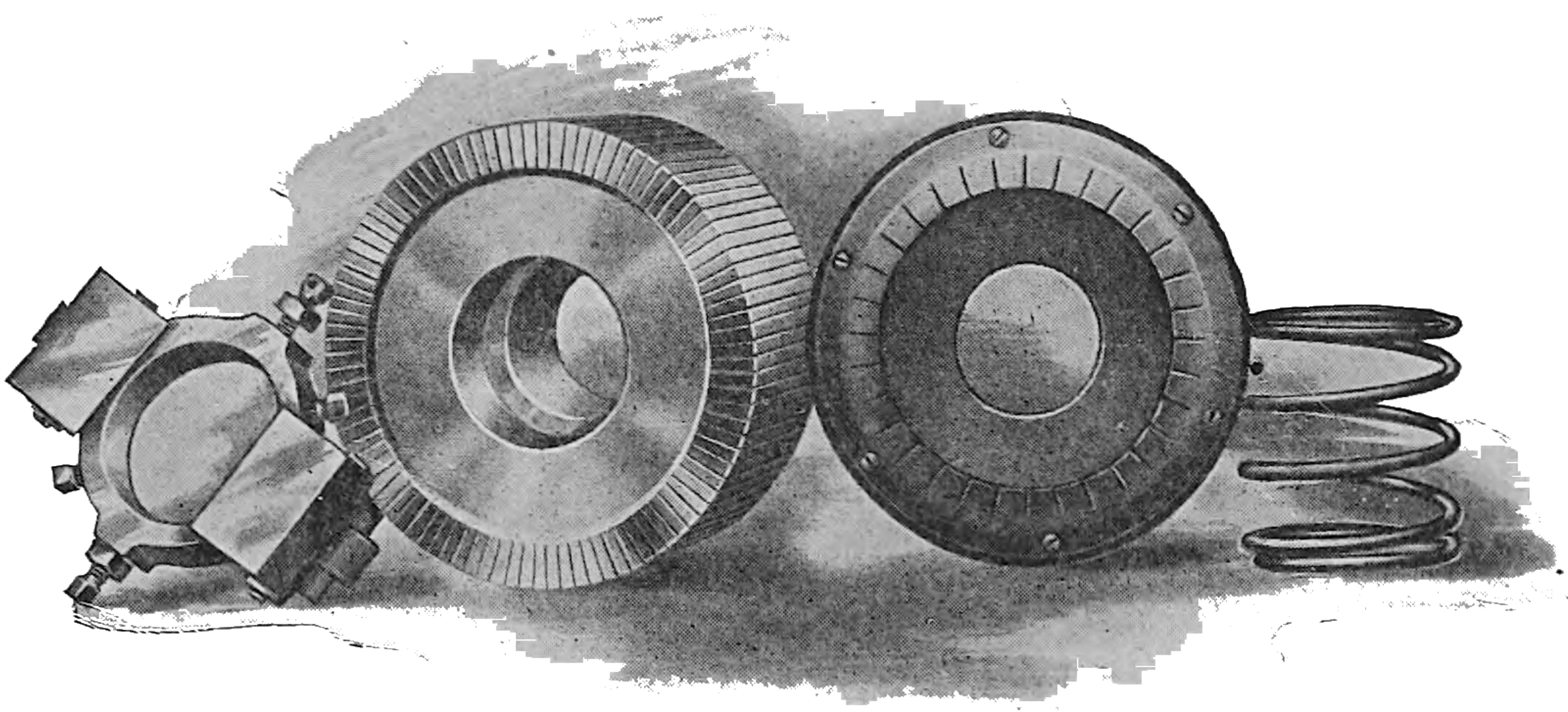


Fig. 177. Exploded View o fBell Short-Circuiting Device

on themselves, allow great starting torque with small starting current. While starting, therefore, the machine is a repulsion motor.

When the armature has attained full speed, all of the windings are short-circuited. The windings have now become the equivalent of a squirrel cage and the motor runs as a single-phase induction machine. The details of the short-circuiting device are shown in Fig. 177. After the motor has obtained nearly full speed, the commutator segments are entirely short-circuited by the copper ring, actuated by the centrifugal force of the weights. When the motor is stopped, the copper ring is pushed from the commutator segments by means of the steel spring and assumes its starting position. The direction of rotation may be reversed by simply loosening the set

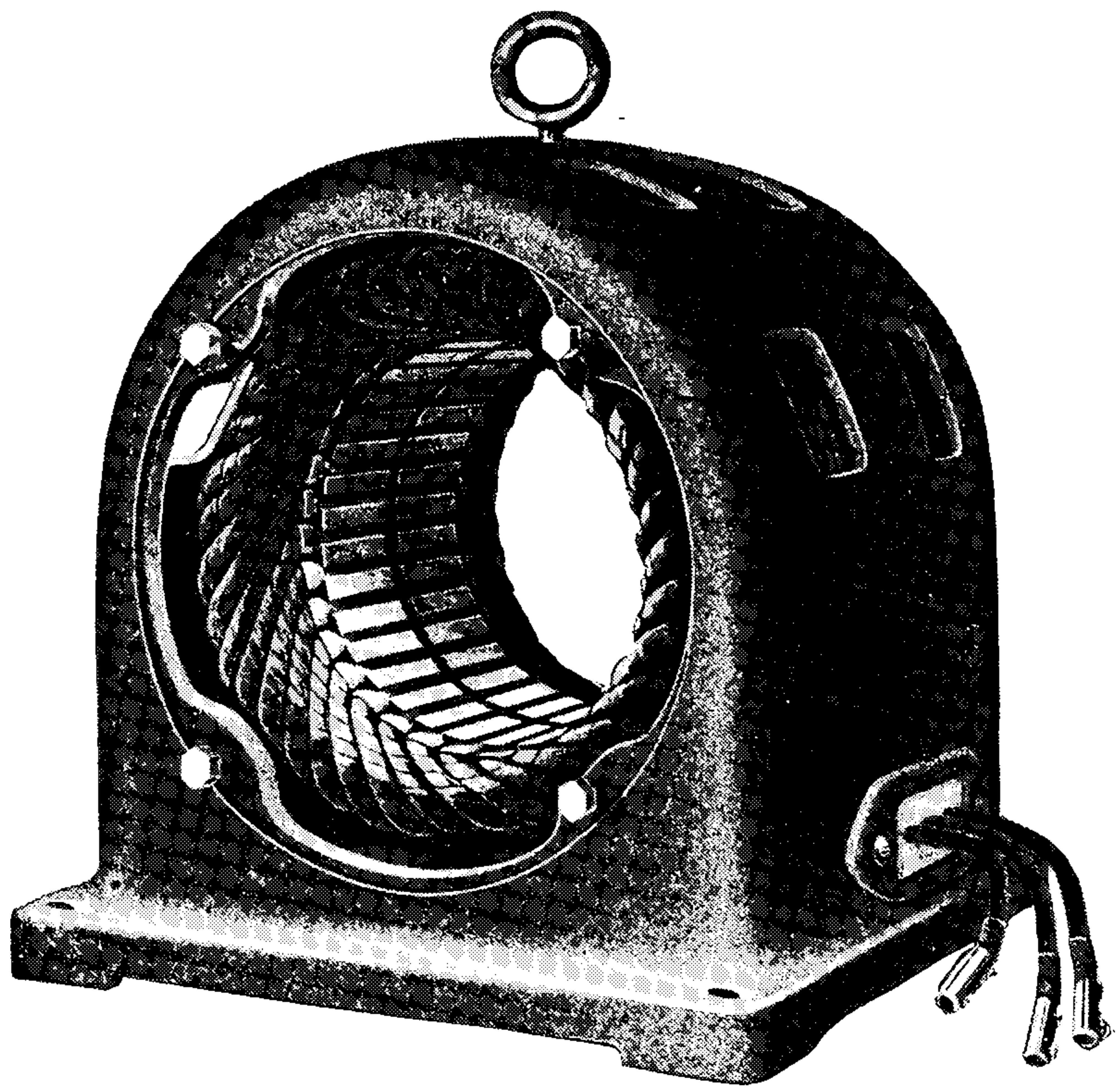


Fig. 178. Stator of 5 H. P. Polyphase Induction Motor
*Courtesy of Burke Electric Company*

screw and rotating the rocker arm carrying the starting brushes to a new indicated position.

**Burke Electric Company.** *Polyphase Induction Motors.* The Burke Electric Company makes a line of induction motors of a very rugged and substantial frame, in many sizes, from $\frac{1}{4}$ to 100 h. p., for the standard voltages and frequencies. The stator or primary member, Fig. 178, comprises the usual slotted core of laminated steel, mounted in a massive cast-iron housing and equipped with form-wound and individually insulated coils. The core laminations are

ends of the various coils together; each one forms its own closed circuit. The slip-ring type of motor, Fig. 181, is, of course, equipped with a polar winding, the terminals of which are connected to collector rings. This form is used for variable-speed service and for conditions requiring high starting torque with moderate starting current. The bearings are mounted in the usual bonnets or brackets, fitted to the face and bore of the stator housing. The journal sleeves are cast-iron shells with babbitt linings, and the oil rings consist of a number of thin metal disks. Motors of 5 h. p. and under are not supplied with starters, but those of larger power employ starters of the resistor or auto-transformer types.

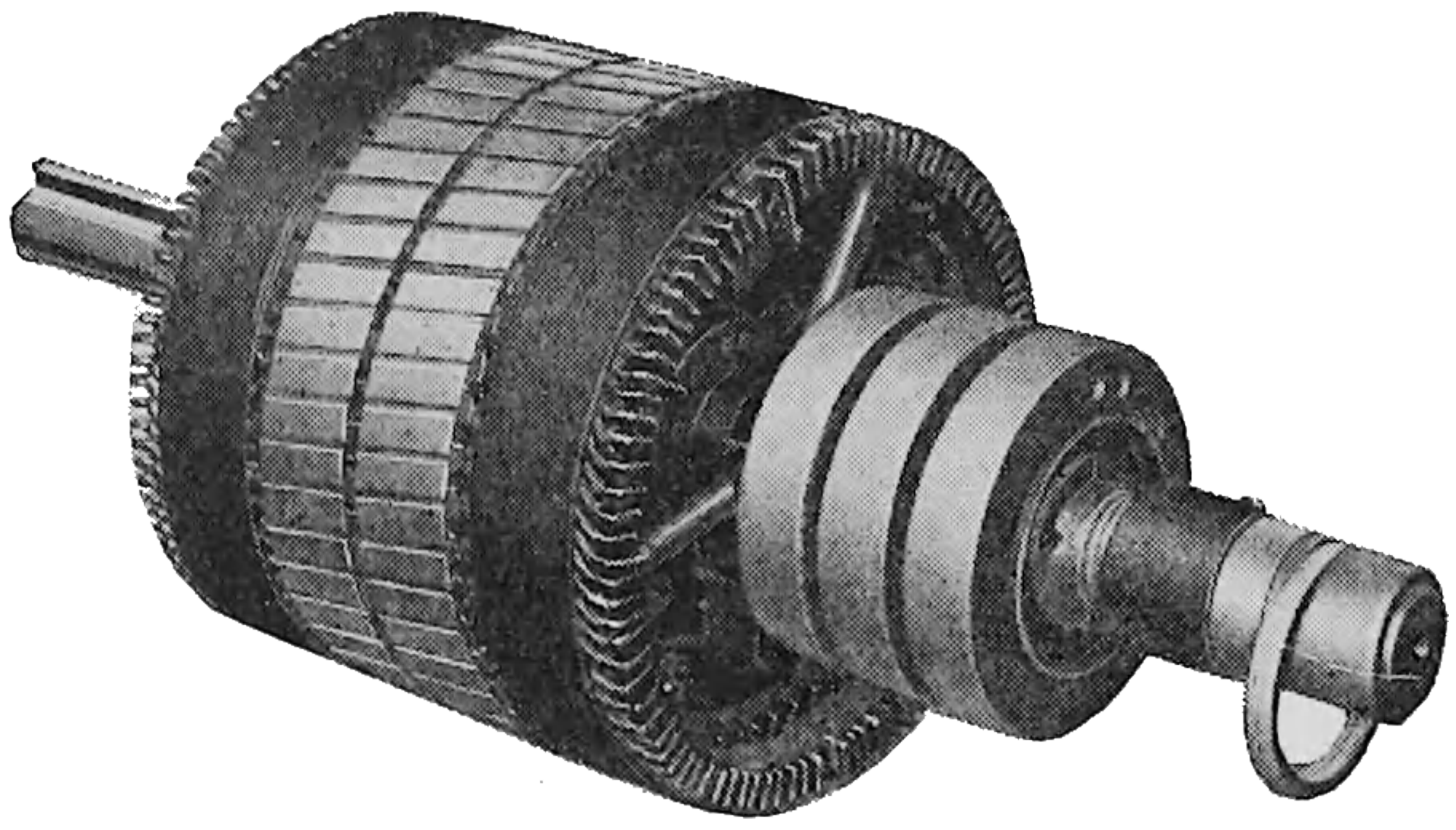


Fig. 181. Burke Rotor for Variable Speed-Induction Motors Showing Construction of Rotor and Slip Rings

**Century Electric Company.** *Single-Phase Induction Motors.* Fig. 182 shows the parts of a single-phase motor made by the Century Company. This line is built for all frequencies between 25 and 140 cycles and all voltages between 100 and 250 volts. As small power motors they are from $\frac{1}{30}$ to $\frac{1}{6}$ h. p.

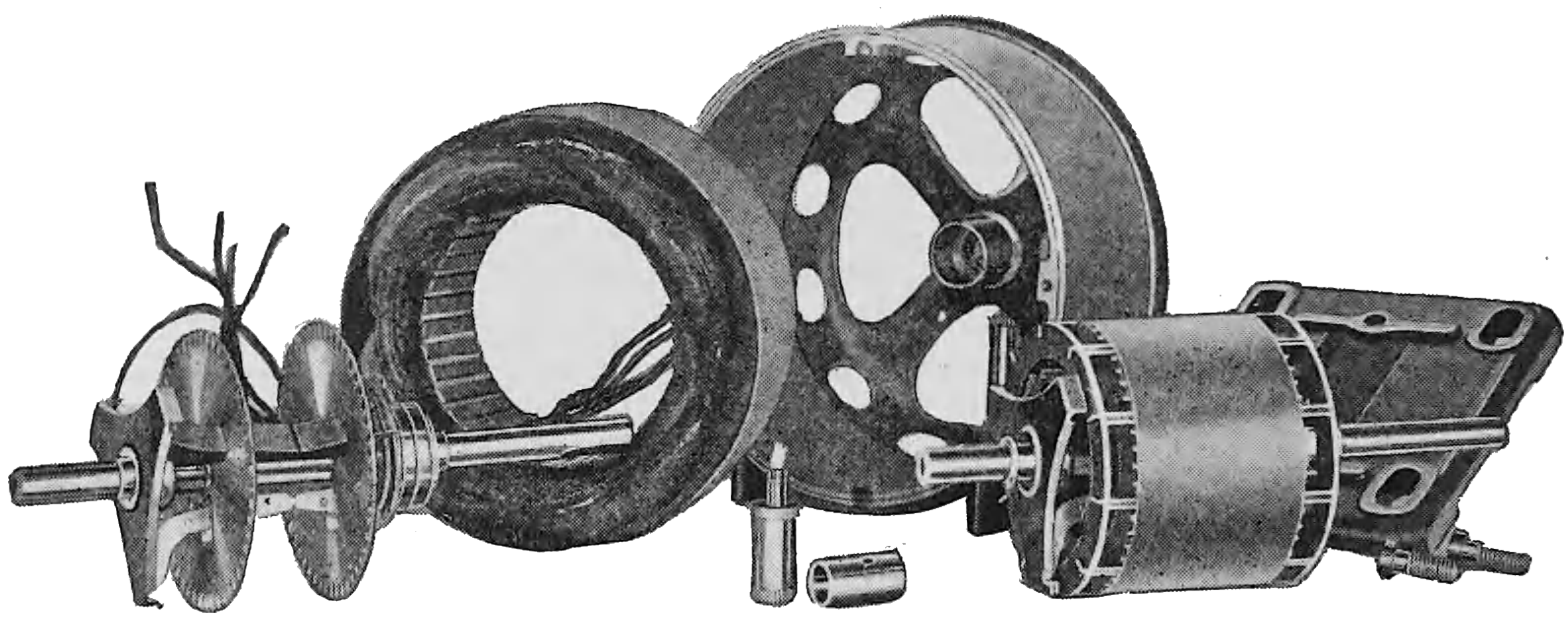


Fig. 182. Exploded View of Century Split-Phase Induction Motor

Certain sizes are also used as a complete line of fan motors. They are built in two types: clutchless and clutch. The clutchless type is designed to develop a starting torque equal to full-load running torque but requires four or five times the full-load current to do it. It is well adapted for driving fans, blowers, and centrifugal pumps.

The clutch type will stand a heavier load but requires the same starting current. When the circuit is closed, the rotor starts to revolve on the shaft; when it reaches a certain speed, a three-piece centrifugal clutch expands and engages the clutch disk fastened to the shaft. The rotor is of the well-known squirrel-cage type; bare copper bars are imbedded in the laminations, securely fastened mechanically, and then soldered to bare copper rings on each end of the rotor. The field is built up of thin laminations wound with form-wound coils that are thoroughly impregnated with oil and

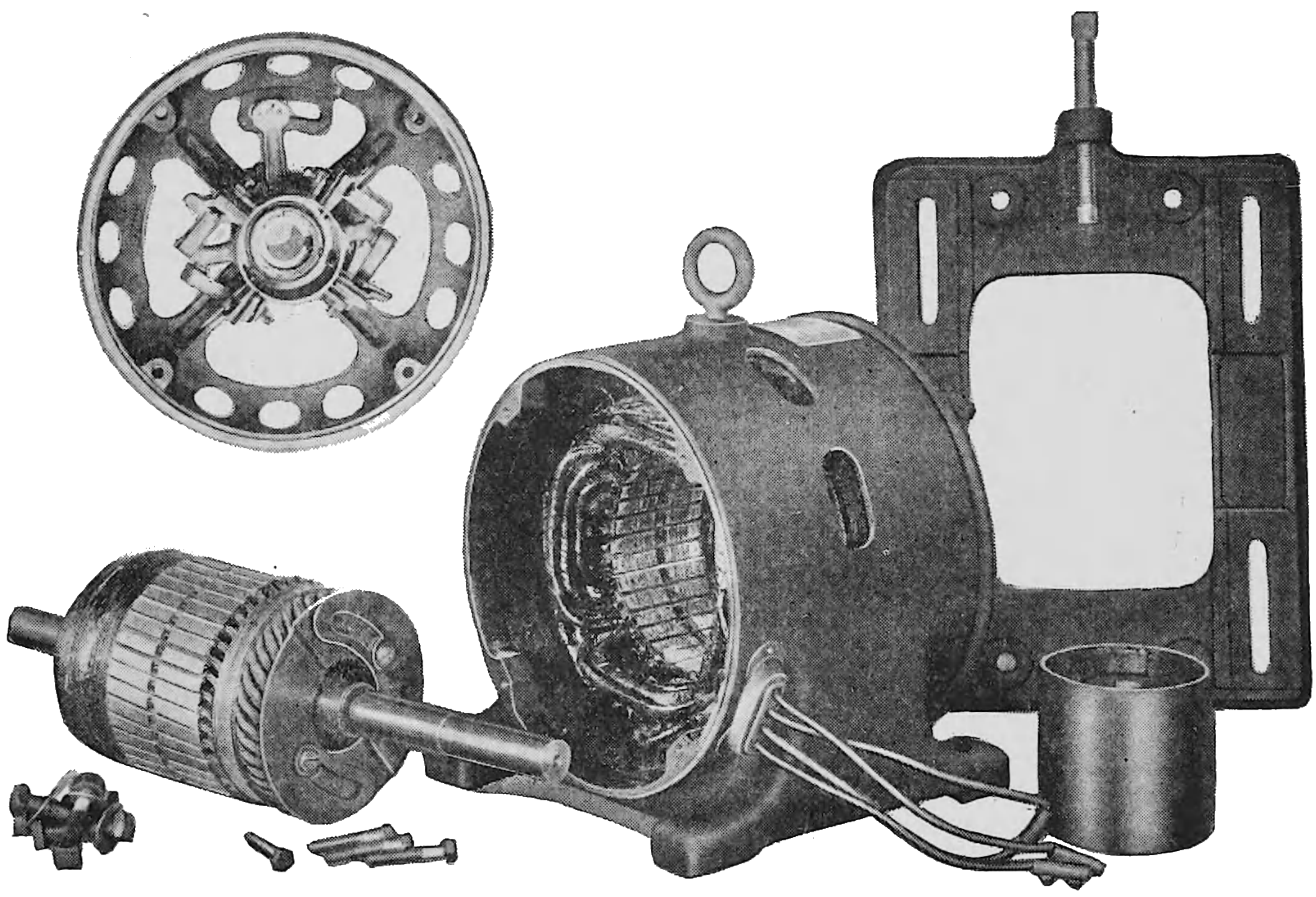


Fig. 183. Parts of Single-Phase Repulsion Induction Motors
*Courtesy of Century Electric Company*

moisture-resisting paint and then pressed into the motor frame. The split-phase or starting coils are in circuit only during the period of acceleration. When the motor reaches nearly full speed, a centrifugal switch opens this circuit.

*Repulsion Induction Motors.* A second line of motors in sizes from $\frac{1}{6}$ to 40 h. p. (Fig. 183), are single-phase, constant-speed, repulsion induction motors; that is, while running they are single-phase induction motors but start as repulsion motors. On reaching full speed, the governor weights are expanded and move a device which short-circuits every commutator bar to one common ring of high conductivity and at the same time releases the tension on the carbon brushes and pushes them back away from the commutator. When the motor is stopped or slows down to a low speed, the governor device automatically returns to its starting position.

**Crocker-Wheeler Company.** *Polyphase Induction Motors.* The Crocker-Wheeler Company manufacturers full lines of polyphase

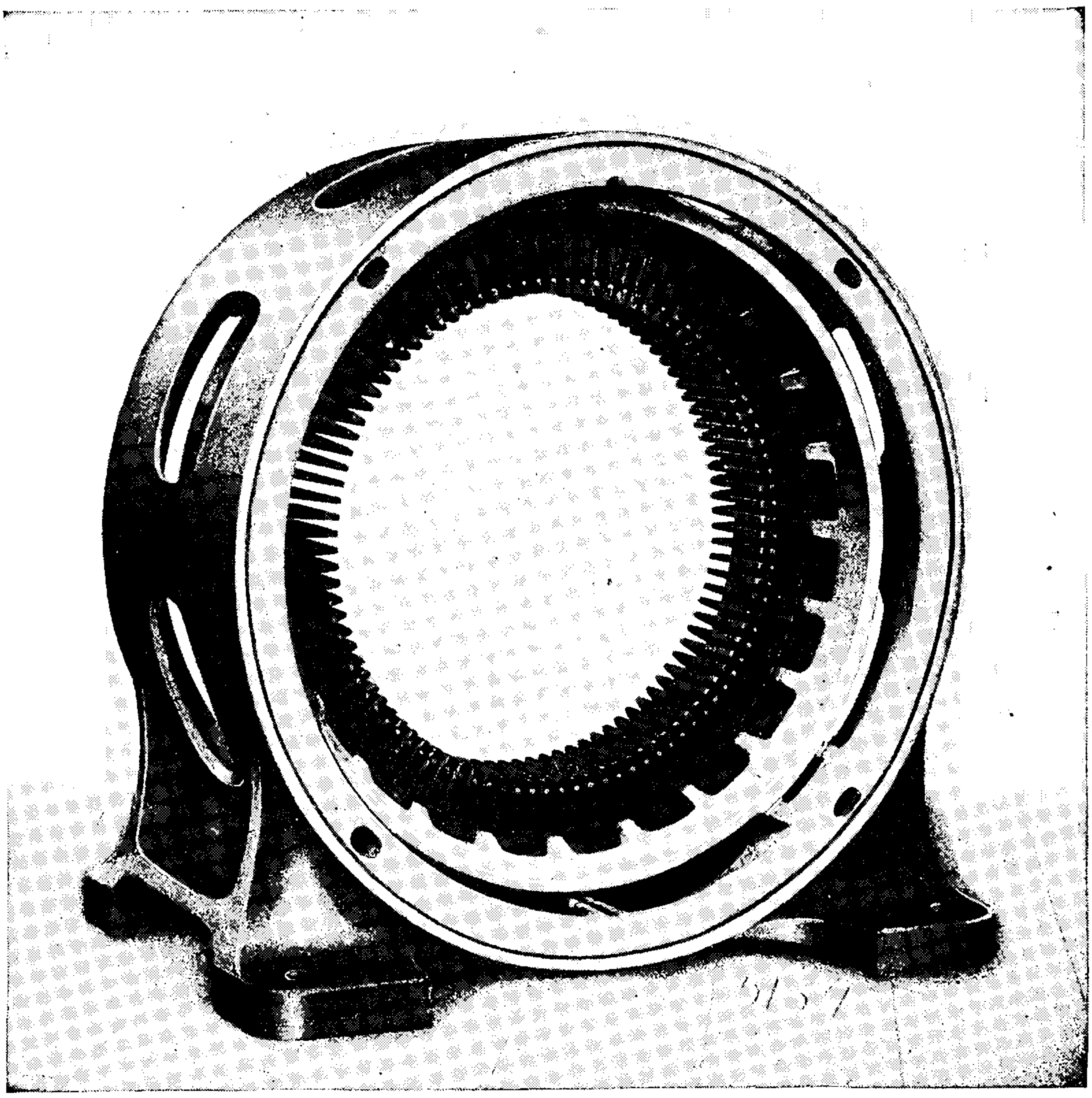


Fig. 184. Assembled Stator Core and Housings of Form Q Induction Motor
*Courtesy of Crocker-Wheeler Company*

induction motors for 60 and 25 cycles, at the standard voltages. They embody the usual features of cast-iron frame, cast-steel laminations for stator core, form-wound interchangeable coils in stator winding, laminated core on rotor, with squirrel-cage or polar winding as desired, and usual methods for obtaining cool running. Figs. 184 and 185 show a stator and a rotor of these machines.

teeth $A$. The magnetic bridge, therefore, has the same effect as shortening the air gap and improves the power factor. In order to prevent flux leakage across the ends of adjacent teeth, the magnetic bridges are divided in the middle by a long slot $F$, as shown in Figs. 187 and 188. This slot is many times wider than the air gap between the teeth and the rotor and practically prevents leakage of flux in this

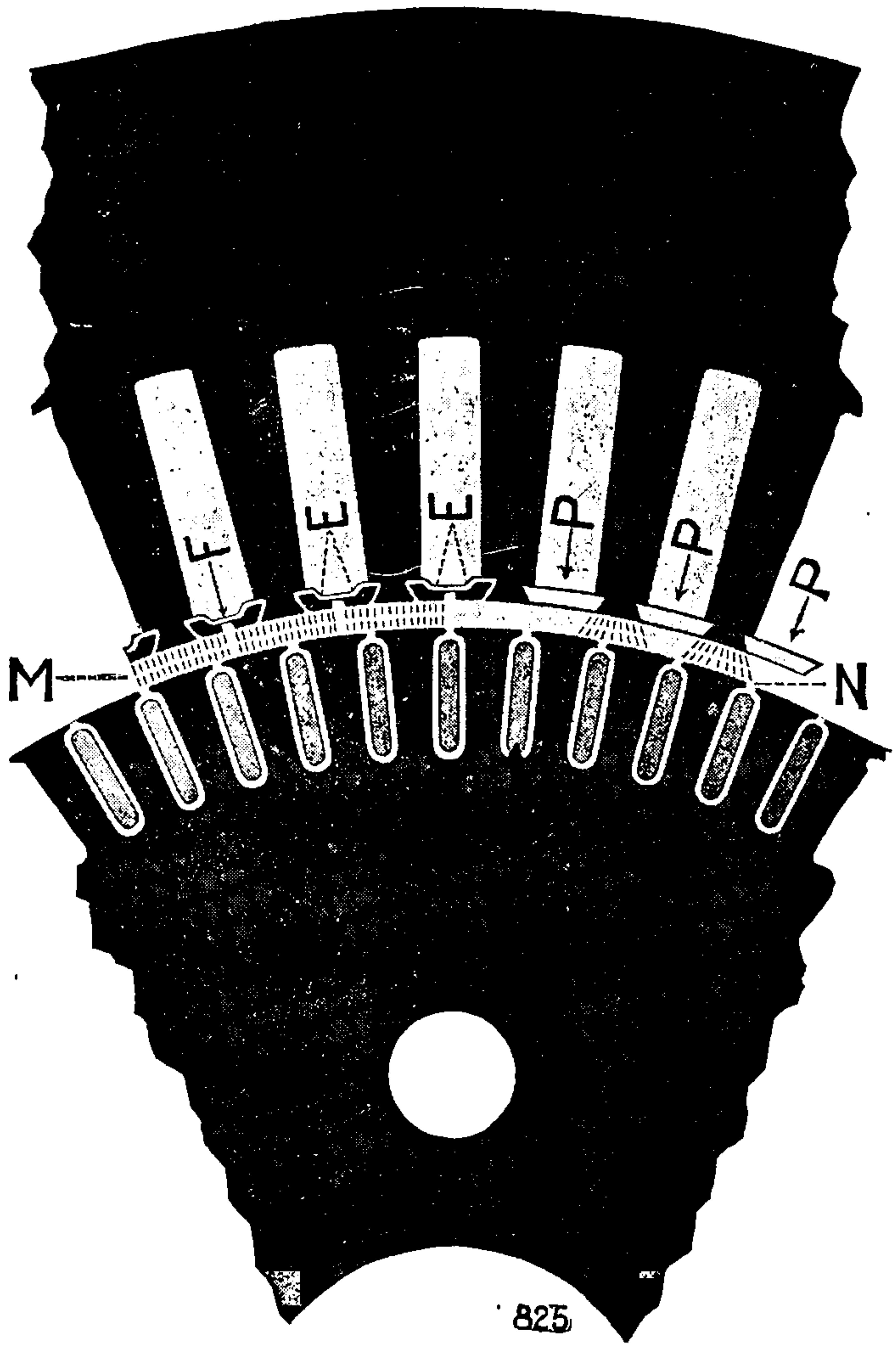



Fig. 186. Details of Magnetic Wedges for Crocker-Wheeler Induction Motors

direction. The connections by which the two halves of the bridge are held together are of such small cross section and are so highly saturated with magnetic flux that they need not be considered in connection with flux leakage. In order that this magnetic bridge $E$ may not act as a short-circuit path between core laminations, it is insulated from the tooth $A$ by the thin sheet of insulation $K$, Fig. 187. This insulation is effective for this purpose but offers very little resistance to the magnetic lines traveling across the air gap. Where wood wedges are used, pulsations of high frequency occur in the flux in the teeth, causing eddy-current losses. By the use of the magnetic bridges a better path for the flux is provided, thus largely avoiding the eddy-current effect and increasing the efficiency of the motor. Another feature is an improved type of end rings which connect the rotor bars in the squirrel-cage winding. Where continuous rings or butt-joint rings are used for this purpose, it is found that the current concentrates in the ring nearest the core. This increases the resistance and, by causing local heating, may melt the soldered connections. By the spiral arrangement of the bars shown in Fig. 189, these troubles are avoided and the electrical resistance of all bars made equal. The bars in the rotor are proportioned to give a moderately high resistance, resulting in a good starting torque. This result is accomplished without loss of efficiency, owing to the gain realized by the use of the magnetic bridges. In their slip-ring motors, the brushes are made of a composition of carbon which is submitted to an electroplating process while in a pulverized state, and each of the small particles is given a copper coating. After this process, the material is compressed into a solid brush.

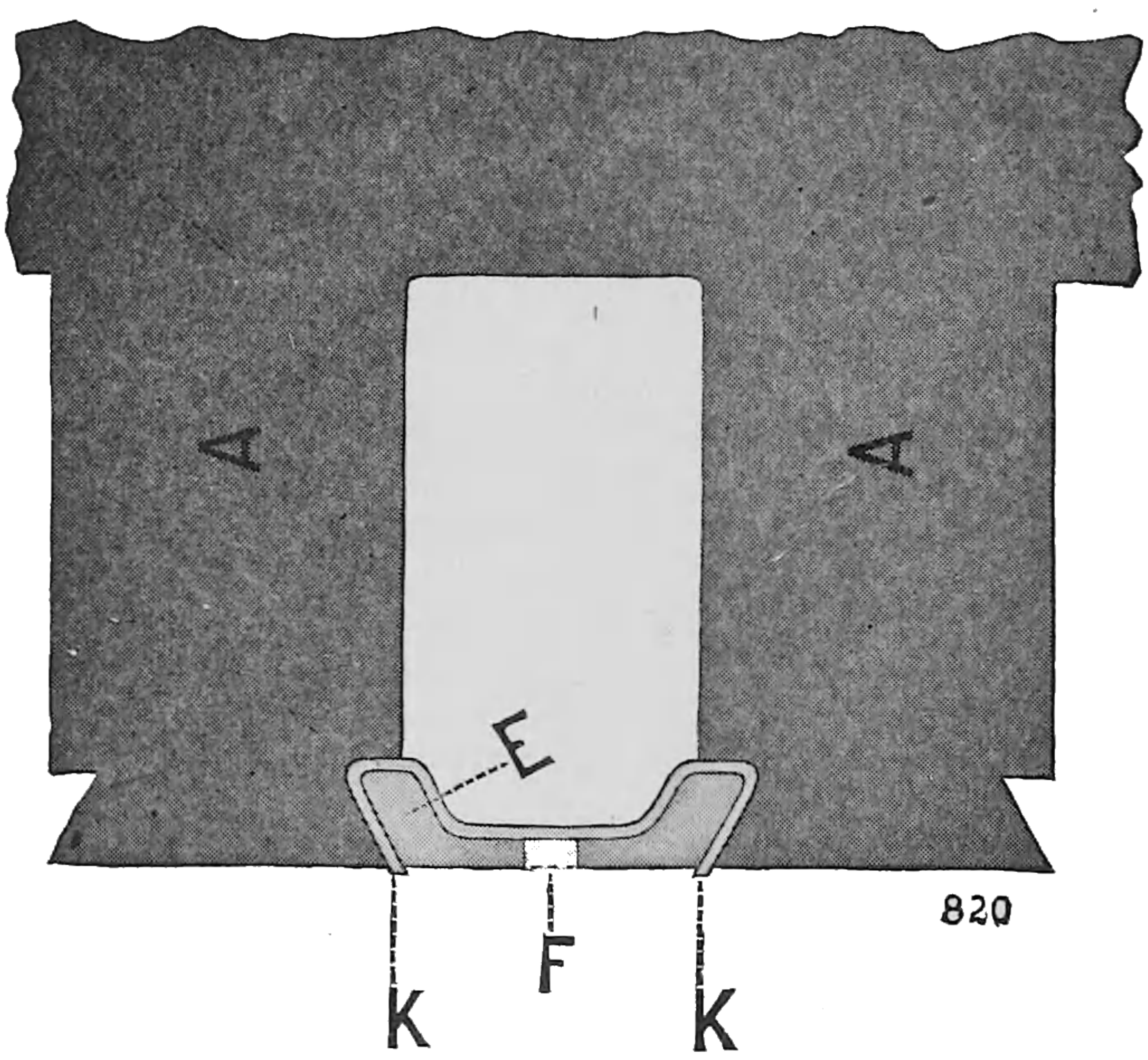


Fig. 187. Section of Magnetic Bridge in Place
*Courtesy Crocker-Wheeler Company*

Fig. 188. Magnetic Bridge

The smaller sizes below 5 h. p. may be started by simply closing a switch connecting the stator windings to the line. For sizes of 30 h. p. or under, the Crocker-Wheeler Company supplies a switch by means of which the machine is started with its stator coils connected in star, or Y=fashion, and the motor takes about one-third of the current that it would, if connected directly across the line. As the speed increases, a movement of the handle makes the change to delta (Δ) connection, the normal running condition. With this star-

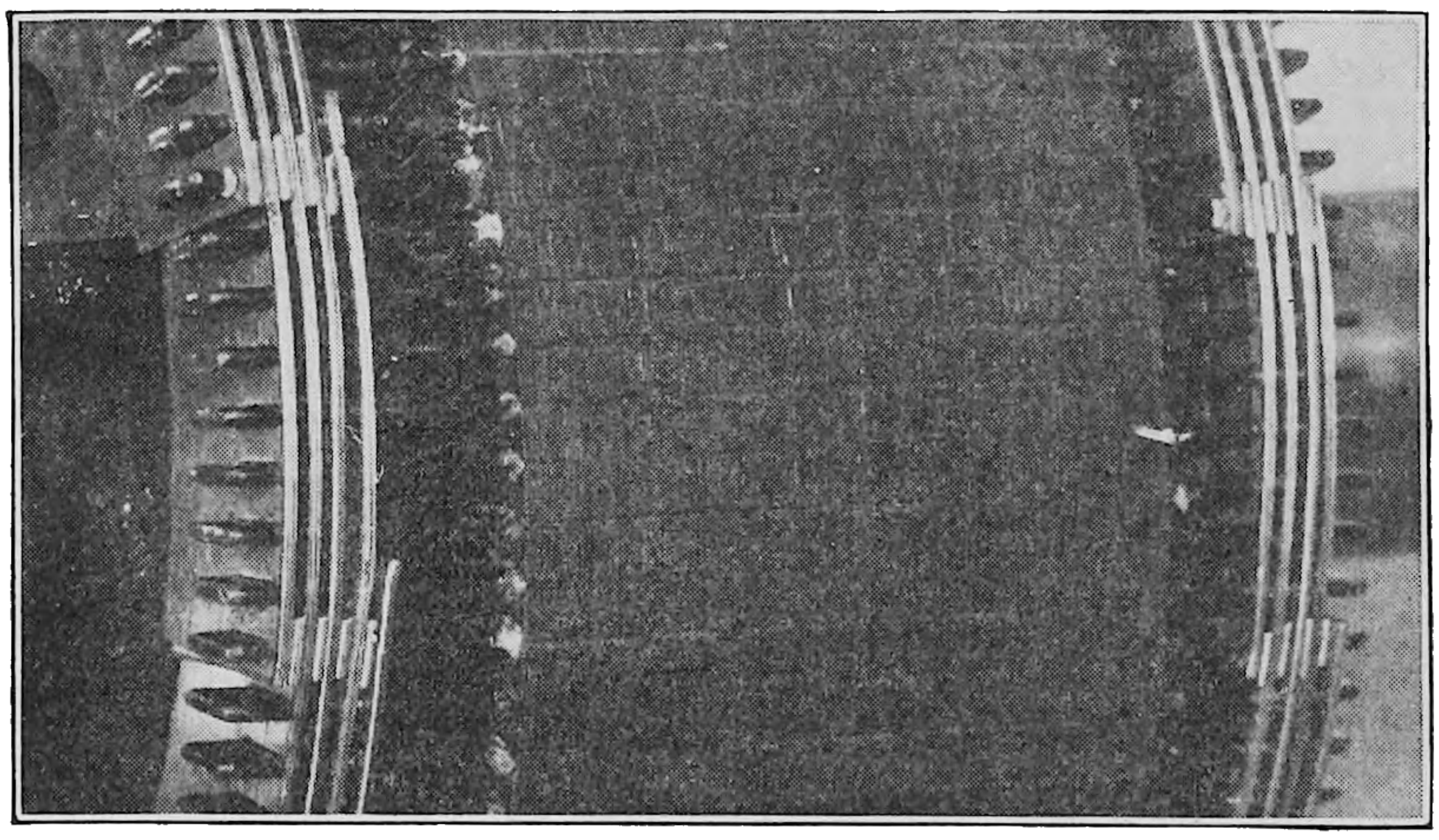


Fig. 189. Crocker-Wheeler End-Ring Connections

delta method, the effect at starting is the same as if about 58 per cent of normal voltage were applied to the motor terminals. Three-phase motors above 35 h. p. capacity and, of course, all two-phase motors are not adaptable to the star-delta method of starting, but are started by the use of an auto-transformer connected through a starting switch to the stator windings of the machine. By means of the transformer a low voltage is first applied to the terminals of the motor to start it, and after the machine has increased its speed, the voltage is raised in steps to normal value by means of a controller.

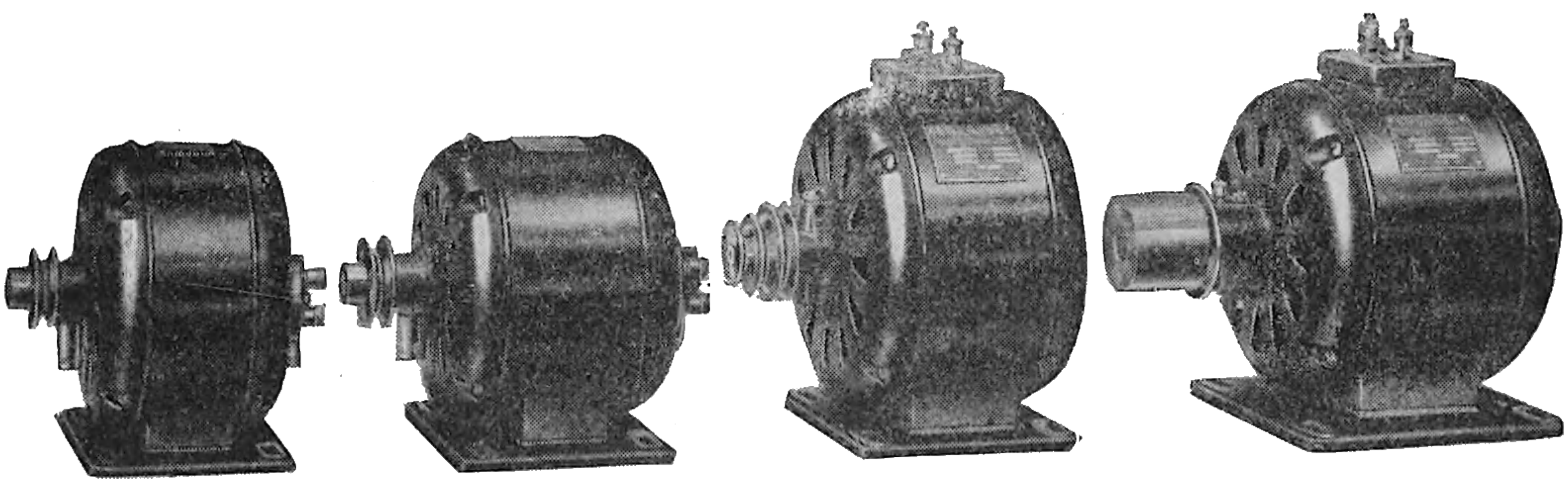


Fig. 190. Line of Single-Phase Induction Motors
*Courtesy of Emerson Electric Manufacturing Company*

**The Emerson Electric Manufacturing Company.** *Single-Phase Induction Motors.* The Emerson Company makes a line of single-phase induction motors designed for all frequencies from 25 to 133 in sizes from $\frac{1}{20}$ to $\frac{1}{2}$ h. p. and operating on 100 to 115 volts.

openings, allowing free ventilation through the field of the motor. The motor field or stator consists of laminations of specially selected steel. The punchings are slotted and the stator windings are carefully insulated and imbedded in the slots. The rotor or armature is also built up of laminations with heavy copper conductors and is of the ordinary squirrel-cage type.

**General Electric Company.** *Polyphase Induction Motors.* The G. E. Company builds complete lines of polyphase induction motors from $\frac{1}{4}$ to 6000 h. p. for standard frequencies of 25, 40, and 60 cycles at the standard voltages of 110, 220, 440, 550, and 2200 volts for two-phase or three-phase operation. Their intermediate sizes, built in three types, employ the method of construction called the skeleton frame, as shown in Fig. 191. The three different types employ the same stator but differ in the rotors employed.

The stator is built up of circular laminations, keyed to the frame ribs and held together at each end by iron rings securely fastened to the frame. Besides having the usual ventilating ducts,

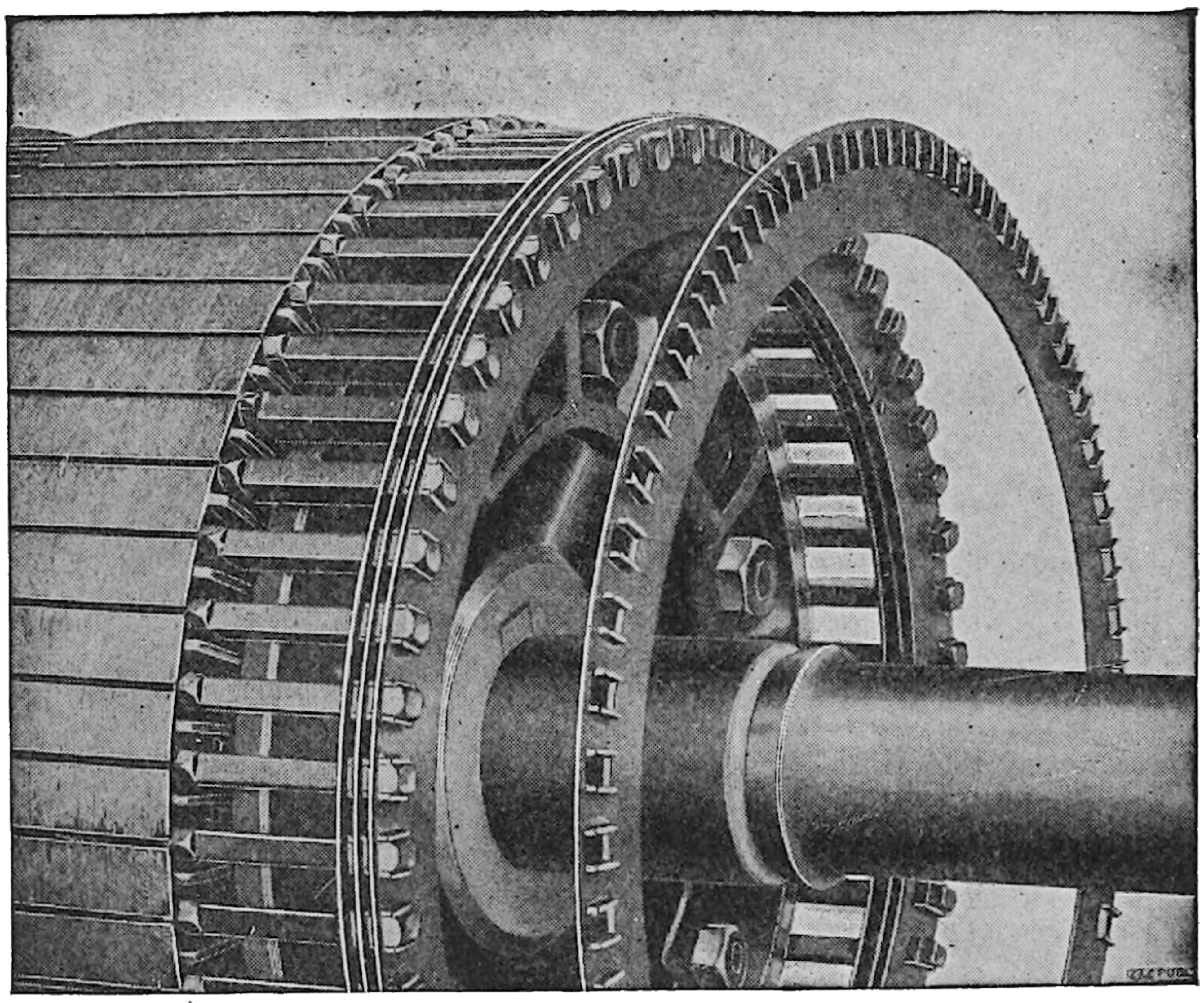


Fig. 192. Soldered Form of End-Ring Construction for Form K Rotor
*Courtesy of General Electric Company*

the outer circumference of the laminations is almost entirely exposed to the air, thus increasing the cooling surface. The interchangeable stator windings are form-wound and placed in open slots which are used in all but the smaller sizes.

The rotor is built up of annular punchings, dovetailed to the spider arms. Bolts passing through solid end rings underneath the punchings clamp the laminations together. The partly closed slots for the conductor bars assist in holding the windings in place.

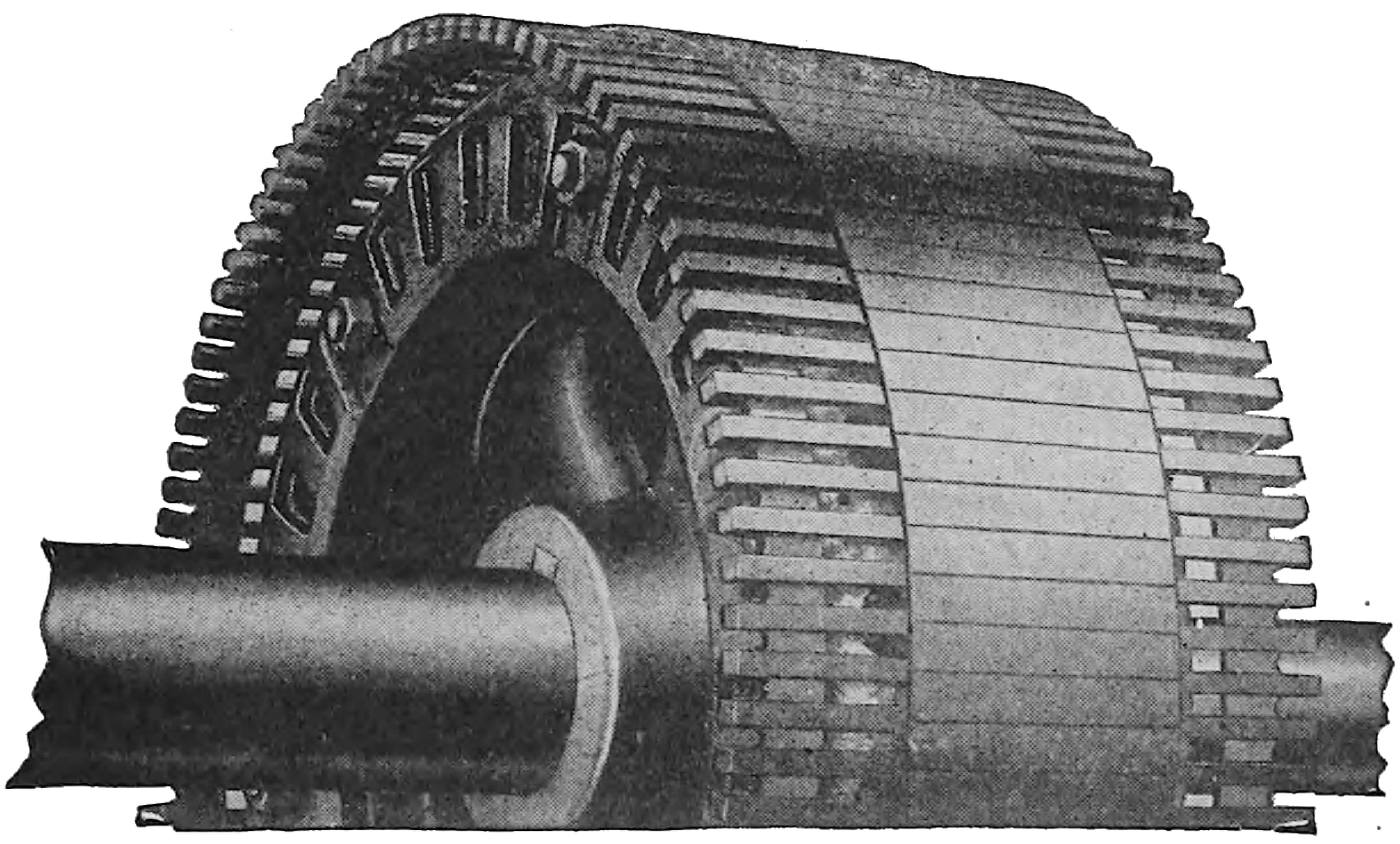


Fig. 193. View of General Electric Form K Rotor Showing Welded Type of End-Ring Construction

The different rotor windings give rise to the three different types of these machines, forms K, L, and M. Form K employs a squirrel-cage winding, consisting of bars laid in the core slots and short-circuited at the ends by copper rings. For the smaller sizes these rings are thin but of considerable radial depth and are held apart by spacing washers. They have rectangular holes punched near their outer peripheries through which the rotor bars pass. Lips are formed in the rings of ample area, to which the bars are thoroughly soldered, as shown in Fig. 192. In the larger frames, on account of the difficulty of providing multiple soldered rings of sufficient cross section, a welded ring construction, as shown in Fig. 193, is employed. This consists of a cylindrical copper ring of ample width and cross section placed beneath the bars at each end of the rotor. Short radial bars are welded to the edges of these rings and to the rotor bars, thereby making a good electrical contact and rendering the structure mechanically secure. These rings improve the ventilation of the motor, when running, by drawing in a current of air and forcing it through the ends of the stator coils and ventilating ducts.

To reduce the current at starting and increase the torque, the form L motor, unlike the form K, is provided with a wound rotor, that has a starting resistance and switch located on the shaft within the rotor. Form L motors are used in preference to those of the form K type where the voltage regulation of the system is of importance. The starting resistance in motors up to about 35 h. p. consists of cast-iron grids enclosed in a triangular frame that is bolted to the end plates holding the rotor laminations together, and is short-circuited by sliding laminated spring metal brushes along the inside surface of the grids. The brushes are supported by a metal sleeve sliding on the shaft and operated by a lever secured to the bearing brackets. A rod passing through the end of the shaft operates the short-circuiting arrangement. Intermediate size frames use as resistances brass grids arranged in three sets 120 degrees

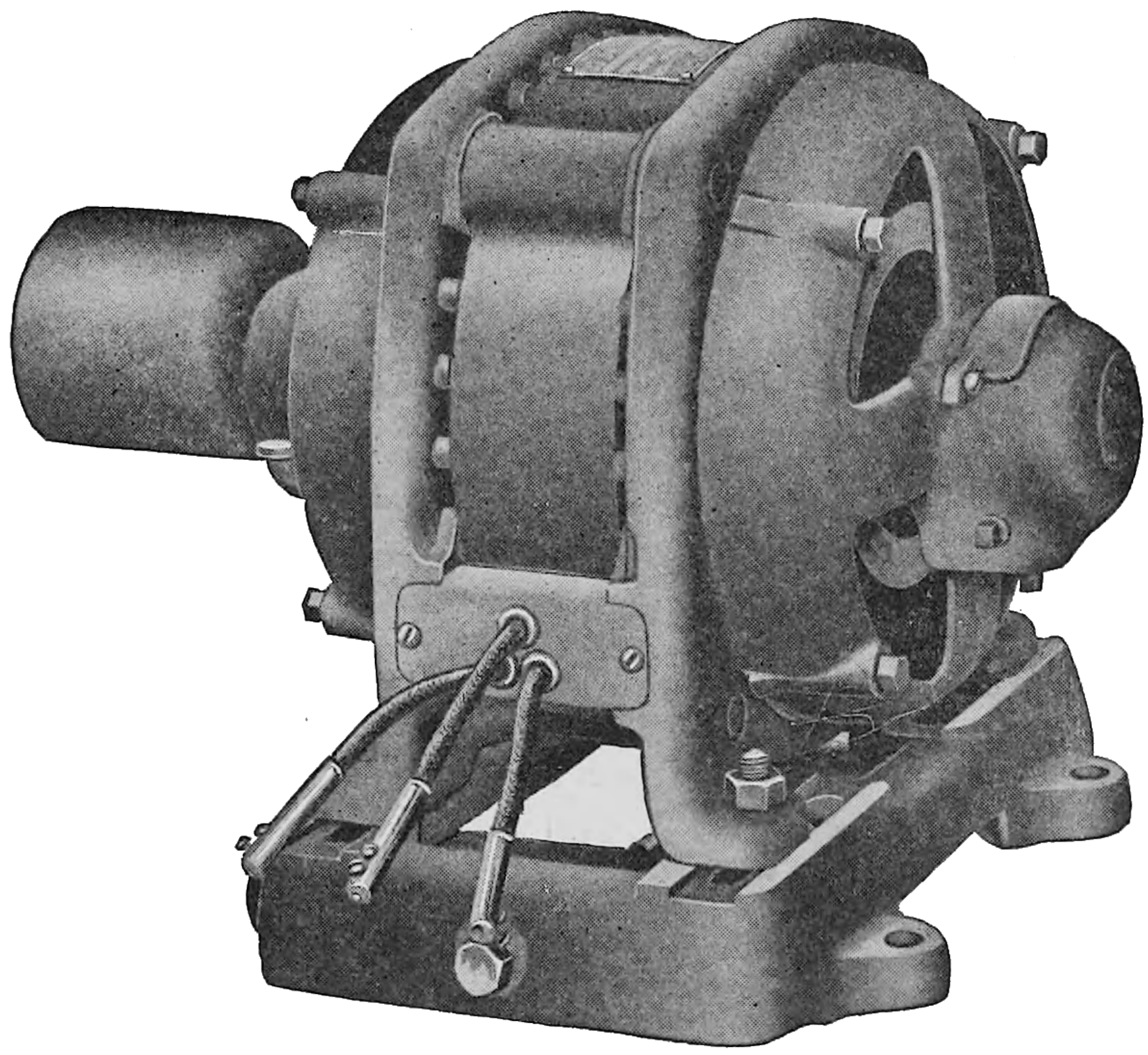


Fig. 194. Riveted-Frame Induction Motor with Sliding Base
*Courtesy General Electric Company*

apart. These are bolted to end plates holding the rotor laminations together and are short-circuited by sliding laminated copper brushes along the inside surface of these grids. These brushes are supported by a yoke sliding on the shaft and controlled by a lever. For the largest frames, cylindrical coil resistances of German silver wire wound on edge are used. These coils are bolted 120 degrees apart to bosses on the spider hub and are clamped together by a ring on their front end. Two laminated metal brushes bear directly on each of these resistances and are supported on a yoke sliding on the shaft.

The form M rotor is similar in construction to form L except that collector rings and controller are necessary because of the

struction and can be designed for operation requiring constant torque or for constant horsepower. They run at 600, 900, 1200, and 1800 r. p. m., the four speeds being obtained by changing the polar groupings of the stator coils.

*Standard Single-Phase Induction Motors.* The single-phase induction motors of General Electric manufacture are built in two lines, type KS and type RI. The standard type KS machines illustrated in Fig. 196, are built in sizes from 1 to 15 h. p. for 60 cycles and run at 1800 and 1200 r. p. m. The stators have symmetrical three-phase windings with form-wound coils placed progressively in the slotted punchings. The rotor is of smooth core, squirrel-cage,

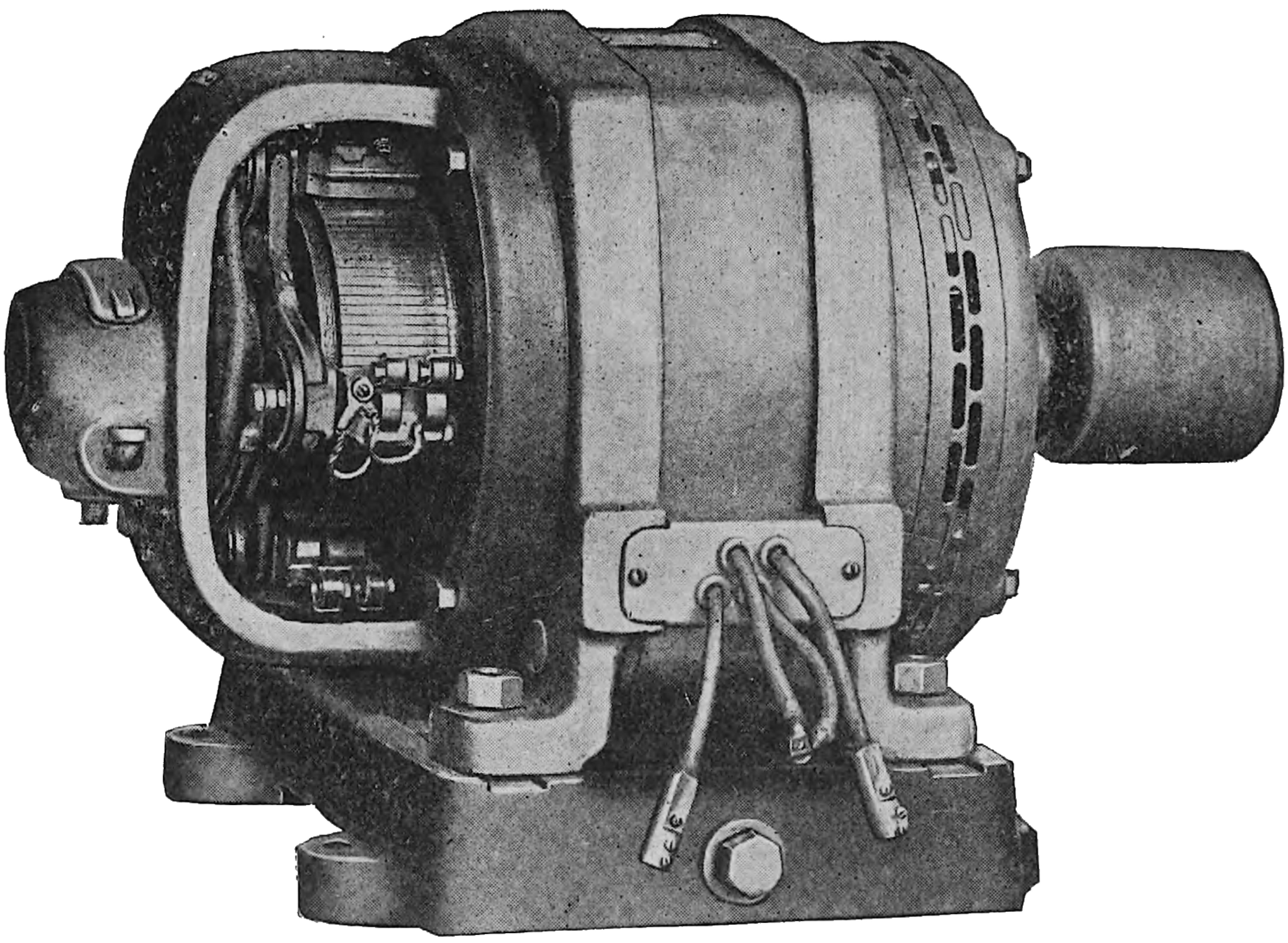


Fig. 197. Type RI Single-Phase Repulsion Induction Motor
*Courtesy of General Electric Company*

high-resistance type consisting of soft steel disks assembled upon a steel sleeve, the disks being slotted near the circumference to retain the bar winding which extends beyond the core at both ends where it is permanently connected to heavy short-circuiting rings. The rotating member is supported upon the shaft by a special lining bearing interposed between the steel assembly sleeve of the rotor and the shaft. Rotor acceleration is accomplished by means of a starting box containing both resistance and reactance units and operated in much the same manner as the well-known direct-current motor rheostat. The rotor revolves freely on the shaft until about 75 per cent of rated speed is reached, when the load is picked up by the automatic action of a centrifugal clutch that rigidly engages an outer shell keyed directly to the shaft.

*Compensated Repulsion Induction Motors.* Type RI machines, illustrated in Fig. 197, are really compensated repulsion induction motors having a combination of series and shunt characteristics and capable of operation above or below synchronous speeds. RI motors are built in sizes up to 15 h. p. in the riveted-frame form. The field consists of slotted laminations assembled between end flanges and wound with two windings; a main winding of the distributed concentric type, and a compensating winding which is either the center portion of the main winding or a separate winding concentric therewith, depending upon the size of the frame used. The armatures are built up of selected sheet-steel laminations in which the coil slots are punched before being assembled. In sizes up to and including 5 h. p. the laminations are built up directly on the shaft, the larger sizes employing cast-iron spiders held in place by retaining rings and cast-iron core heads. The armature winding is of the series type, the smaller sizes being form-wound, while the larger employ bar windings. The commutators are made from the best grade, hard-drawn, high conductivity copper segments, insulated with selected mica, slotted to reduce the brush contact resistance and friction. To secure proper ventilation, in addition to the usual ducts between laminations of the stator, the armature shaft is fitted with a rigid fan. The brushes are in two different sets; one, the energy brushes; the second, the compensating, connected to the compensating field winding.

The action of the machine is as follows: In the straight repulsion motor, to secure the necessary starting torque, a direct-current armature is placed in a magnetic field excited by an alternating current and short-circuited through brushes set with a predetermined angular relation to the stator. To further improve the operating characteristics of the plain repulsion motor, a second set of brushes, the compensating set, is placed at 90 electrical degrees from the main short-circuiting brushes, the energy brushes, and is connected to the compensating field. This field is auxiliary to the main field and impresses upon the armature an electromotive force which is in angular and time phase with that generated by the main field. This improves the phase relation between current and voltage (resulting in high power factor), serves to restrict the maximum no-load speed, and also permits, when desired, a slight increase over synchronous values.

RI motors can also be built reversible and for varying and adjustable speed operation. The reversibility is accomplished by the addition of an auxiliary winding spaced 90 degrees from the main field winding and connected in series with it. By reversing the relative polarity of the two windings by means of a reversing switch, the direction of rotation is changed in a simpler manner than if the reversal were secured by mechanically shifting the radial position of the brush holder yoke. The varying-speed brush-shift motor is obtained by using a slight modification in the windings and brush rigging. To a grooved ring on the movable brush yoke is attached a flexible steel cable supported and guided in any desired direction by a small grooved pulley. The terminals of this cable are fastened respectively to the controller handle and the movable brushes.

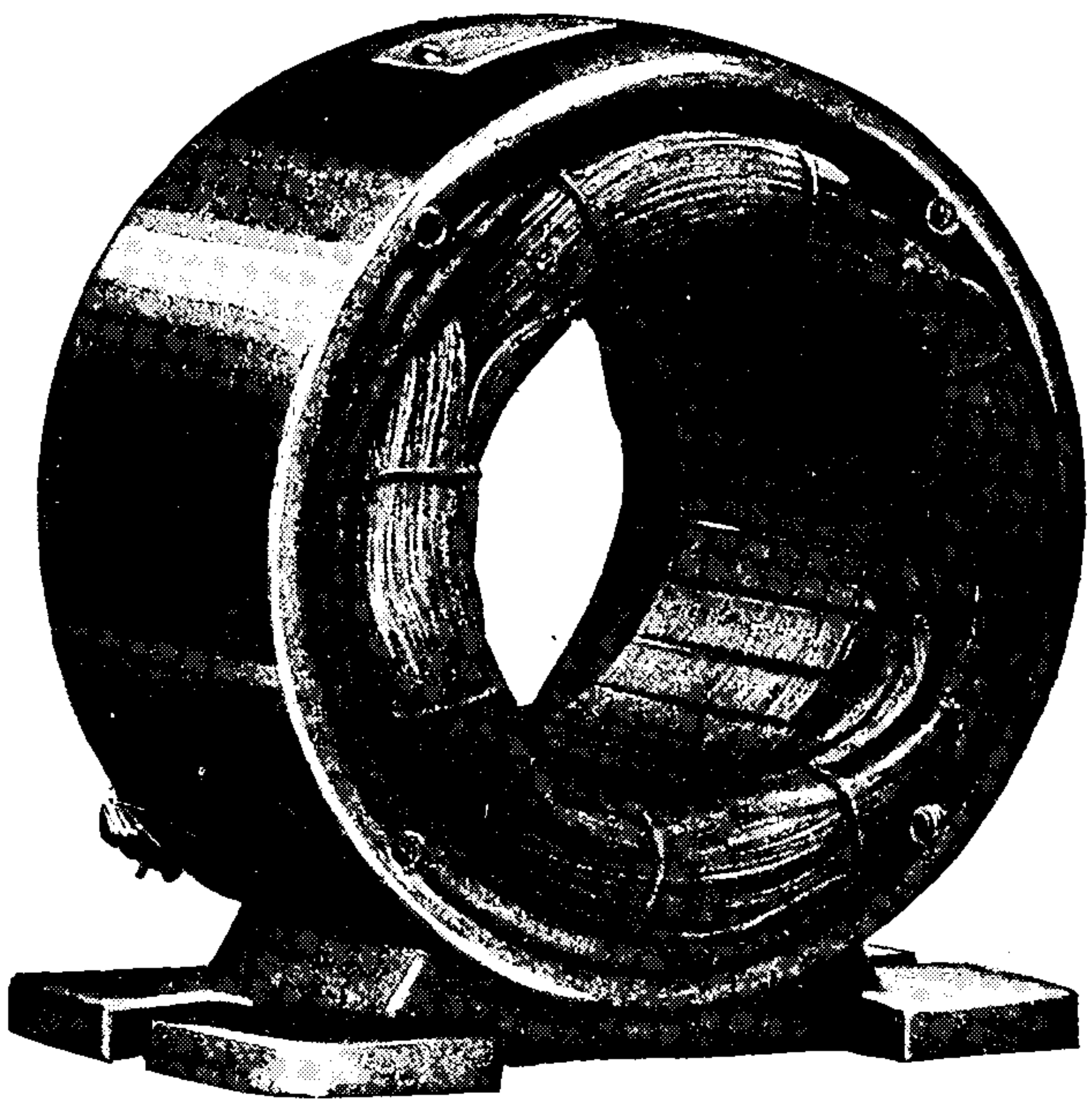


Fig. 198. General Electric Single-Phase Motor with Wound Field and Drawn Shell

RI adjustable-speed motors allow a speed range of 2 to 1, about half this range being above synchronous speed and half below. This is obtained by modifying the windings and employing transformers whose primaries are excited by the line circuit. The secondaries of these transformers are divided into two sections; the first, or regulating circuit, is placed across the energy brushes; the other section is connected in series with the compensating winding.

*Small Size Induction Motors.* A line of very small motors from $\frac{1}{50}$ to $\frac{1}{4}$ h. p. employs the drawn shell construction of the similar size direct-current motors. They are single-phase induction motors with squirrel-cage armatures and employ the split-phase method of

from the alternating-current side. This line of generators, when so modified, are also used as synchronous phase-modifiers, or synchronous condensers. They are so-called because a synchronous motor, when used as a synchronous condenser, has the property of altering the phase relation between voltage and current, the direction and extent of the displacement being dependent on the field excitation of the synchronous condenser. It can be run at unity-power factor and minimum current input, or it can be over-excited, and, thereby, take leading current which compensates for the induc-

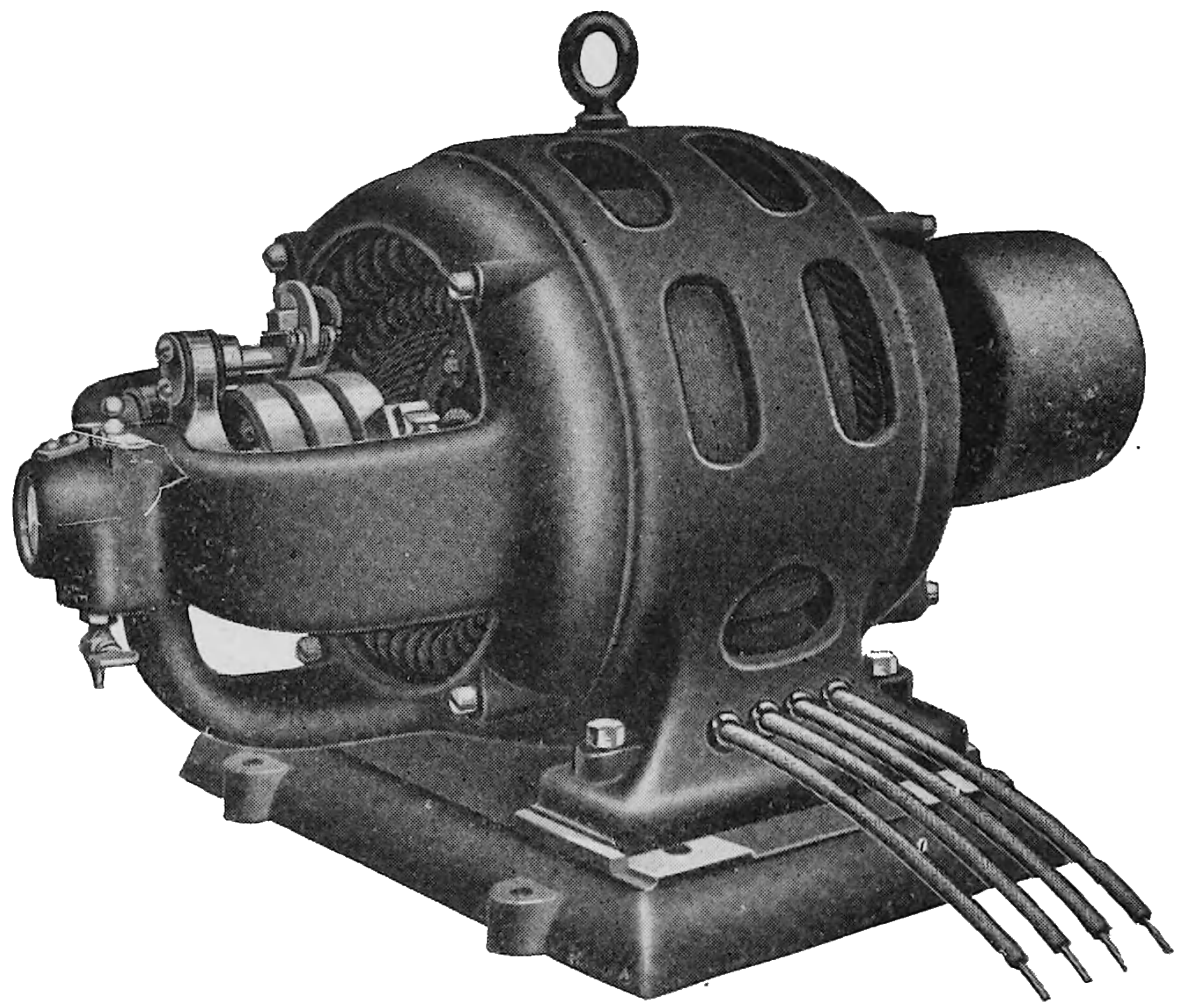


Fig. 201. Triumph Electric Company Phase-Wound Motor

tive load on other parts of the system. Fig. 199 shows a machine of this type and Fig. 200 shows the grid winding carried in pole pieces of the rotor. This acts as a squirrel-cage winding during starting and minimizes hunting during running.

**Triumph Electric Company.** *Polyphase Induction Motors.* The Triumph Company manufactures a complete line of polyphase induction motors in sizes up to and including 200 h. p., wound for 110, 220, 440, 550, and 2300 volts for two-phase and three-phase circuits and for 25, 40, and 60 cycles. They can be arranged for any desired mounting, including the vertical-shaft type. The stator core is built from punchings of a special non-ageing steel, thoroughly japanned. The thoroughly insulated coils are form-wound and held firmly in position in the stator slots by wedges. Besides the insulation around the coils, the slots are also lined with insulating materials. The squirrel-cage rotor is built up of thin sheet-steel laminations, thoroughly japanned, and clamped together by heavy malleable-iron end-plates. Semi-enclosed slots are punched in the outer periphery to receive the windings and hold them in place against the action of centrifugal force. These conductors are set on edge and are riveted and soldered into heavy resistance rings of ample section. These rings are punched to receive the conductors in such a manner that there is an unbroken strip of metal completely surrounding each conductor. The short-circuiting rings are set some distance from the ends of the core so that the rotor bars between the core and the ring act as vanes and force large volumes of air through the coils and ventilating openings in the stator frame. For adjustable-speed work and for extremely heavy starting duty, phase- or wire-wound rotors are employed, as illustrated in Fig. 201. The rotor circuits are completed by connecting to the collector rings mounted upon the shaft suitable external resistances.

**Wagner Electric Manufacturing Company.** *Polyphase Induction Motors.* The Wagner Company builds complete lines of induction motors for standard frequencies at 110, 220, and 440 volts, wound either two-phase or three-phase. The stator forms the field and the usual construction is employed. The rotor is the armature and is built in the usual squirrel-cage or wound-rotor type, the squirrel-cage rotor being employed for constant speed. In order to prevent any possibility of the rotor bars shifting lengthwise and thereby unbalancing the rotor, al squirrel-cage end rings are shouldered on the armature flanges. The wound rotors with their slip rings and external resistances are used for variable-speed motors or constant-speed motors, wherever the load at starting is heavy, so as to avoid voltage disturbance resulting from heavy starting currents. In these lines the angular position of the end plates on the frames may be shifted so as to permit the installation of the motors in any position on floor, wall, or ceiling.

Another form of polyphase induction motor put upon the market by this company is their type BW. It is built in complete lines of three different speeds 1800, 1200, or 900 r. p. m. for 60 cycles, at

110, 220, or 440 volts in sizes from 3 to 50 h. p. and wound either two-phase or three-phase. These machines in outward appearance are like the single-phase machines built by this company. The stator or field is built according to the usual standard construction of polyphase squirrel-cage induction motors of other makes. The rotor or armature has a distributed winding, tapped to a vertical commutator in such a way that, by short-circuiting all the segments, the winding is converted into one of a squirrel-cage type. This is accomplished by a centrifugal device that acts shortly before the motor reaches full speed. These motors are constant-speed poly-

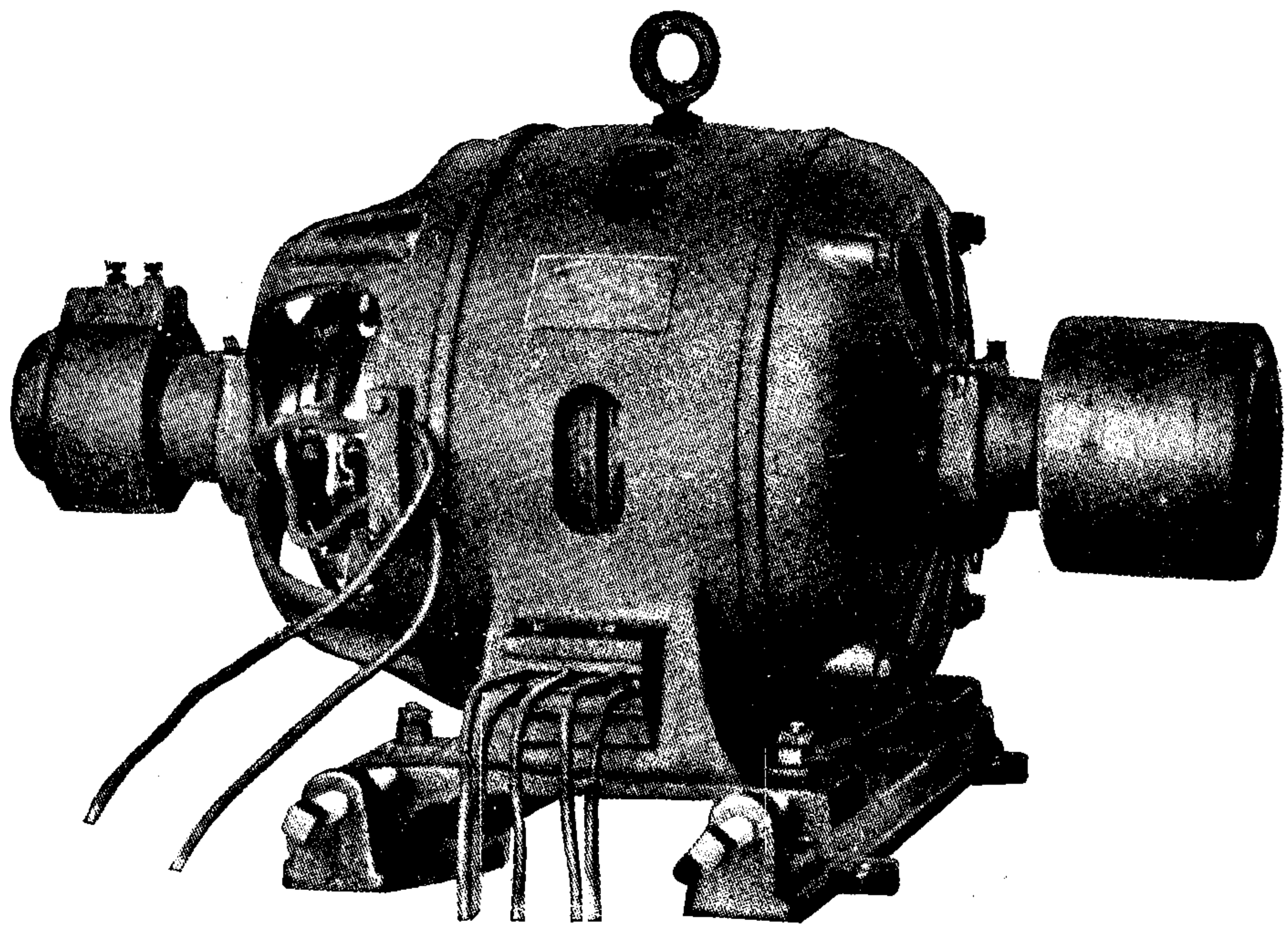


Fig. 202. Single-Phase, Unity Power Factor Motor
*Courtesy of Wagner Electric Manufacturing Company*

phase motors suitable for practically all installations in which ordinary squirrel-cage motors can be used and will also take the place of the usual wound rotor type for any purpose not requiring speed variation. They have all of the advantages of the wound rotor during starting.

*Constant-Speed Single-Phase Motors.* A novel form of constant-speed single-phase motor, shown in Fig. 202 and known as type BK, is built by the Wagner Company in sizes up to 15 h.p. Standard methods of mechanical construction are followed. The windings on both the stator and the rotor, as well as the principles of operation, are different from any other machine upon the market. In the

by making said winding less responsive to outside inductive effects. The influence, however, of this separator is nullified along the axis of the main stator winding by the presence of the short-circuited brushes *5-6*, while no means are provided for nullifying its effect along the axis at right angles to that of the main stator winding. Thus the main stator winding *1* will be able to induce heavy currents in both rotor windings because of the short-circuited brushes in the axis *5-6* in spite of the magnetic separator; while the rotor winding *3*, connected in series with *1*, will not be able to produce heavy currents in the squirrel-cage winding *4* along the axis *7-8* because of the magnetic separator between *3* and *4* shunting the inducing magnetic flux.

At starting, switch *9* of Fig. 203 is open, the commuted winding *3* along the axis *7-8* being connected in series with the main stator winding *1* across the mains. The winding *1* induces a large current in the rotor windings *3* and *4* along the axis *5-6*, and the winding *3* produces a large flux along the axis *7-8*, the motor starting as a series machine. As the motor speeds up, the squirrel cage gradually assumes those functions that it performs in the ordinary single-phase motor and produces a magnetic field of its own along the axis *7-8*. Since the magnetizing currents circulating in the bars of the squirrel cage of a single-phase induction motor at synchronism are double the frequency of the stator currents, the fluxes they produce must be of double frequency. Now the magnetic separators are so proportioned of solid steel that while they form sufficiently effective shunts for the fluxes of line frequency induced from the stator, they are quite ineffective as shunts for the double-frequency fluxes produced by the rotor.

As far as the squirrel cage is concerned, the effect of the magnetic separator diminishes with increasing speed and at synchronism the machine operates practically in the same manner as if the separator did not exist at all. This form of motor under running conditions has a power factor leading at light loads and practically unity from half load to fifty per cent overload. The employment of the squirrel-cage winding in combination with the commuted winding secures a very small change in speed from no load to considerable overload, the speed being slightly above synchronous speed at light loads. The squirrel cage also prevents the motor from racing or running away.

**Westinghouse Electric and Manufacturing Company.** *Squirrel-Cage Induction Motors.* The new line of Westinghouse type CS squirrel-cage induction motors possesses several new features, among which are the extensive use of pressed steel in the construction and rotors with cast-on short-circuiting rings. These motors are put upon the market in all commercial sizes from 1 to 200 h. p. for the standard frequencies and voltages. A 10 h. p. machine is shown in Fig. 205. Pressed steel imparts great mechanical strength and is very uniform in structure, hence a motor of given weight can be made with more active material than motors of corresponding capacity in

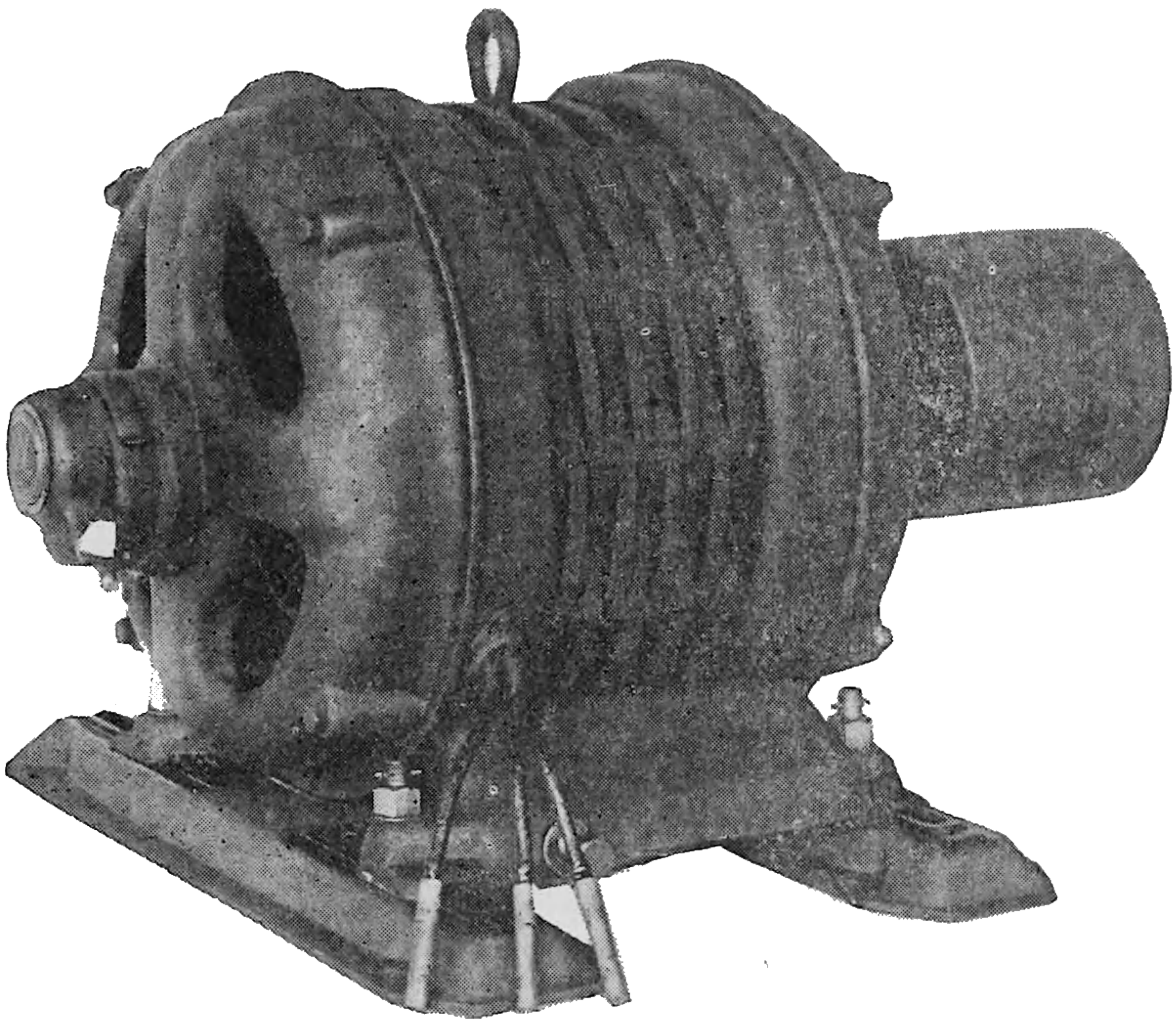


Fig. 205. Type CS Squirrel-Cage Induction Motor
*Courtesy of Westinghouse Electric & Manufacturing Company*

cast-iron frames. In these motors, rolled steel is used in the frames of the sizes above 20 h. p., as well as in the end plates of the smaller sizes and in the feet and slide rails of all sizes. Above 5 h. p. the form-wound stator coils are laid in open slots. In all sizes the rotor bars are insulated with a special cement, which is moisture-proof and will withstand a high degree of heat and large mechanical stress. In motors above 15 h. p. the bars are connected electrically and mechanically by casting the short-circuiting rings around the ends. The bearings are protected from dust by a cap on the front end and by felt washers between metal rings on the pulley end.

*Phase-Wound Slip-Ring Motors.* Another line called type HF are phase-wound slip-ring motors, as shown in Fig. 206. They are made in capacities ranging from 5 to 200 h. p. for two-phase or three-phase circuits of 25 and 60 cycles; small motors are made for voltages up to 550 and large motors for voltages up to 2200. The

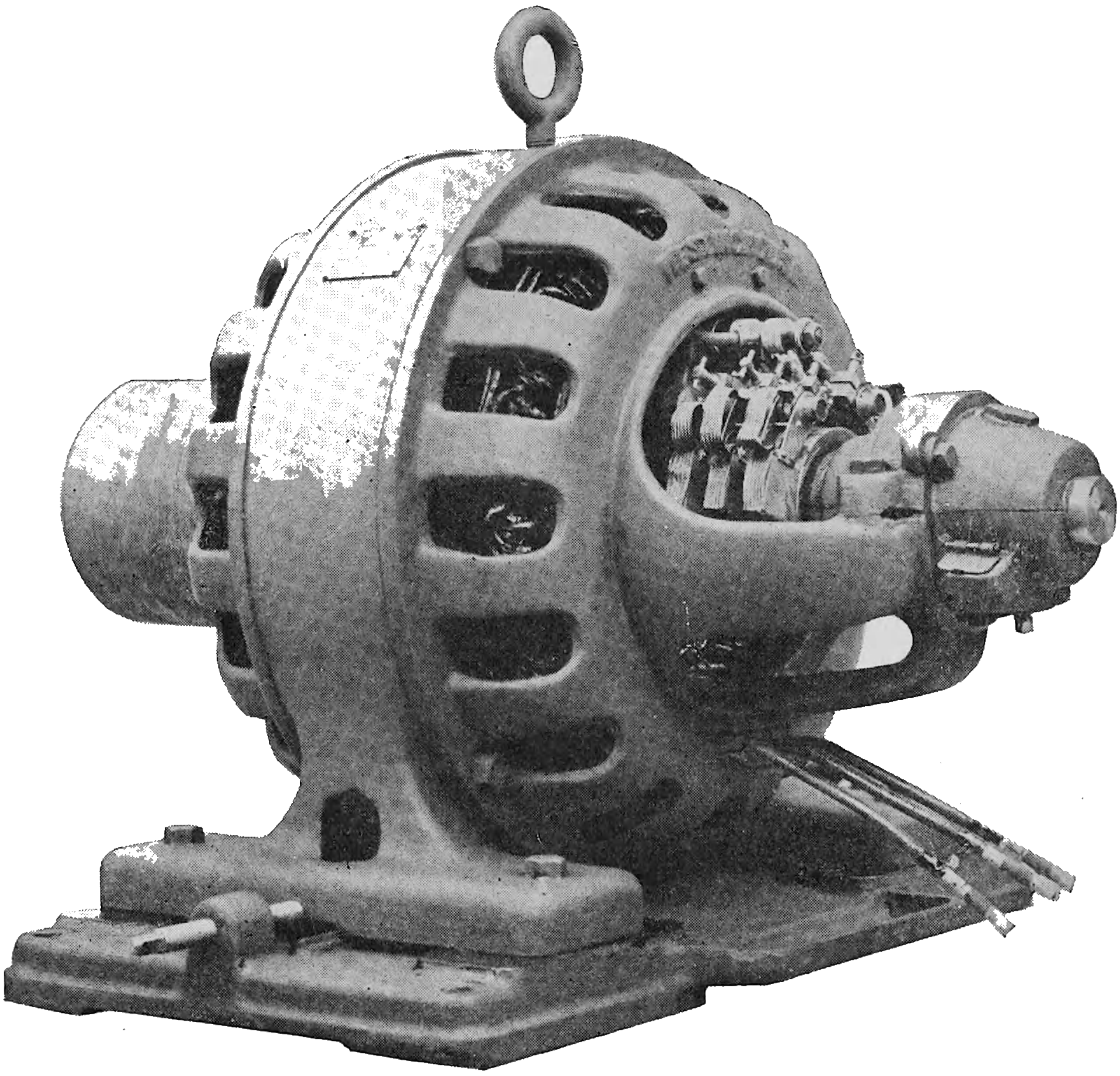


Fig. 206. Type HF Polyphase Induction Motor with Bed Plate
*Courtesy of Westinghouse Electric & Manufacturing Company*

frame is a one-piece cylindrical iron casting. The stator core is built up of sheet-steel laminations, enameled before assembling, clamped between cast-iron end plates, and keyed or dovetailed to lugs cast inside the frame as shown in Fig. 207. The stator windings are form-wound coils of insulated wire or strap. For the lower voltage machines a semi-enclosed insulated slot is used, while for frames for high voltages open slots are employed. The rotor laminations are enameled, assembled on a cast-iron spider, and clamped between

iron end plates; the spider is then pressed on the shaft and keyed. Wherever necessary, the end plates are cast with extensions to support the ends of the rotor coils. The rotor slots are skewed, as shown in Fig. 208, in all except the largest motors. The rotor windings are three-phase, star-connected, and of insulated copper wire or strap placed in partly closed slots. The collector consists of three copper alloy rings assembled on a cast-iron bushing that is pressed on the motor shaft and keyed. One, two, or four carbon brushes per slip ring are used according to the size of the motor. When

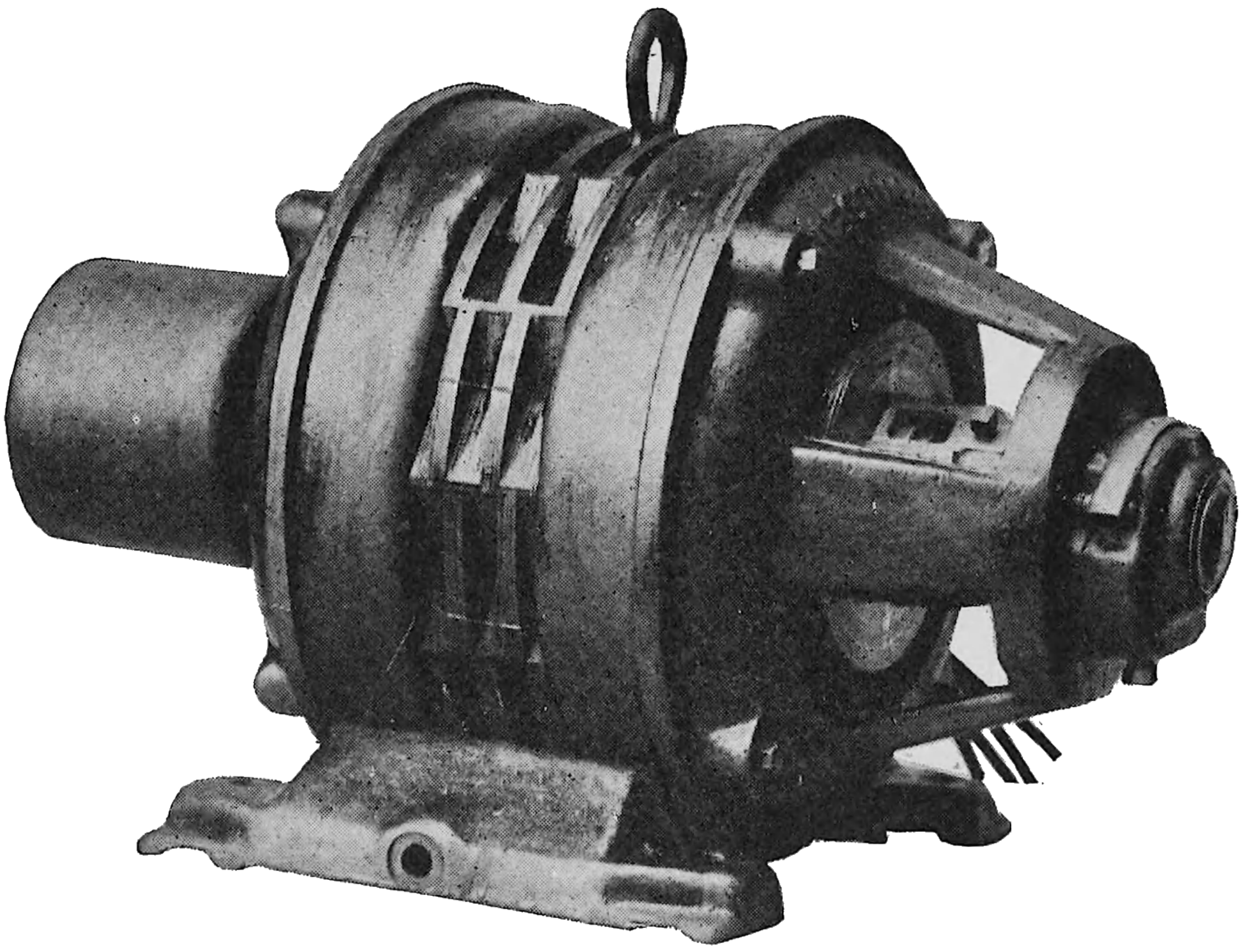


Fig. 209. Westinghouse Type AR Single-Phase Repulsion Motor

called for, motors of 100 h. p. and larger are built with a device for directly short-circuiting the secondary windings shunting the current from the collector rings, brushes, and controller.

*Small Single-Phase Repulsion Type Motors.* The Westinghouse Company also builds smaller single-phase motors of the repulsion starting type. Their type AR motors illustrated in Fig. 209, are built in capacities of 2, 3, 5, 7½, and 10 h. p. for 60 cycles, 110 or 220 volts and synchronous speed of 1200 and 1800 r. p. m. The stator construction is shown by Fig. 210. The primary winding consists of laminations riveted together under pressure, pressed-steel end plates being riveted to the unit thus formed. This construction combines great strength, light weight, and ease of ventilation. The stator coils are thoroughly insulated. The secondary, or rotor, Fig. 211, has laminations with spacers for ventilating ducts riveted between end plates, and the unit thus formed is keyed to the shaft. The coils are made of strap copper and are pushed into the slots from the pulley end. The coils are held in place by fibre wedges and band wires. Each motor is equipped with a centrifugal switch, which short-circuits the rotor windings and releases the brushes. This is

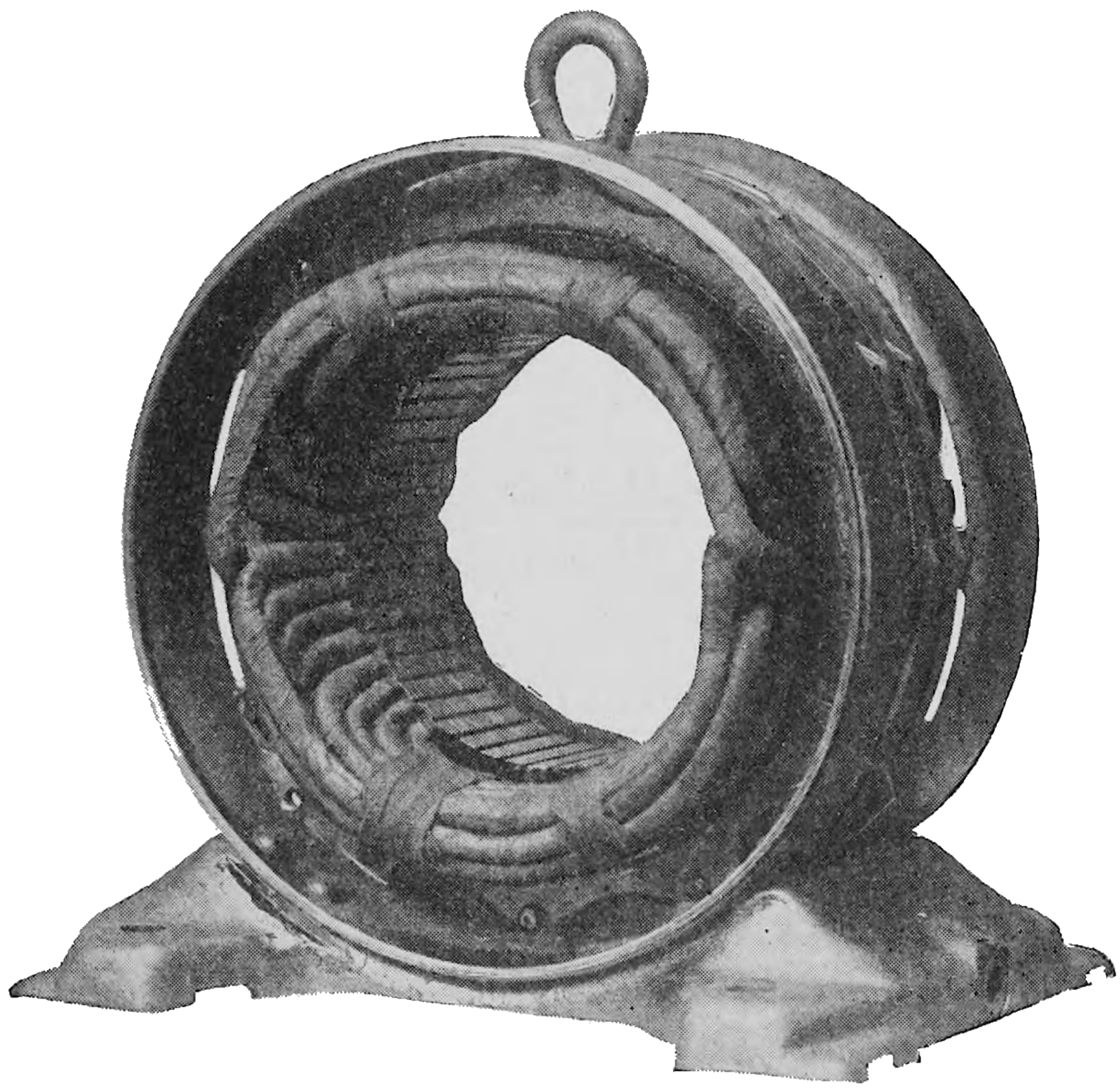


Fig. 210. Stator of Type AR Repulsion Motor

located inside the rotor at the commutator end, and consists of a steel sleeve, a centrifugal governor, and a spring. The sleeve carries a short-circuiting coil which consists of a helical phosphor-bronze spring inside of which is a ring of flexible copper shunts. When the motor is at rest, the short-circuiting sleeve is pressed back into the rotor by the spring. When the motor speeds up, centrifugal force causes the governor weights to move outward, and the sleeve is forced forward. At nearly full speed, the short-circuiting coil is forced under the ends of the commutator bars and into very close contact with them, thus completely short-circuiting them. At the same time the end sleeve presses back the brush springs, and the brushes, being free to move away from the commutator, are pushed back by the end-play of the rotor.

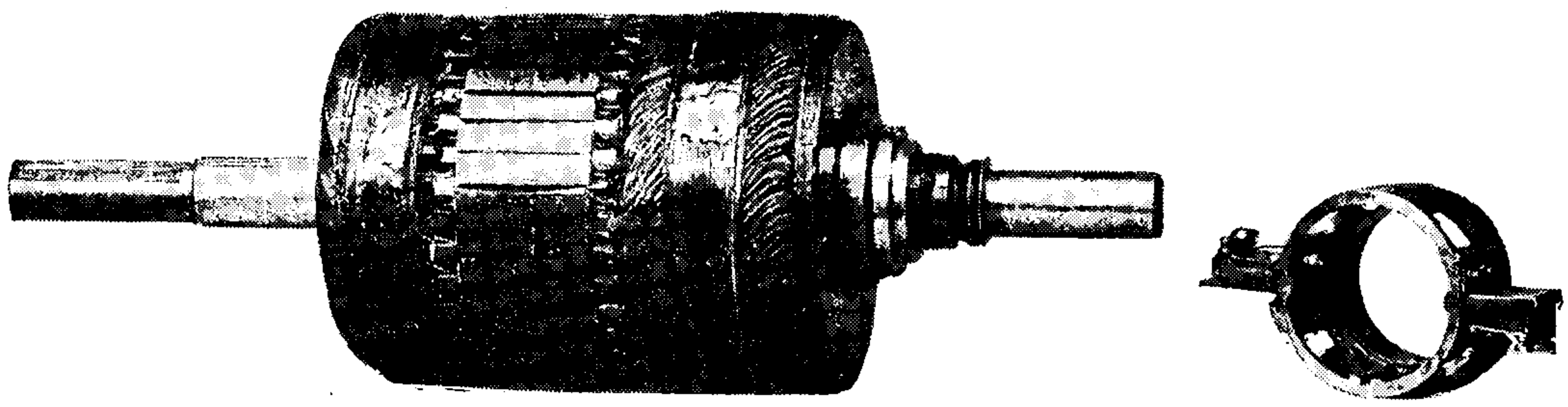


Fig. 211. Rotor of Type AR Repulsion Motor

*Split-Phase-Starting Induction Motors.* A line of small power motors ranging from $\frac{1}{20}$ to $\frac{1}{4}$ h. p. called type DA are built for 110

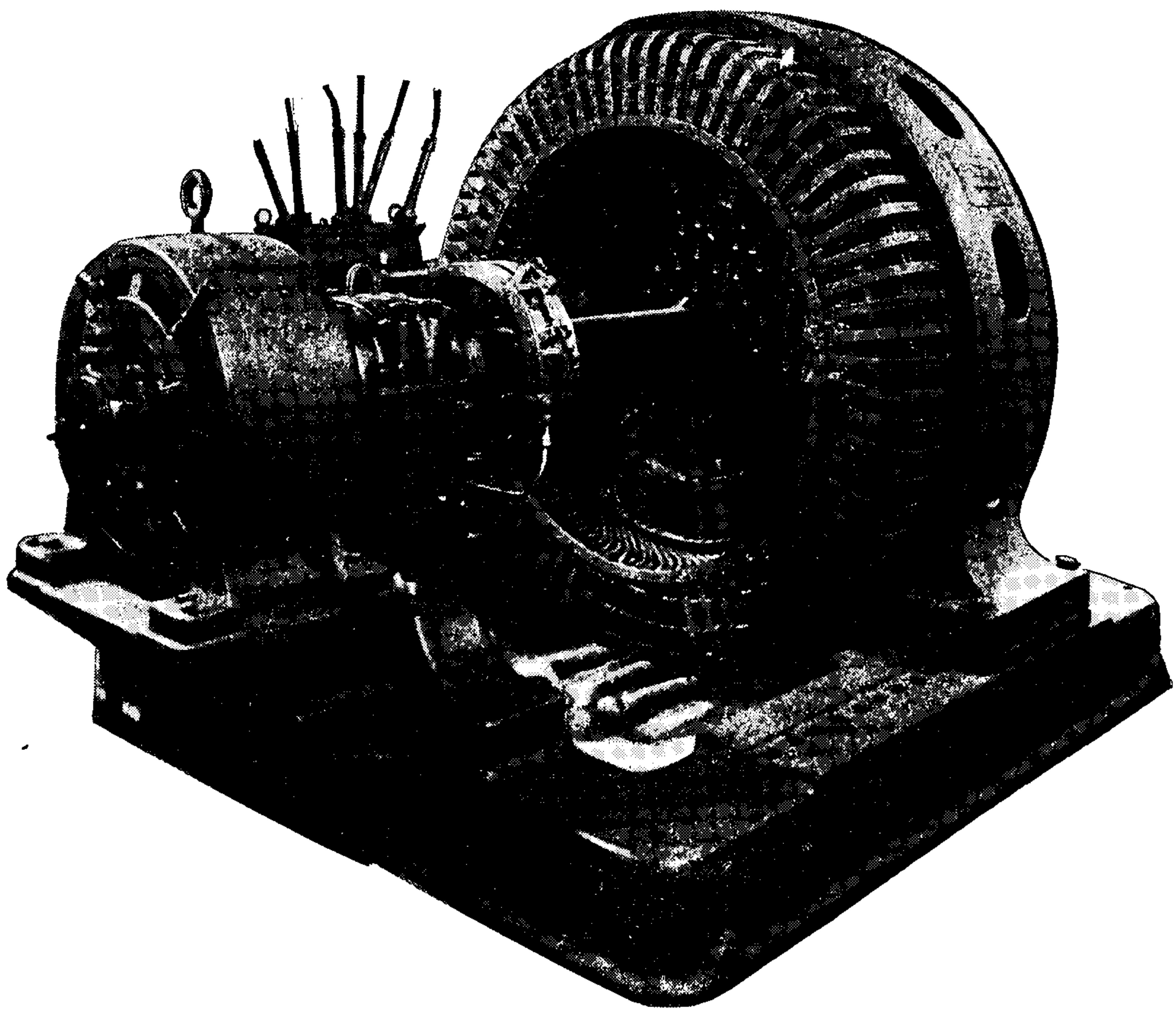


Fig. 212. 600 K. V. A. Self-Starting Synchronous Condenser
*Courtesy of Westinghouse Electric & Manufacturing Company*

and 220 volts. They are single-phase induction motors, starting split-phase and having squirrel-cage armatures. They are furnished

**Compound-Wound Rotary Converter.** Fig. 213 shows a compound-wound rotary converter. Used in connection with external reactances, this type of machine is standard for railway work. The range in voltage obtainable is just about sufficient to take care of the drop in voltage from no load to full load between the generating station and the direct-current side of the rotary converter. This is due to the facts that adjusting the field strength of a rotary converter

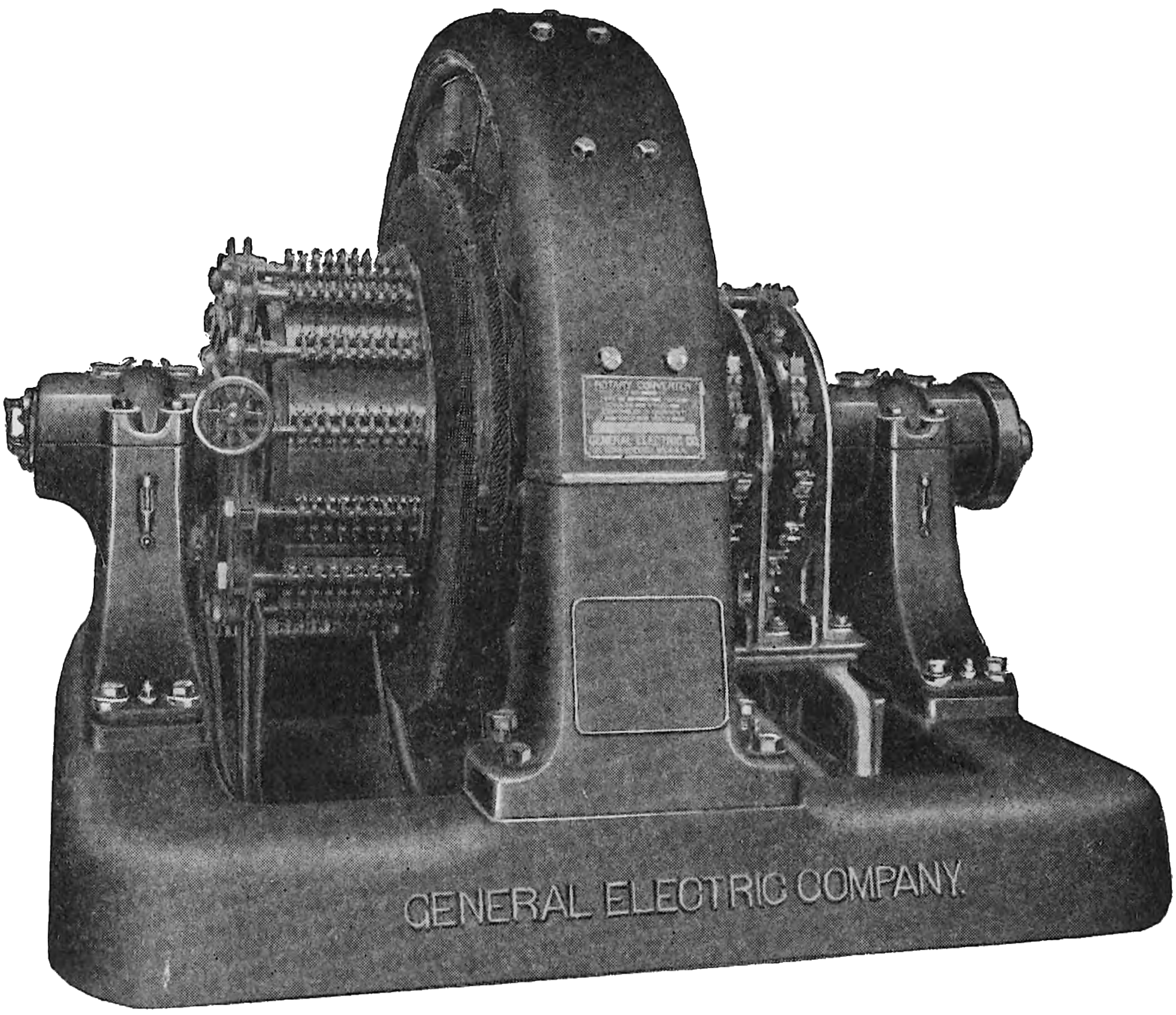



Fig. 213. General Electric 600 Volt Compound-Wound Rotary Converter

changes the phase of the current just as in a synchronous motor, and also that a lagging alternating current passing through an inductive circuit causes a decrease in voltage while a leading current will cause a rise. Therefore, by placing sufficient reactance on the alternating-current side of a rotary converter the voltage at the collector rings can be varied by changing the field strength.

**Regulating Pole Converter.** Fig. 214 shows a General Electric regulating pole rotary converter. In this machine the variation of the voltage ratio is obtained, not by a variation of the impressed alternating voltage, but by varying the distributed flux under the poles, or, as it is usually called, by varying the field form of the converter. The field structure is divided into two parts, a main pole and a regulating pole; and the ratio between the direct and the alternating voltages can be readily varied by varying the excitation of the regulating poles, the only auxiliary apparatus required being a special field rheostat for controlling the exciting current. For

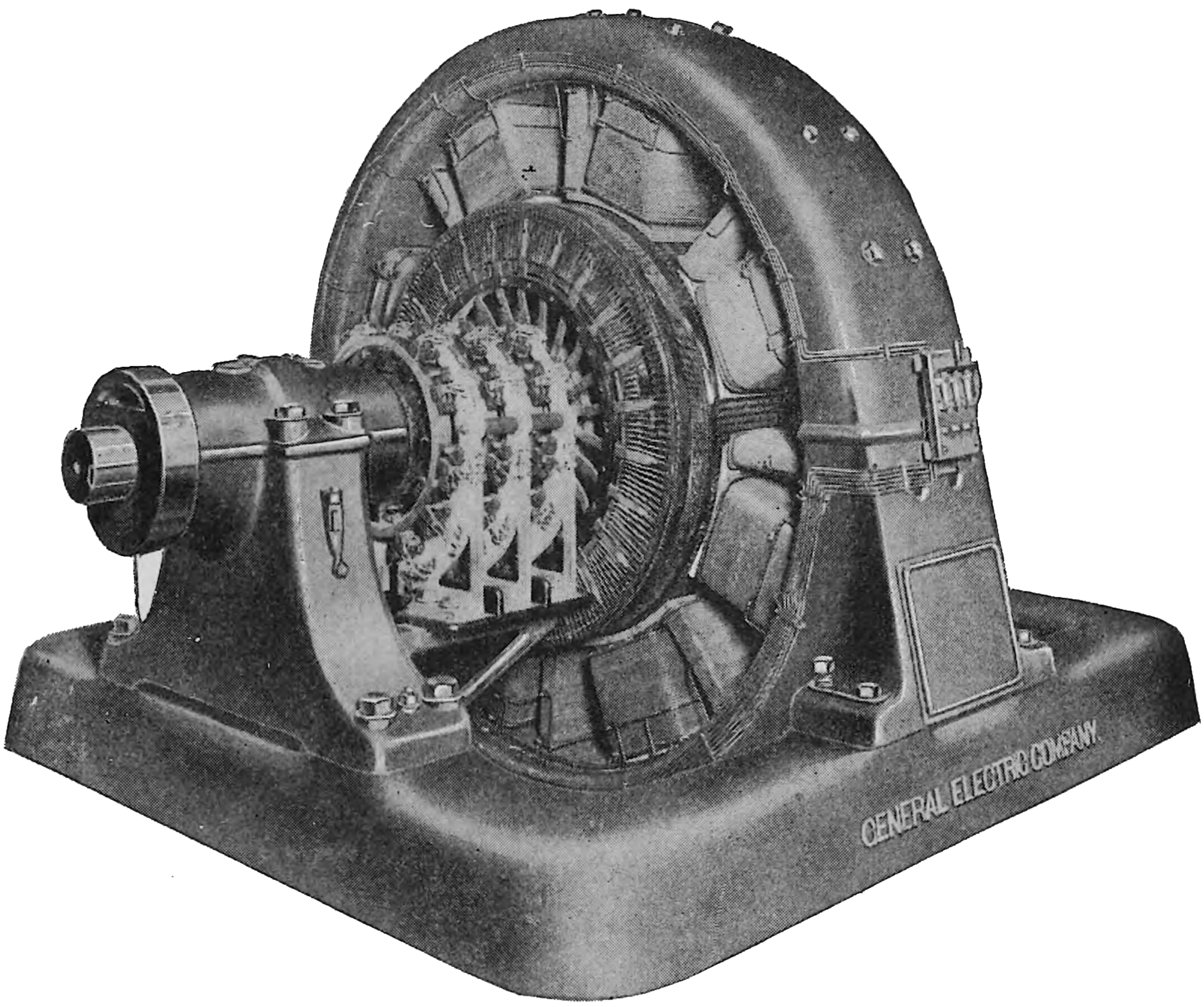



Fig. 214. General Electric Regulating Pole Rotary Converter

normal voltage the main pole only is excited, while in order to raise or lower the direct voltage, the regulating pole is excited so as to assist or oppose the effect of the main pole.

**Shunt-Wound Converter with Synchronous Booster.** Fig. 215 shows a General Electric shunt-wound converter with synchronous booster. This type of converter consists of a shunt-wound converter and an alternator with revolving field mounted on the same shaft as the converter armature. The armature of the alternator, or booster, is stationary and connected electrically in series between the supply circuit and the collector rings of the rotary converter.

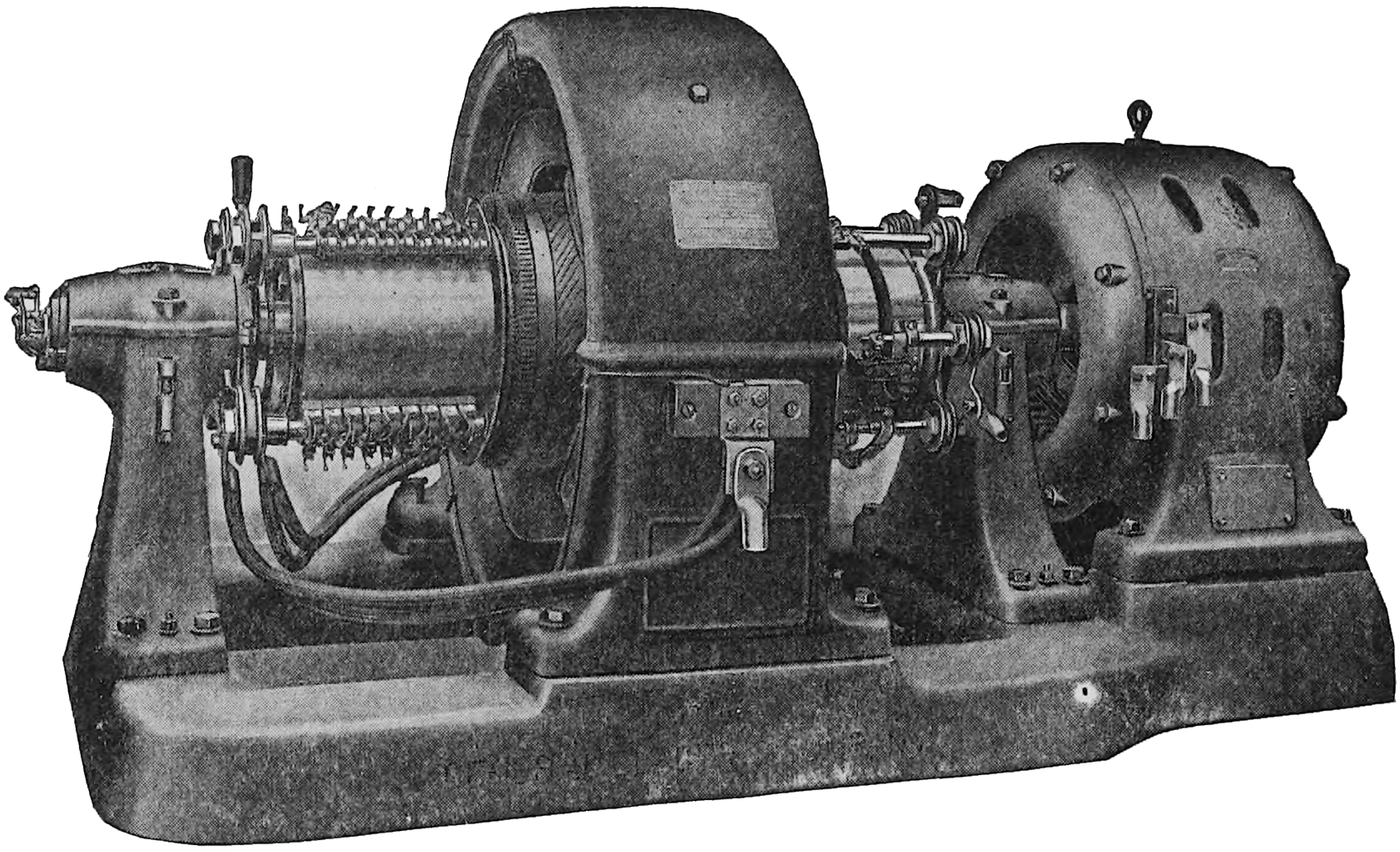


Fig. 215. General Electric Shunt-Wound Rotary Converter with Synchronous Booster

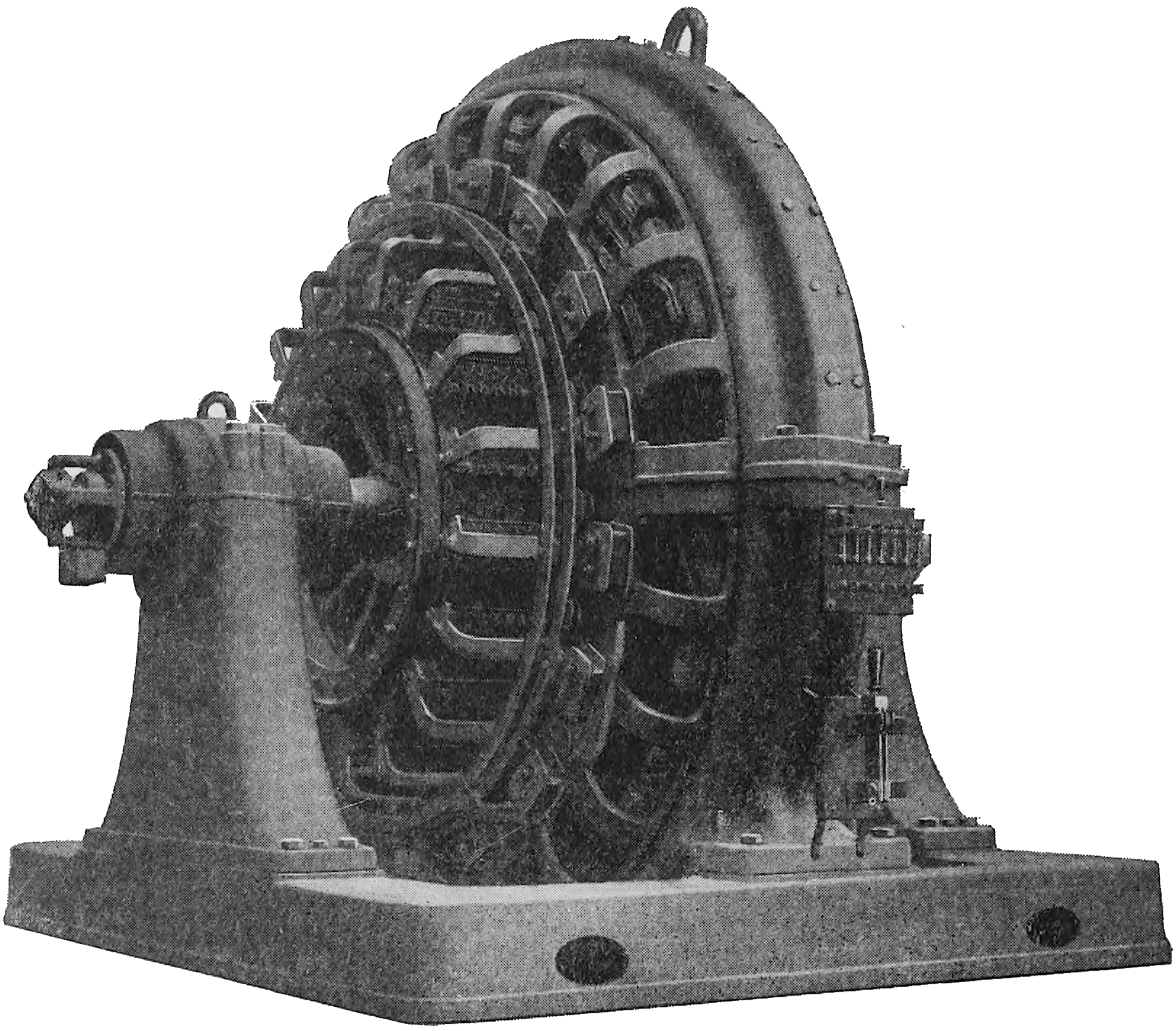


Fig. 216. Westinghouse Rotary Converter Showing Direct-Current End with Oscillator and Speed-Limit Device

limit device. Since a rotary converter will normally take a definite position in its bearings relative to the field, and revolve in a uniform plane without endwise oscillation, some device is necessary to produce a periodic axial movement of the armature shaft, assuring uniform wear of the commutator and the collector rings.

**Converter with Synchronous Regulator.** For the safe operation of rotary converters it is necessary that they be equipped with a device for automatically opening the circuit in case the speed becomes too high. Fig. 217 shows a Westinghouse rotary converter with a synchronous regulator. This company builds the synchronous regulator so that the armature is the revolving part, the armature windings of the regulator generator being connected in series

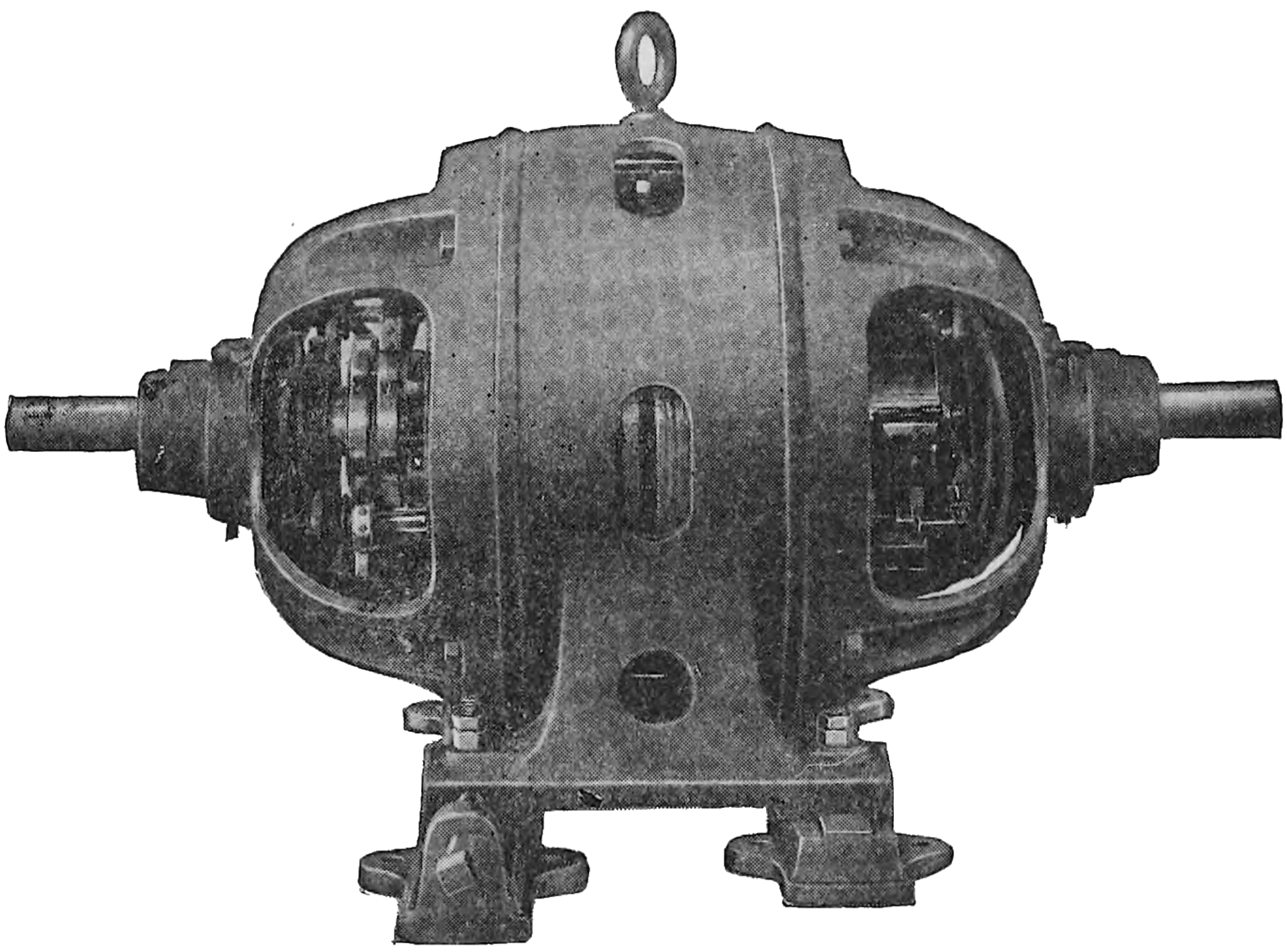


Fig. 219. Wagner Single-Phase Motor Converter

between the armature and the collector rings of the rotary converter. This method of construction is shown clearly in Fig. 218. Fig. 219 shows a single-phase rotary converter brought out by the Wagner Electric Manufacturing Company to be used for battery charging in automobile, telegraph, and telephone work.

## MOTOR GENERATORS

**Comparison with Rotary Converters.** Motor generators, consisting of alternating-current motors and direct-current generators,

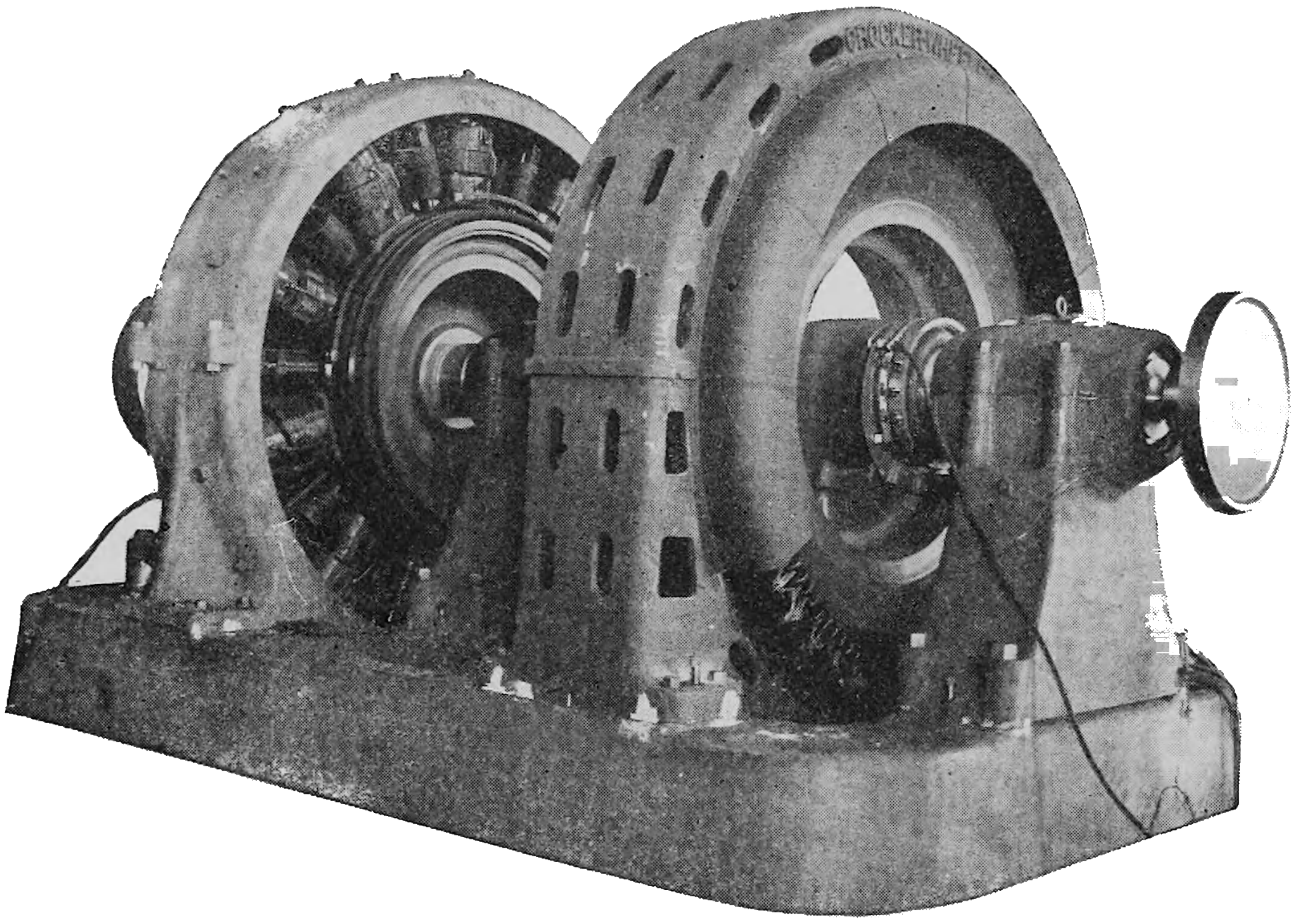


Fig. 220. 1200 KW Synchronous Motor-Generator Set
*Courtesy of Crocker-Wheeler Company*

are used for battery charging, for exciter sets in large alternating-current power stations, for railway sets, and for arc lighting sets. A motor-generator set may have decided advantages over a rotary

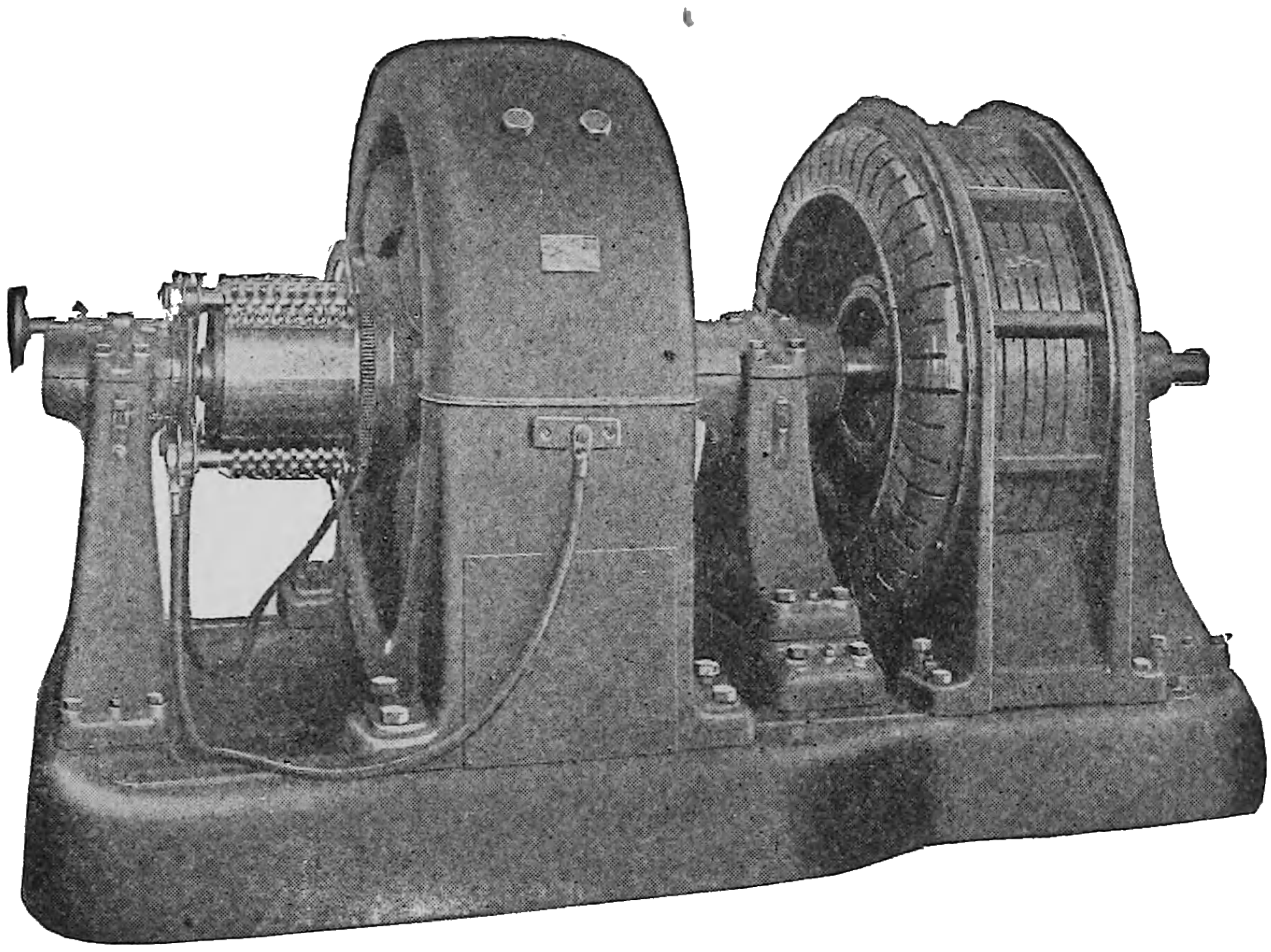


Fig. 221. 2300 Volt GE Synchronous Motor Connected to 550 Volt Generator

converter in special cases, as there is no electrical connection between the two sides of the system, an independent voltage adjustment is

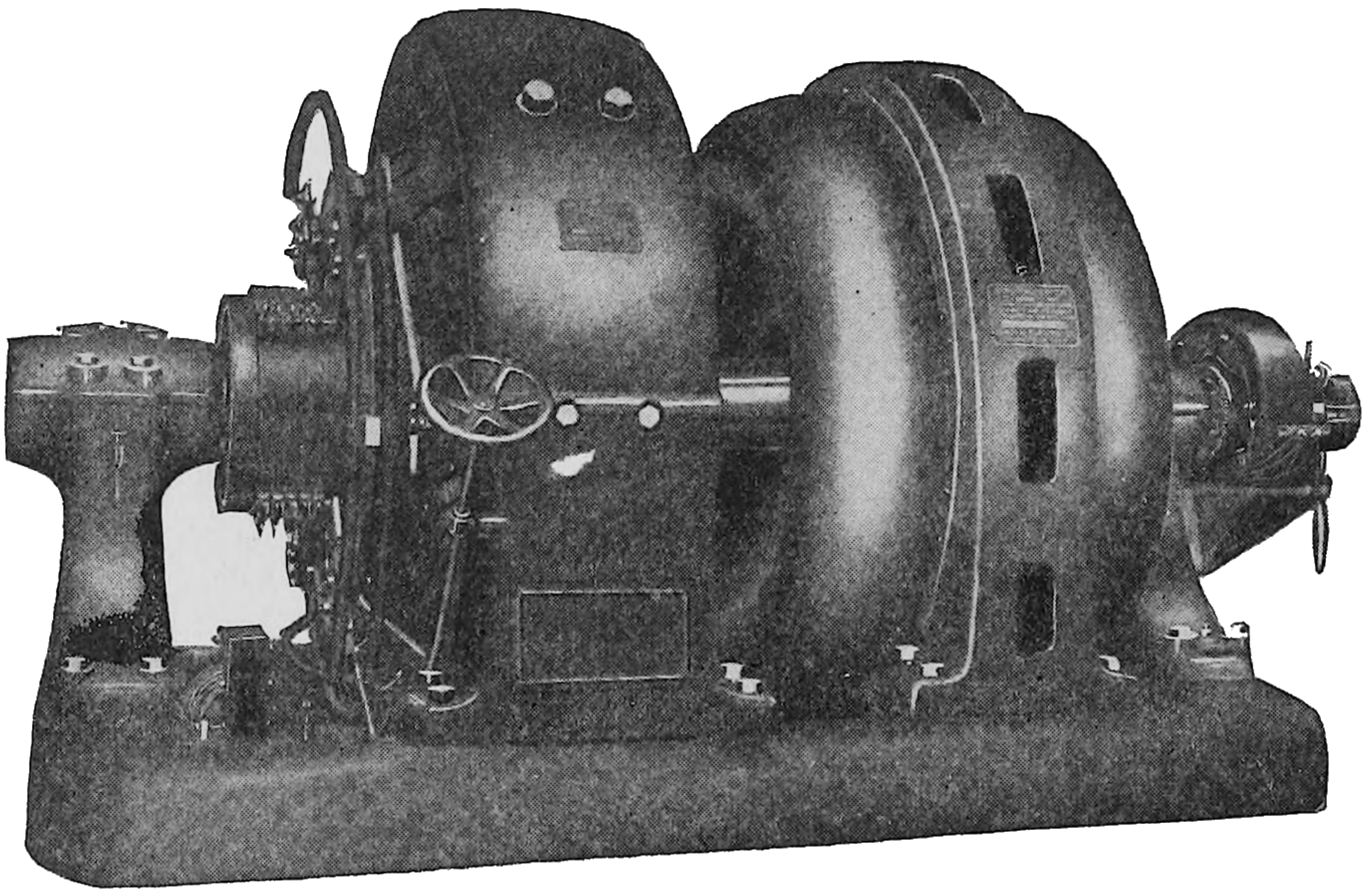


Fig. 222. 13,200 Volt Synchronous Motor Connected to 1575 Volt DC Generator
*Courtesy of General Electric Company*

possible over a wide range, and the regulation is not so greatly affected by fluctuations in the supply circuit. Illustrations of this kind of motor generator are given in Figs. 220, 221, and 222. Fig.

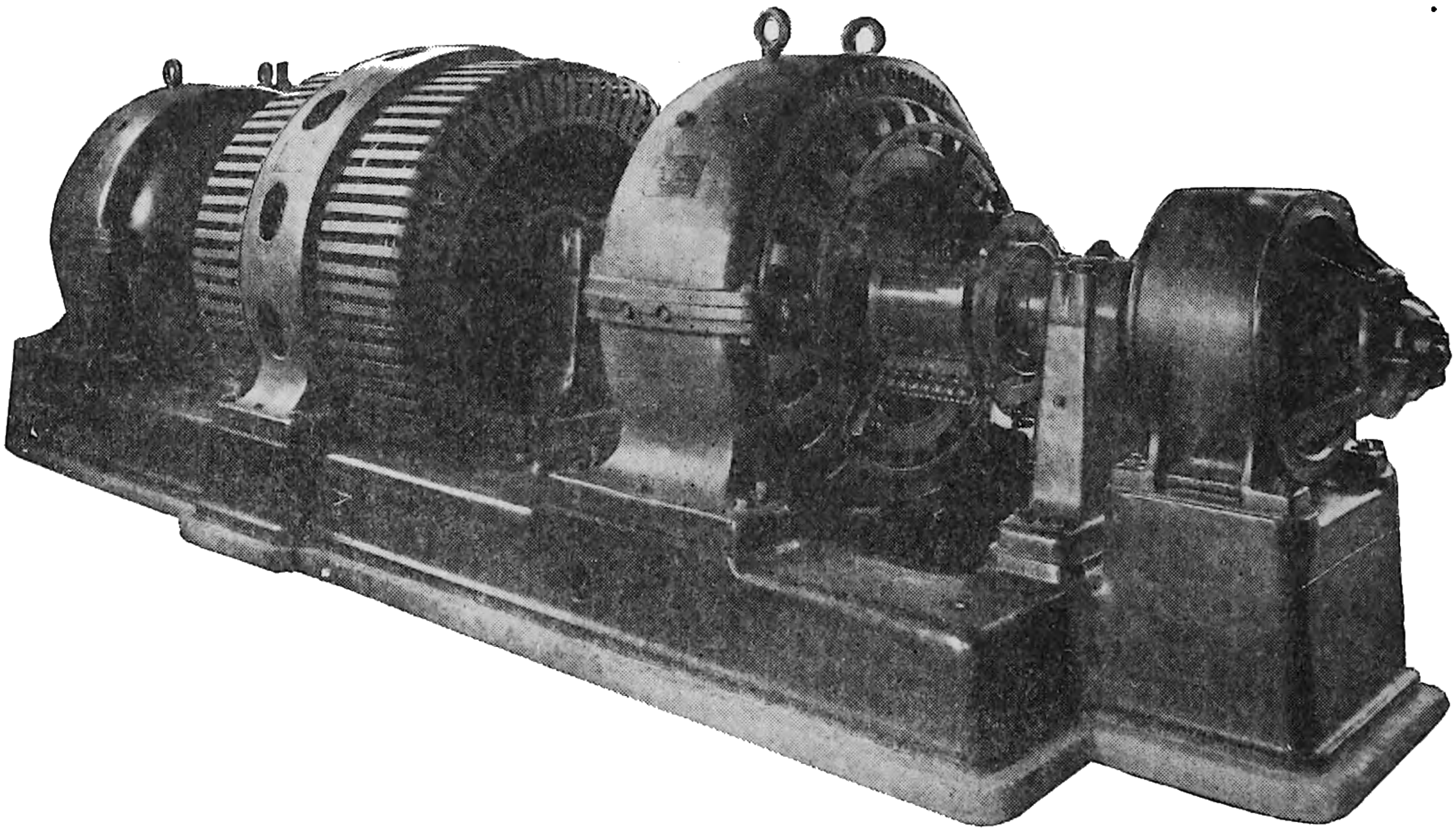


Fig. 223. Low Voltage, 300 KW Direct-Current Motor-Generator Set
*Courtesy of Westinghouse Electric & Manufacturing Company*

223 shows a low-voltage 300 k. w. direct-current motor-generator set, manufactured by the Westinghouse Company.

**Used as Frequency Changers.** When the motor-generator set is composed of two synchronous machines designed to operate at different frequencies it is used as a frequency changer. For large operations in power service and railway service a low frequency has been generally adopted. There are, however, other classes of service, as lighting, for instance, where a higher frequency is desirable. A transformation from one frequency to another is easily effected by means of a motor-generator set made up of two alternating-current machines. The generator may be wound for any practical voltage, phase, and frequency, and the motor designed to operate from any commercial circuit. Figs. 224 and 225 illustrate examples of frequency changers.

# REVIEW QUESTIONS

14. How may the effect of eddy-currents be reduced?

15. If a conductor is cutting magnetic lines, what relation exists between the voltage generated and the magnetism?

16. Assuming a conductor moves in a magnetic field at a rate such that it cuts 2,000,000 lines of force in .01 of a second, what is the voltage thus generated?

17. If a conductor is moved upwards through a magnetic field the lines of which pass from left to right, what is the direction in which current would flow if the circuit were closed?

18. Describe the generation of an e. m. f. as a coil revolves in a magnetic field, and show by diagram the character of this generated pressure.

19. What is a dynamo?

20. Name the main parts of a generator, and mention briefly the function of each part.

21. Show by sketch how the wire is wound on a ring armature.

22. What is meant by the expression *drum armature?* Show how the inductors are placed upon it, and state how it differs from the ring-wound armature.

23. Which of the above types is more extensively employed to-day, and why?

24. What do you mean by a *magneto-machine?*

25. Why is the use of a magneto-machine limited to such service as requires only very small amounts of power?

26. What do you mean by the term *separately-excited* generator? Give diagram of its connections and windings.

27. What do you mean by *self-excited* generator?

28. What are the various types of self-excited generators? Show by diagram how they are wound.

29. Describe the various methods of regulating the voltage of a dynamo.

30. What does the curve of potential around the commutator of a dynamo-electric machine show?

31. What do you understand the term *armature reaction* to mean, and how is its presence indicated?

32. What produces the cross-magnetizing effect of an armature winding, and how does this affect the flux distribution around the armature core?

# REVIEW QUESTIONS

## ON THE SUBJECT OF

## DIRECT-CURRENT DYNAMOS

## PART II

## CALCULATIONS

1. Upon what factors does the generated voltage of a dynamo depend?

2. Combine these various factors into an equation, and apply it in determining the voltage generated by a generator the armature of which is parallel-wound with 1,176 inductors, and which revolves in a 4-pole field at 1,200 r. p. m. Assume the flux entering or leaving the armature per pole to be 1,700,000 lines of force.

3. If the armature of a 10-pole generator is series-wound with 1,400 inductors, revolves at the rate of 400 r. p. m., and generates 150 volts, what is the flux entering or leaving the armature per pole?

4. What do you mean by the expression *efficiency of a generator?*

5. What is the difference between the terminal volts and generated volts of a generator?

6. An armature has an internal resistance of .05 ohm; it carries a current of 500 amperes; and the terminal voltage is 170. What is the generated pressure?

7. What are the objections to the general use of bipolar machines?

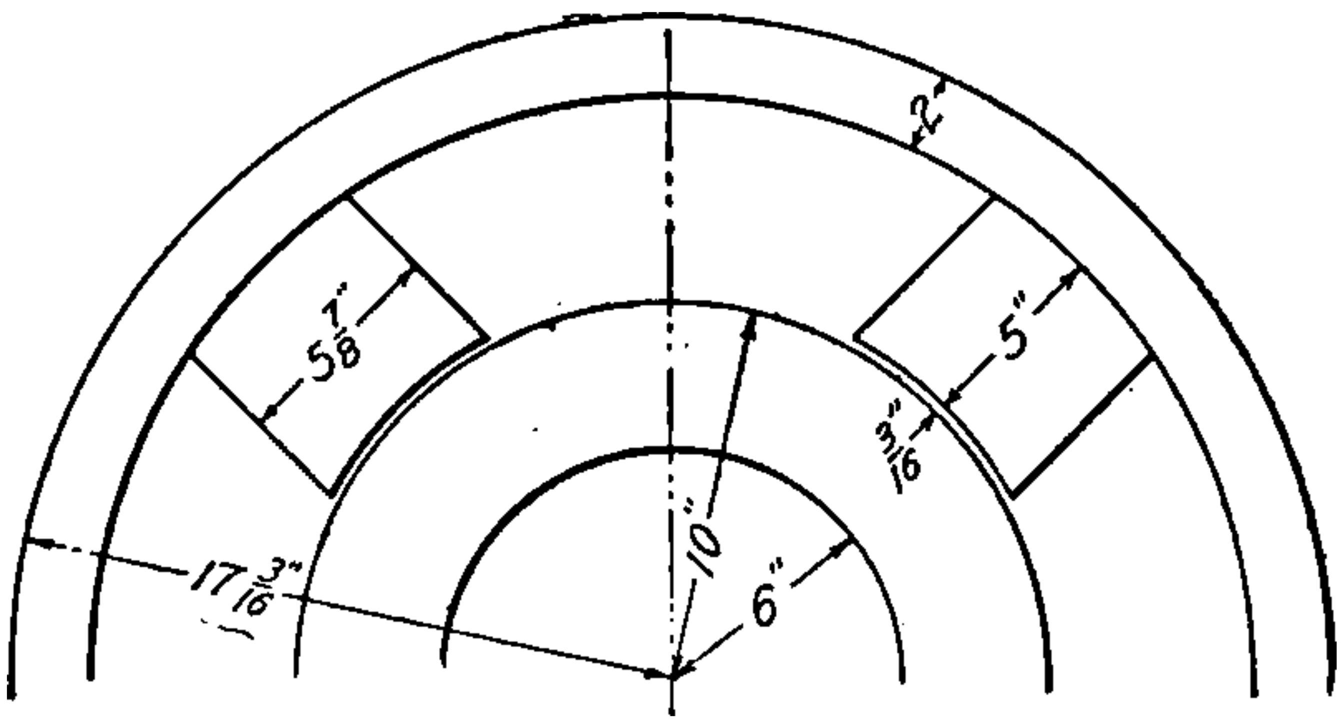
8. What are the advantages of "over-type" bipolar machines with respect to the "under-type"?

9. What are the general advantages of multipolar ring types of frames with respect to bipolar forms?

10. What is the meaning of the expression *magnetic leakage,* and how must we correct for it?

11. How does the magnetic flux divide in passing through the various parts of a multipolar machine?

12. Being given the magnetic circuit shown in the accompanying diagram, determine the number of ampere-turns required per pole to cause a flux of 1,800,000 lines of force to enter or to leave the armature per pole. Coefficient of magnetic leakage = 1.15. The armature is to have 49 slots, and teeth of equal top dimensions, while the slots are parallel-sided and $1\frac{1}{2}$ inches deep. The field-frame and pole-cores are of cast steel, and the armature cores of laminated iron, the effective length of which is 90 per cent. Length of yoke parallel to shaft is 8 inches, while length of armature core is $5\frac{7}{8}$ inches.



13. If the machine of Question 12 is to generate 220 volts, is shunt-wound, and has a field-current of 1.5 amperes, determine the number of turns, size, and amount of wire employed per pole. Assume 20 volts allowed for field rheostat, and coil to be $3\frac{1}{2}$ inches long.

14. What do you understand the terms *open* and *closed-coil* armature windings to mean? Which is it that is employed on constant-potential machines?

15. What is the relation existing between the number of armature coils and the number of commutator bars in the case of Gramme ring and drum-wound armatures?

16. What do you mean by *winding pitch?*

17. Show diagrammatically what you mean by a *wave-wound* drum armature.

18. Show diagrammatically what you mean by a *lap-wound* drum armature.

19. Assume a four-pole machine, upon the armature of which you wish to wind a single-layer wave winding of 24 inductors; how would you proceed to do this? Give winding table.

20. Assume a four-pole machine as above, and wind a lap winding of 24 inductors upon this. Give winding table.

21. What are the relative advantages of wave-wound and lap-wound armatures?

13. What is the most satisfactory insulation material to use between commutator bars, and what special features must it then possess?

14. What are the different types of brush-holders? Describe each and compare them.

15. What properties must a successful brush-holder possess?

16. What features most be considered in determining the number of field-poles to be employed in a contemplated design?

17. What factors must be taken account of in determining the armature dimensions of a proposed design?

18. What actions and reactions must be allowed for in determining the length of the air gap in the magnetic circuit of a dynamo?

19. How could you determine from the data of a given machine, whether it would be likely or not likely to spark at the brushes?

20. How could you determine the efficiency of a dynamo directly from the designing-room data?

21. About what is the proper current-density to allow for carbon brushes?

22. What happens in the case of a dynamo if the brushes are not given sufficient lead?

23. What would happen if the brushes are given too great a lead?

# REVIEW QUESTIONS

ON THE SUBJECT OF

# TYPES OF GENERATORS AND MOTORS

## PART I

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1. Define dynamo-electric machinery.
2. What are the most important subdivisions of dynamo-electric machinery?
3. In what combinations are direct-current generators manufactured?
4. In what different ways are steam or gas-driven engine generators arranged?
5. What shaft arrangements have water-wheel-driven generators in sizes from about 100 to 10000 kw. capacity?
6. Describe a pulley on a belt-driven generator on a 150-kw. generator.
7. Is a steam turbine ever belted to a generator?
8. In what cases is gearing used for driving generators?
9. What is the best present practice for driving generators?
10. What are the advantages and the disadvantages of direct-driven generators?
11. What should be the distance between the centers of the engine and generator shaft in belt-driven generators?
12. Is there any difference in driving generators or motors?
13. What subdivisions may be made for direct-current machinery?
14. How are generators of sizes above 200 kw. commonly driven?
15. What is the speed of direct-current generators of larger sizes?
16. What is, in general, the relation between the kw. capacity and the speed?

# REVIEW QUESTIONS

ON THE SUBJECT OF

# TYPES OF GENERATORS AND MOTORS

## PART II

1. Give the general classification of alternating-current dynamo electric machinery.
2. What are the standard frequencies of alternators?
3. What are the speed limits of belted alternators; of turbo-alternators?
4. Into what types are alternators divided?
5. Describe the method of ventilation in a Crocker-Wheeler turboalternator.
6. Give a description of the rotor construction of a Westinghouse water-wheel-driven alternator.
7. How are alternating-current motors classified?
8. Give the characteristics of a polyphase induction motor.
9. What is a compensated repulsion motor?
10. State the differences between the AN and ANY type of Allis-Chalmers motors.
11. Describe the single-phase induction motors of the Century Electric Company.
12. Describe and sketch the magnetic bridge as used in the polyphase induction motors of the Crocker-Wheeler Company.
13. Upon what principle does the starting of the single-phase induction motors of the Emerson Electric Manufacturing Company depend?
14. State the differences in Forms K, L, and M of the General Electric Company's polyphase induction motors.
15. Give a description of the performance of a compensated repulsion induction motor of the General Electric Company.

# INDEX

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