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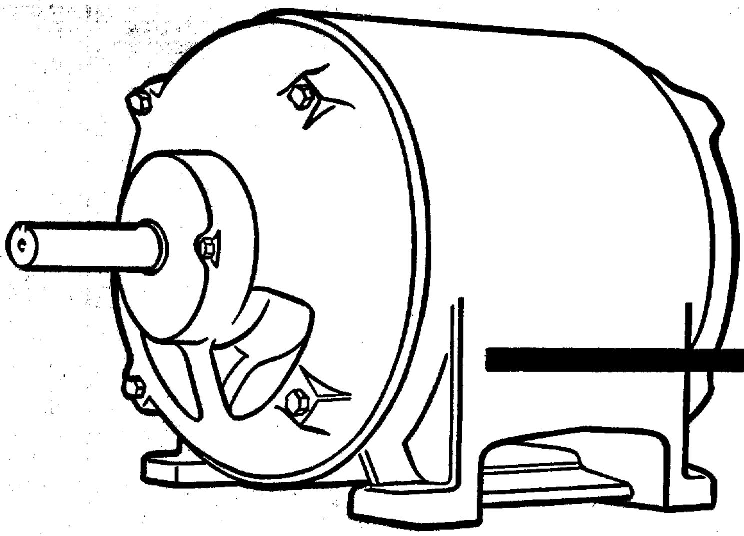
ALLIS-CHALMERS
MOTOR and GENERATOR Reference Book



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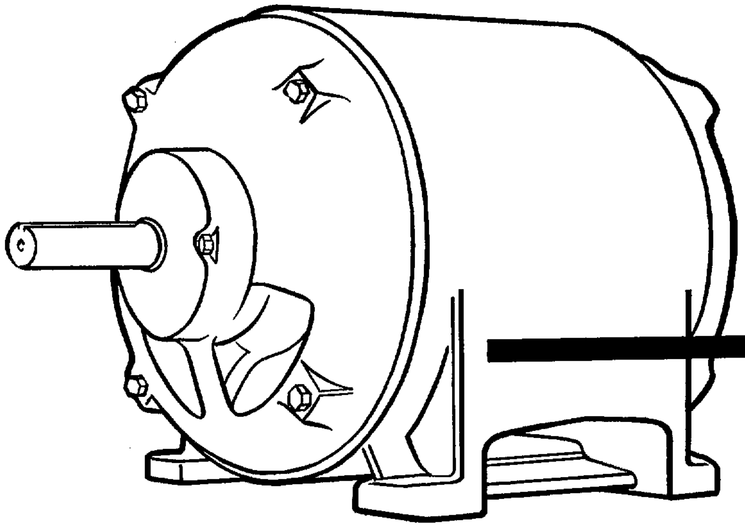


This Allis-Chalmers Motor and Generator Reference Book is reprinted from the complete Electrical Reference Book published by the Electrical Modernization Bureau and edited by Mr. E. S. Lincoln. Allis-Chalmers sponsored this section of the book and furnished all of the text and illustrations for the part on integral horsepower motors and generators.

This is not intended to be a text book on the broad field of motors and generators. It is rather a brief outline of information that we believe will assist in the selection of motive power to handle most industrial applications.

For specific information on any of the equipment described in these pages we suggest that you get in touch with the Allis-Chalmers sales office nearest you. A complete list is given at the end of the book.

The complete Electrical Reference book of over 1700 pages covers the entire field of industrial electric operations from service entrance equipment to power distribution and utilization. It can be obtained for $18.75 each from The Electrical Modernization Bureau, Inc., 124 Mamaroneck Ave., White Plains, N. Y.

MOTORS AND GENERATORS

INTRODUCTION

One of the most important functions of electricity is the production of mechanical power for industrial plants through the medium of electric motors. The millions of horsepower provided by electric motors have done much to make our modern standard of living possible.

Motors, like all electrical equipment, have been developed to the point where they provide outstanding reliability and flexibility if they are properly applied.

Basically, a motor is simply a means of producing mechanical power from electricity through change in the direction of a magnetic field. In ac motors, this change is produced by the current itself, while in dc motors, the change is produced by a commutator, which acts as a switch to maintain the proper relationship between the magnetism of the armature and field. In other words, both ac and dc motors operate on the principle of magnetic induction, attraction and repulsion, and differ only in the method by which magnetic action is applied.

This same principle and distinction also applies to generators. Electricity can be generated commercially only from motion produced by a prime mover.

STANDARDIZATION

The National Electrical Manufacturers Association, in cooperation with other organizations, such as the AIEE and ASA, has done much toward developing standards for motors and generators. The standards define products, processes and procedures with reference to nomenclature, composition, construction, dimensions, tolerances, safety, performance, quality, rating, testing, and service.

While conformance to the standards is not compulsory, most manufacturers generally adhere to them. Hence the difference between products of various manufacturers is in the means by which the applicable standards are met. This is one of the main reasons why manufacturers' descriptive literature emphasizes particular features of construction as the best means of simplifying comparison of different makes.

Standardization benefits both the manufacturer and the purchaser. The standards are designed to eliminate misunderstanding between the manufacturer and purchaser and to assist the purchaser in selecting and obtaining the product for his particular need. Selection would be extremely difficult if every manufacturer proceeded on his own entirely independent way. In addition, the standards help promote production economies, which benefit both manufacturer and purchaser.

MOTORS—GENERAL INFORMATION

Today, industry is more dependent than ever on uninterrupted operation of electric motors in successive production steps. At the same time, the motors are subjected to increasingly severe operating conditions. In many modern plants, processing has become an integral part of the production line, and the electrical equipment may have to operate successfully in the presence of corrosive and explosive fumes, conducting and abrasive dusts, steam, vapor, or dripping or splashing liquids.

The insulation used on standard motors is suitable for most applications—even where moderate amounts of moisture, weak acids or alkalies, non-conducting abrasive dusts, oil, and so forth are present. But for unusually severe conditions, special insulation or enclosing features, or both, may be needed to give the motor a normal operating life.

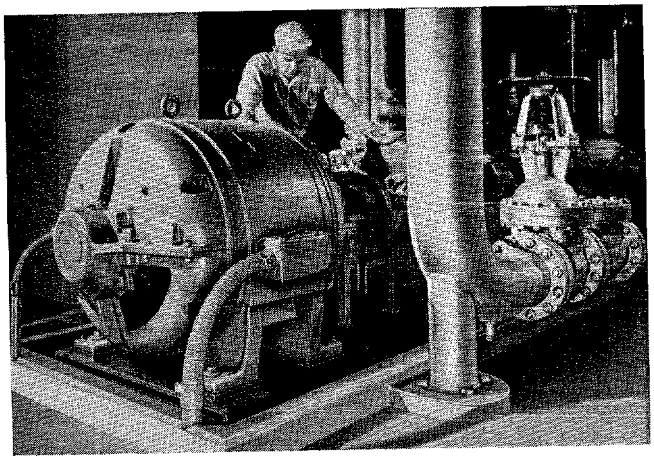


Fig. H-1. Squirrel-cage induction motor rated 250-hp, 1170-rpm, driving power-plant condensate pump.

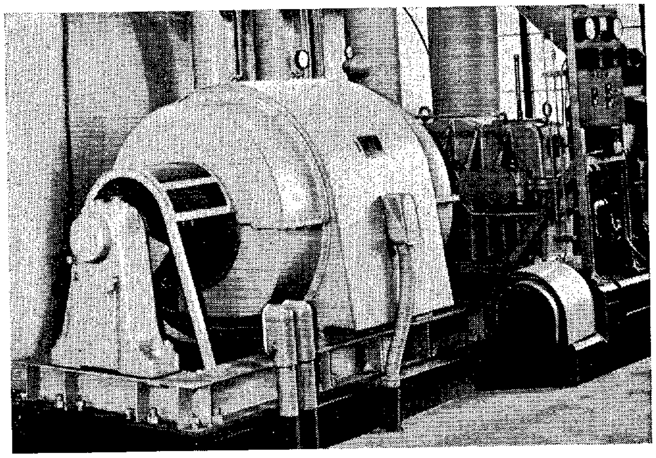


Fig. H-2. Centrifugal compressor for brine-cooling installation is driven by 1250-hp wound-rotor motor.

HORSEPOWER RATINGS

Motor manufacturers, under the auspices of NEMA, have agreed on certain rating standards based on definite operating conditions, such as voltage, frequency, speed, ambient temperature, etc. Standard horsepower ratings are given under the various motor divisions which follow.

Open-type general-purpose motors are guaranteed to develop their rated horsepower continuously without a temperature increase of more than 40 C above a normal ambient or room temperature of 40 C. Where enclosures are used, motors generally operate at higher temperatures because of ventilating restrictions. Such motors have temperature ratings of 50, 55, 70, or 75 C, depending upon the type of enclosure and insulation.

Open-type general-purpose motors, when operated at rated voltage (and frequency in the case of ac motors), will carry continuously 1.15 times their rated load without injurious temperature rise. This is known as their service factor. (Alternating-current motors smaller than three hp have slightly larger service factors.) There may be slight differences in efficiency and power factor from those at rated load.

For maximum efficiency, a motor that will operate as near full load as possible should be selected. In most cases, the manufacturer of the machine to be driven by the motor can give the power requirements. If definite information is not available, the best method of obtaining the power requirements of a given application is by actual test, using a spare or rented motor.

EFFICIENCY

The efficiency of a motor is the ratio of its output (or its input minus all losses that take place in the motor) divided by its input expressed in the same terms.

Efficiency varies with the load placed on the motor; it is usually highest when the motor is fully loaded and decreases as the load decreases. Efficiency is also affected by variations of voltage and frequency.

Large motors are more efficient than small motors. For the same horsepower ratings, high-speed motors are more efficient than low-speed motors because high-speed motors have lower losses since less material is required in their construction. Except for the larger sizes, high-voltage motors (2300 volts and over) are less efficient than low-voltage motors of the same ratings, due to the greater space required for insulating the windings.

SPEED CHARACTERISTICS

Except for synchronous motors, speeds of motors vary somewhat with their loads. This variation in speed is termed *speed regulation* and is expressed in percent of full-load speed. For a normal speed of 1750 rpm a variation of 10 percent below normal would mean a loss of 175 rpm, resulting in a running speed of 1575 rpm.

Direct-current motor speeds depend upon the voltage of the circuit on which they operate and may be increased or decreased by varying the supply voltage. Alternating-current motor speeds, however, depend upon the frequency of the circuit and cannot be increased except by increasing the frequency of the circuit.

Synchronous speeds for different ac frequencies are given in Table 1. These speeds apply directly to synchronous motors. Induction motors operate at slightly lower speeds due to the *slip* which is inherent in their design.

Speed limitations recommended by NEMA for motors using belt, gear and chain drives are given by Table 2.

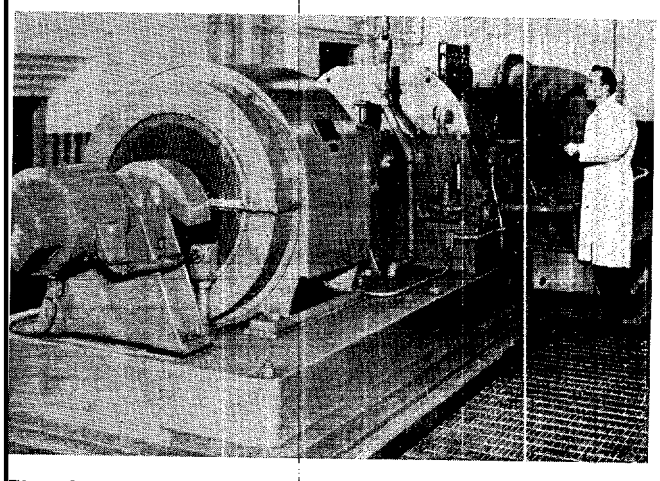


Fig. H-3. This centrifugal blower is driven by a 1750-hp synchronous motor with overhung exciter.

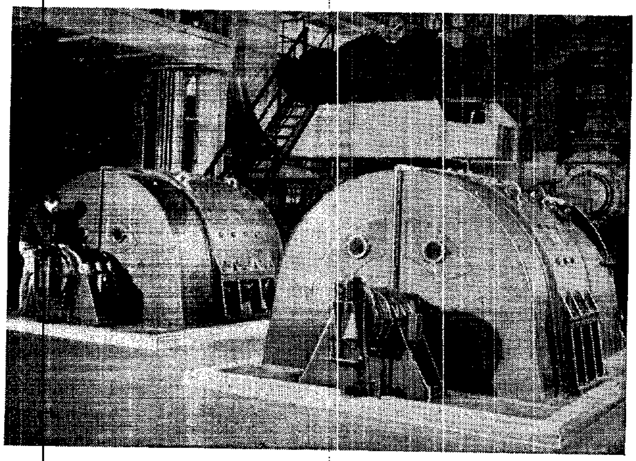


Fig. H-4. These 3000 and 2500-hp direct-current motors are used in an aluminum cold rolling mill.

TABLE 1—SYNCHRONOUS SPEEDS—AC GENERATORS AND MOTORS

$$\text{Frequency} = \frac{\text{Poles} \times \text{Rpm}}{120}$$

Number of Poles (Generator or Motor)	Revolutions per Minute When Frequency Is 25 Cycles	50 Cycles	60 Cycles
2	1500	3000	3600
4	750	1500	1800
6	500	1000	1200
8	375	750	900
10	300	600	720
12	250	500	600
14	214	429	514
16	188	375	450
18	167	333	400
20	150	300	360
22	136	273	327
24	125	250	300
26	115	231	277
28	107	214	257
30	100	200	240
32	94	188	225
36	83	167	200
40	75	150	180
44	—	136	164
48	—	125	150
52	—	115	138
56	—	107	129
60	—	100	120
66	—	91	109
72	—	83	100
76	—	79	95
80	—	—	90
84	—	—	86
90	—	—	80

MOTOR TORQUES

One of the principal factors in the selection of the proper motor is the torque required by the driven machine from starting to shutdown. Following are the NEMA definitions of the torques that must be considered:

The *full-load torque* of a motor is the torque necessary to produce its rated horsepower at full-load speed. In pounds at one foot radius it is equal to the horsepower times 5250 divided by the full-load speed.

The *locked-rotor* (*static*) *torque* of a motor is the minimum torque which it will develop at rest for all angular positions of the rotor, with rated voltage applied at rated frequency.

The *pull-up torque* of an ac motor is the minimum external torque developed by the motor during the period of acceleration from rest to the speed at which breakdown torque occurs. For motors which do not have a definite breakdown torque, the pull-up torque is the minimum torque developed up to rated speed.

The *breakdown torque* of an ac motor is the maximum torque which it will develop with rated voltage applied at rated frequency, without an abrupt drop in speed.

The *pull-out torque* of a synchronous motor is the maximum sustained torque which the motor will develop at synchronous speed for one minute, with

TABLE 2—SPEED LIMITATIONS—BELT, GEAR AND CHAIN DRIVES

This table, based on NEMA definitions, represents good practice (under normal operating conditions) for the use of these drives on motors and generators which are not provided with outboard bearings.

Full-Load Rpm of Motor or Generator Above	Including	Maximum Hp Rating of Motor	Maximum Kw Rating of Generator
Flat-Belt Drive (1)			
2400	3600	20	15
1800	2400	30	20
1200	1800	40	30
900	1200	75	50
750	900	125	75
720	750	150	100
560	720	200	150
V-Belt Drive (2)			
2400	3600	20	15
1800	2400	40	30
1200	1800	75	50
900	1200	125	75
750	900	200	100
720	750	250	150
560	720	300	200
Gear Drive (3) (4)			
1500	1800	7½	5
1200	1500	15	10
900	1200	25	15
750	900	50	30
560	750	75	50
Chain Drive (5)			
2400	3600	20	15
1800	2400	40	30
1200	1800	75	40
900	1200	125	75
750	900	200	125
720	750	250	150
560	720	300	200

(1) See NEMA MG1-3.13 for dimensions of standard pulleys and for limiting dimensions of pulleys.

(2) Limiting dimensions of V-belt sheaves for general-purpose motors in frames 505 and smaller are given in NEMA MG1-3.15. Limiting dimensions for V-belt sheaves for motors in frames larger than 505 have not been standardized; they are specified by the motor manufacturer.

(3) These values are based on the use of steel pinions.

(4) In general, for quiet operation and freedom from severe vibration, the peripheral speed of cut-steel gearing at the pitch diameter should not exceed 1400 feet per minute. For further information, see *American Standard Gear Tolerances and Inspection*, Publication No. B6.6-1946, or latest revision thereof.

(5) Limiting dimensions of chain-drive sprockets for general-purpose motors in frames 505 and smaller are given in NEMA MG1-3.14. Limiting dimensions of chain-drive sprockets for motors in frames larger than 505 have not been standardized; they are specified by the motor manufacturer.

NOTES: The above limitations are based on the use of pulleys, etc., as standardized by NEMA. The limitations will be less tha those given when motors are belted to low-speed drives, suc as countershafts.

The above values are not intended to establish a definit dividing line below which the use of outboard bearings is no standard, but rather to establish a dividing line which wil indicate to the motor user what the manufacturers consider t be good practice in general service.

The use of outboard bearings is approved and recommende for belted motors in frame sizes of 250 hp, 575 to 600 rpm an larger.

Where an outboard bearing is specified, it is assumed that th necessary three-bearing type base plate and slide rails, if re quired, are included with the motor.

rated voltage applied at rated frequency and with normal excitation.

The *pull-in torque* of a synchronous motor is the maximum constant torque under which the motor will pull its connected inertia load into synchronism, at rated voltage and frequency, when its field excitation is applied.

The speed to which a synchronous motor will bring its load depends on the power required to drive it, and whether the motor can pull the load into step from this speed depends on the inertia of the revolving parts, so that the pull-in torque cannot be determined without having the Wk^2 as well as the torque of the load.

The locked-rotor torque of a motor must be well above the torque required to start the driven machine from rest. This may be anywhere from 10 to 250 percent of full-load torque, depending upon the type of driven machine. Low voltage and the type of starter employed affect the locked-rotor torque of the motor.

The torque delivered by the motor (after breakaway) for acceleration to full speed must also be well in excess of the torque required by the driven machine. The greater this margin, the shorter will be the time required to accelerate the inertia (Wk^2) of the rotating parts of the driven machine (and the motor rotor) to full speed. In other words, the time required for acceleration is a function of the torque available for this purpose and the Wk^2. (Note also the effect of load inertia on pull-in torque of synchronous motors as discussed under the NEMA definition above.)

To prevent the motor from stalling, the breakdown or pull-out torque (see NEMA definitions above) must be greater than the maximum torque required by the driven machine.

INSULATION AND TEMPERATURE LIMITS

Operating temperatures have a very pronounced effect on the operating life of motors because the temperature, to a large extent, determines the life of the insulation. The type of insulation, in turn, determines the maximum temperature allowable for reasonable motor life.

NEMA has defined several classes of insulation for consideration in connection with temperature limits. The two most commonly used on motors and generators are:

Class A: (1) Cotton, silk, paper and similar organic materials when either impregnated or immersed in a liquid dielectric; (2) molded and laminated materials with cellulose filler, phenolic resins and other resins of similar properties; (3) films and sheets of cellulose acetate and other cellulose derivatives of similar properties; and (4) varnishes (enamel) as applied to conductors.

Class B: Mica, asbestos, fiber glass and similar inorganic materials in built-up form with organic binding substances. A small portion of Class A material may be used for structural purposes only.

The highest observable temperatures permissible for open machines, based on AIEE standards, are as follows:

Measured by—	Class A Insulation	Class B Insulation
Thermometer..........	**90 C**	**110 C**
Resistance............	**100 C**	**120 C**
Imbedded detector....	**100 C**	**120 C**

The limiting observable temperature for totally-enclosed machines is 5 C higher than for open machines.

It should be noted that while a standard motor can be operated at the above temperatures without sacrificing the life expectancy of the insulation, the rating and other operating characteristics may be based on some other temperature. For example, open general-purpose ratings, which have Class A insulation, are rated 40 C rise based on a 40 C ambient temperature—that is, a total temperature of 80 C (by thermometer); in this case, the additional permissible 10 C permits a service factor, as discussed earlier under the heading *Horsepower Ratings.*

Ordinarily, Class A insulation is standard. Class B insulation, which is more expensive, is used principally to permit higher operating temperatures but also affords some other advantages in high-voltage machines. Some machines lend themselves to a combination of the two classes of insulation. In some cases, the additional cost of Class B insulation may be counterbalanced by the fact that it may permit the use of a smaller frame size for a given rating. Intermittent operation or adverse ambient conditions may require specially treated insulation.

MECHANICAL PROTECTION AND METHOD OF COOLING

The mechanical protection features covered by the following definitions (NEMA unless otherwise noted) are in general available in and applicable to most ac and dc motors and generators. There are of course exceptions. For example, the totally-enclosed non-ventilated type is limited to a few horsepower, after which the fan-cooled type takes over. Likewise, a totally-enclosed machine may be enclosed with air coolers and use a recirculating ventilating system, but such construction is generally confined to large high-speed machines having a specific rating over 1 hp (or kva) per rpm. The internal construction of motors with various degrees of enclosure is basically the same as that of open machines.

Open Machines

An *open machine* is one having ventilating openings which permit the passage of external cooling air over and around the windings (see [illegible], page [illegible].)

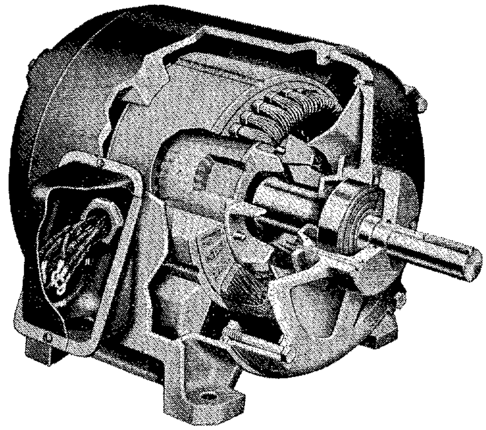


Fig. H-5. Sectional view of typical drip-proof, general-purpose, squirrel-cage induction motor.

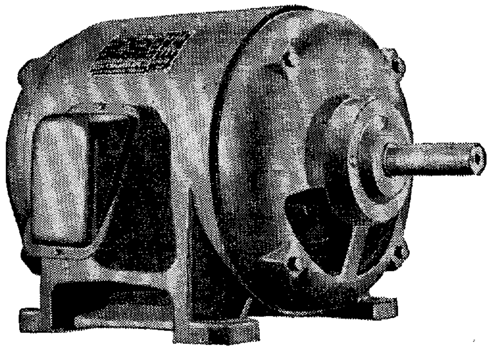


Fig. H-6. Typical construction for drip-proof, general-purpose, squirrel-cage induction motors.

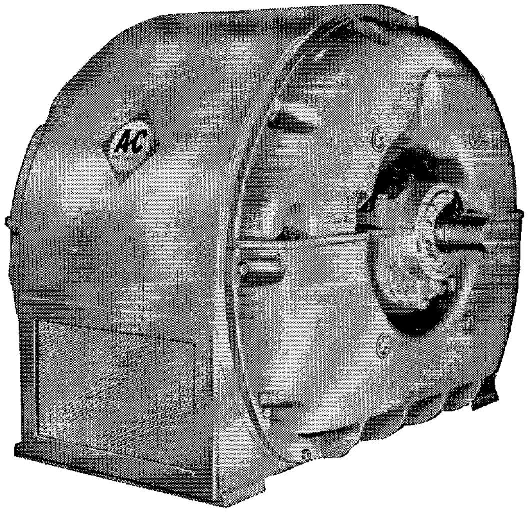


Fig. H-7. Drip-proof construction of large motors is illustrated by this 300-hp, 695-rpm machine.

A *drip-proof machine* is an open machine in which the ventilating openings are so constructed that drops of liquid or solid particles falling on the machine at any angle not greater than 15 degrees from the vertical cannot enter the machine either directly or by striking and running along a horizontal or inwardly inclined surface. (*Figs. 5, 6 and 7.*)

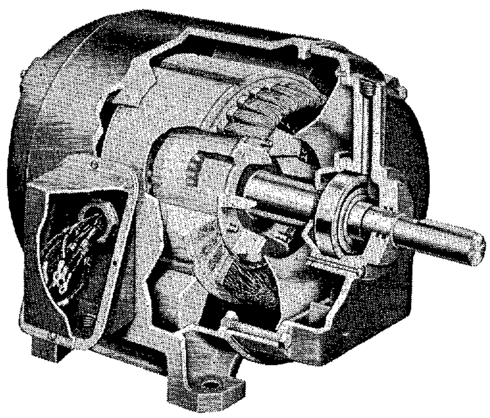


Fig. H-8. Sectional view of splash-proof squirrel-cage motor in general-purpose rating range.

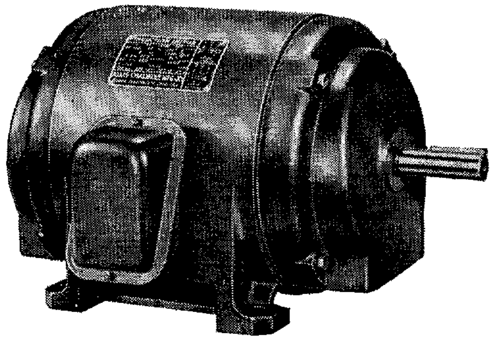


Fig. H-9. Splash-proof construction typical of that used in the general-purpose rating range.

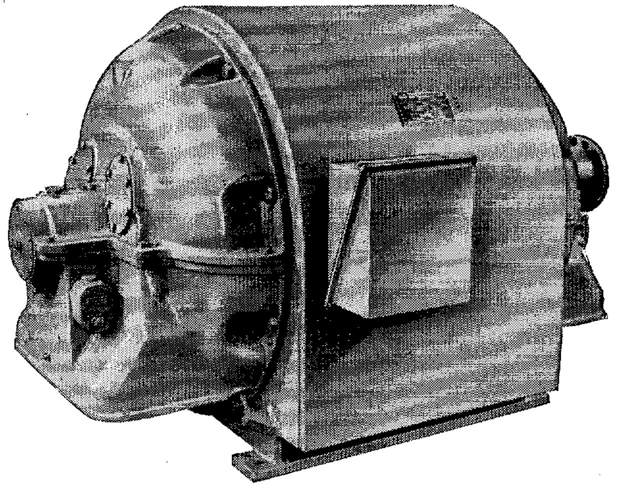


Fig. H-10. Two-pole cage motors, such as this 2000-hp unit, frequently must be splash-proof.

A *splash-proof* machine is an open machine in which the ventilating openings are so constructed that drops of liquid or solid particles falling on the machine or coming towards it in a straight line at any angle not greater than 100 degrees from the vertical cannot enter the machine either directly or by striking and running along a surface. (*Figs. 8, 9, 10, 11* and *12.*)

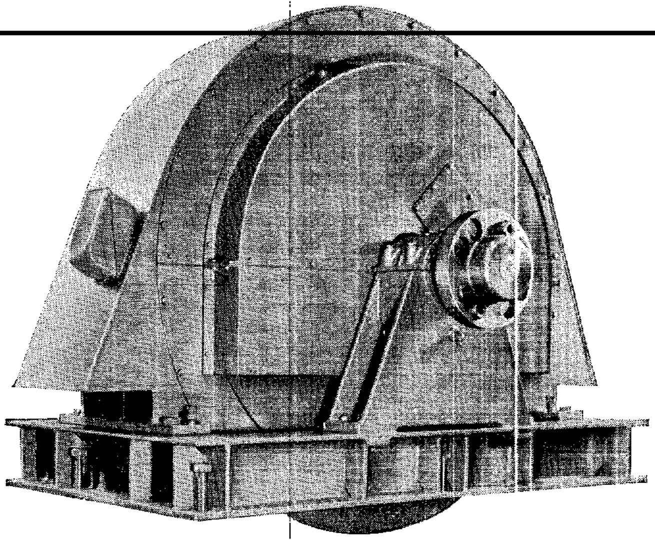


Fig. H-11. Large, splash-proof motor of the pedestal-bearing type.

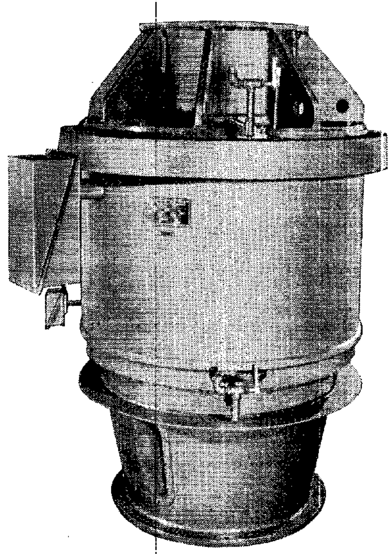


Fig. H-12. Splash-proof construction is also available in vertical motors.

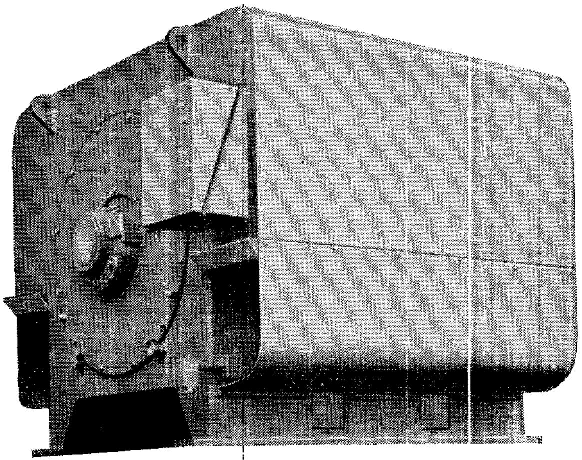


Fig. H-13. Large weather-protected squirrel-cage motor for outdoor service.

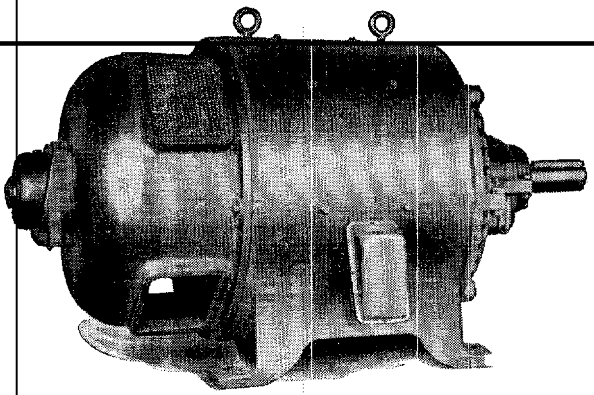


Fig. H-14. This dc motor is semi-protected since it has expanded-metal covers over top half openings.

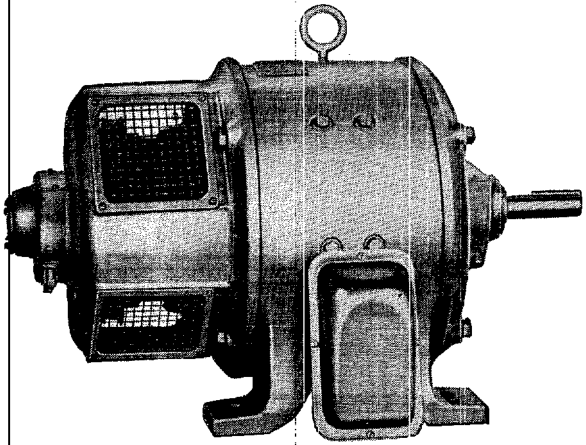


Fig. H-15. Expanded-metal covers on both top and bottom openings make this a protected dc motor.

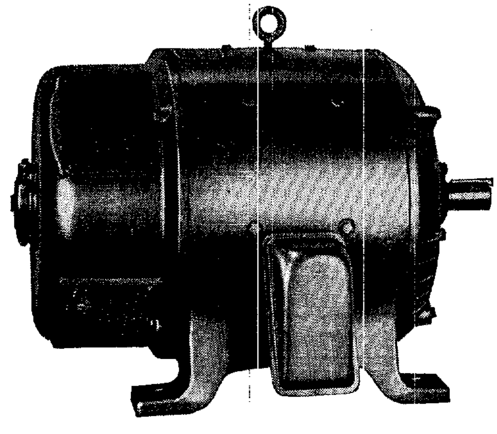


Fig. H-16. Drip-proof protected dc motors have solid and expanded-metal covers, as shown above.

A *semi-protected machine* is an open machine in which part of the ventilating openings in the machine, usually in the top half, are protected as in the case of a "protected machine" but the others are left open.

A *protected machine* is an open machine in which all ventilating openings are limited in size and shape.

Such openings shall not exceed 1/2 square inch (323 square millimeters) in area and are of such shape as not to permit the passage of a rod larger than 1/2 inch (12.7 millimeters) in diameter except where the distance of exposed live parts from the guard is more than 4 inches (101.7 millimeters), the openings may be 3/4 square inch (484 square millimeters) in area and must be of such shape as not to permit the passage of a rod larger than 3/4 inch (19 millimeters) in diameter. (*Fig. 15.*)

A *drip-proof fully protected machine* is a drip-proof machine whose ventilating openings are protected in accordance with the preceding paragraph. (*Fig. 16.*)

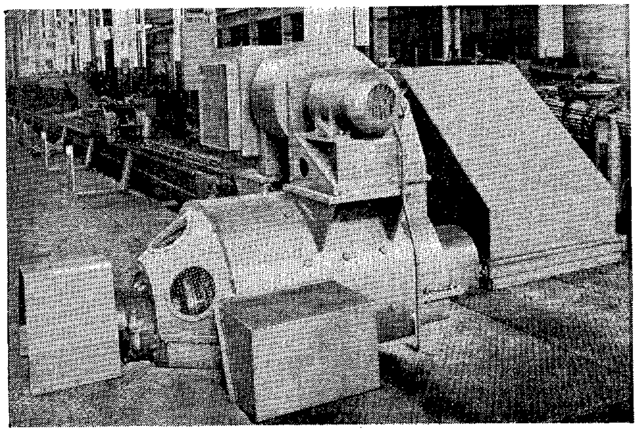


Fig. H-17. Installation view of open, externally ventilated dc motor with frame-mounted blower.

An *open externally-ventilated machine* is one which is ventilated by means of a separate motor-driven blower mounted on the machine enclosure. Mechanical protection may be as defined in the preceding paragraphs. (*Fig. 17.*)

An *open pipe-ventilated machine* is an open machine except that openings for the admission of the ventilating air are so arranged that inlet ducts or pipes can be connected to them. This air may be circulated by means integral with the machine or by means external to and not a part of the machine. In the latter case, this machine is sometimes known as a separately or forced-ventilated machine. Enclosures may be as defined in preceding paragraphs.

A *weather-protected motor* is an open motor (protected in accordance with that definition above) whose ventilating passages are so designed as to minimize the entrance of rain, snow and air-borne particles to the electrical parts.

Note 1: ASA C-42 definition is: An open machine is a self-ventilated machine having no restriction to ventilation other than that necessitated by mechanical construction. Thus, in the sense of this definition an open machine, when the term is used without qualification, is understood not to include the listed protective features.

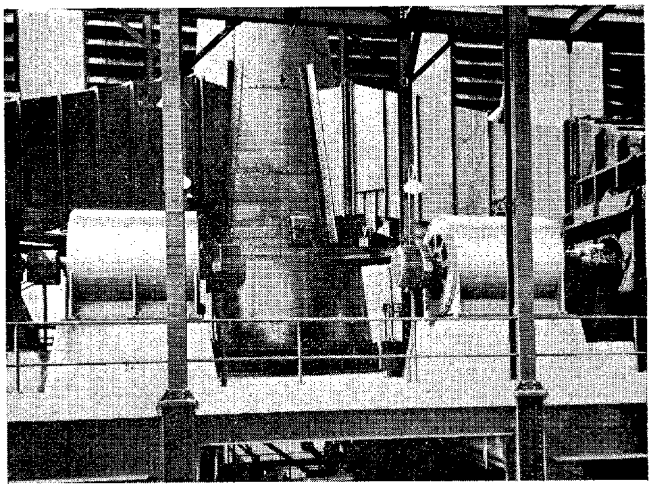


Fig. H-18. Tube-type, totally-enclosed, fan-cooled, wound-rotor motors installed outdoors.

Note 2: Chicago covers consist of hinged perforated covers for all openings on the collector end of wound-rotor motors or the commutator end of dc machines.

Totally-Enclosed Machines

A *totally-enclosed* machine is one so enclosed as to prevent exchange of air between the inside and the outside of the case but not sufficiently enclosed to be termed air-tight.

A *totally-enclosed non-ventilated machine* is a totally-enclosed machine which is not equipped for cooling by means external to the enclosing parts. (*Fig. 20.*)

A *totally-enclosed fan-cooled machine* is a totally-enclosed machine equipped for exterior cooling by means of a fan or fans integral with the machine but

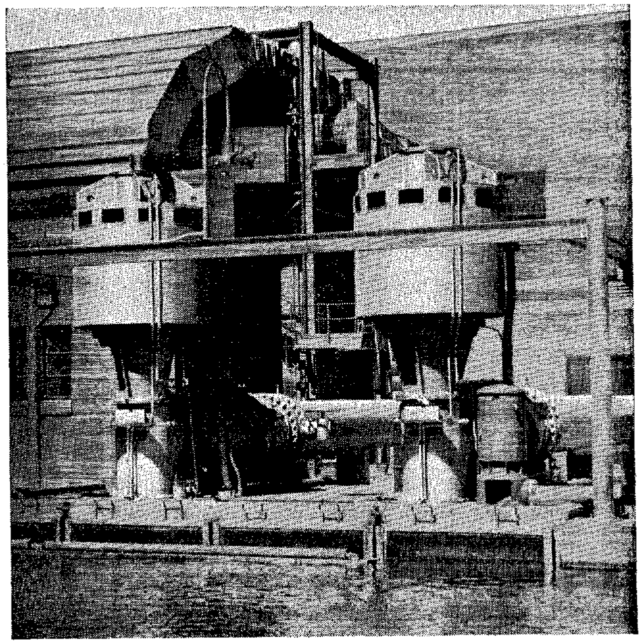


Fig. H-19. Outdoor installation of vertical, tube-type, totally-enclosed fan-cooled large motors.

external to the enclosing parts. (*Figs. 18, 19* and *30* show fan-cooled motors in service. See also *Figs. 21, 22* and *23*.)

An *explosion-proof machine* is a totally-enclosed machine whose enclosure is designed and constructed to withstand an explosion of a specified gas or vapor which may occur within it and to prevent the ignition of the specified gas or vapor surrounding the machine by sparks, flashes or explosions of the specified gas or vapor which may occur within the machine casing. (*Figs. 24, 25* and *31* show typical explosion-proof motors.)

Note: See page 10 for classification of hazards.

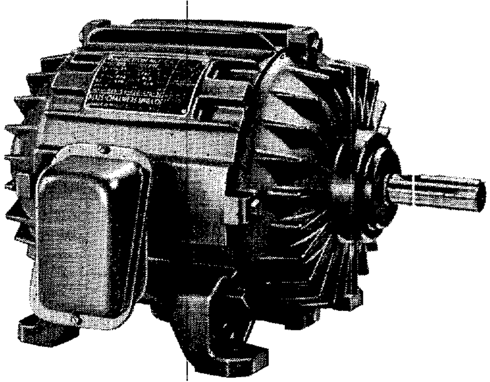


Fig. H-20. Totally-enclosed non-ventilated design is limited to small motors—usually 2-hp or less.

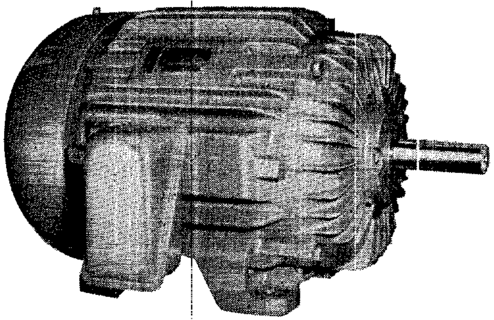


Fig. H-21. Totally-enclosed fan-cooled construction used for general-purpose ratings is shown above.

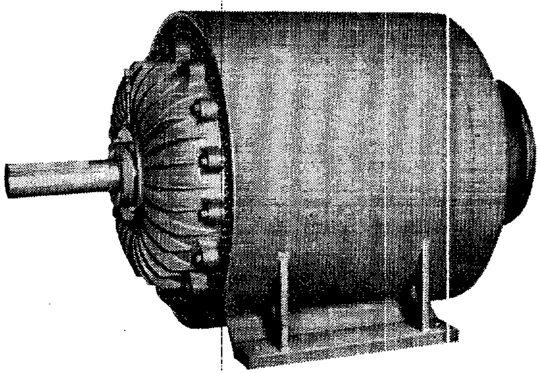


Fig. H-22. Large TEFC motors need special cooling designs, such as the tube-type air-to-air heat exchanger construction used for this motor.

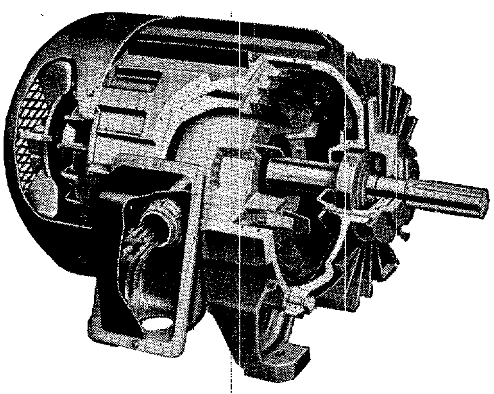


Fig. H-23. Sectional view through typical general-purpose, totally-enclosed, fan-cooled cage motor.

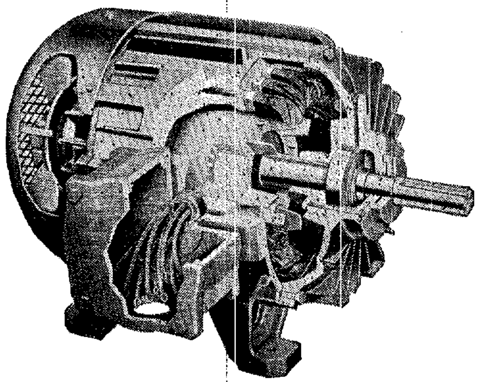


Fig. H-24. Explosion-proof construction is modification of totally-enclosed fan-cooled design.

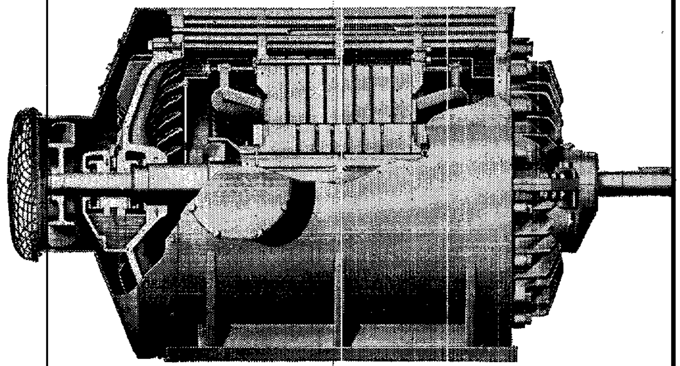


Fig. H-25. Tube-type cooling makes large totally-enclosed explosion-proof motors practical.

A *dust-explosion-proof machine* is a totally-enclosed machine whose enclosure is designed and constructed so as not to cause the ignition or explosion of an ambient atmosphere of the specific dust, and also not to cause the ignition of the dust on or around the machine.

Note 1: Successful operation of this type of machine requires avoidance of overheating from such causes as excessive overloads, stalling, or accumulation of excessive quantities of dust on the machine.

Note 2: See page 10 for classification of hazards.

A *water-proof machine* is a totally-enclosed machine so constructed that it will exclude water applied in the form of a stream from a hose, except that leakage may occur around the shaft, provided it is prevented from entering the oil reservoir and provision is made for automatically draining the machine. The means for automatic draining may be a check valve or a tapped hole at the lowest part of the frame which will serve for application of a drain pipe.

Note: A common form of test for a water-proof machine is to play on the machine a stream of water from a hose with a one-inch nozzle delivering at least 65 gpm from a distance of about 10 feet, from any direction, and for a period of not less than 5 minutes.

A *totally-enclosed pipe-ventilated machine* is a totally-enclosed machine except for openings so arranged that inlet and outlet ducts or pipes may be connected to them for admission and discharge of the ventilating air. This air may be circulated by means integral with the machine or by means external to and not a part of the machine. In the latter case, these machines shall be known as separately or forced-ventilated machines. (*Fig. 26.*)

Note: ASA definition of an enclosed, separately ventilated machine is a machine having openings for the admission and discharge of the ventilating air, which is circulated by means external to and not part of the machine, the machine being otherwise totally enclosed. These openings are so arranged that inlet and outlet duct pipes may be connected to them.

SERVICE CONDITIONS

General-purpose 40 C motors are designed to give successful operation at rated load under the following service conditions defined by NEMA as *usual:*

1. An ambient temperature not exceeding 40 C.
2. A variation in voltage of not more than 10 percent above or below the nameplate rating.
3. A variation in frequency of not more than 5 percent above or below the nameplate rating.
4. A combined variation of voltage and frequency of not more than 10 percent above or below the nameplate rating, providing the frequency does not exceed 5 percent variation.

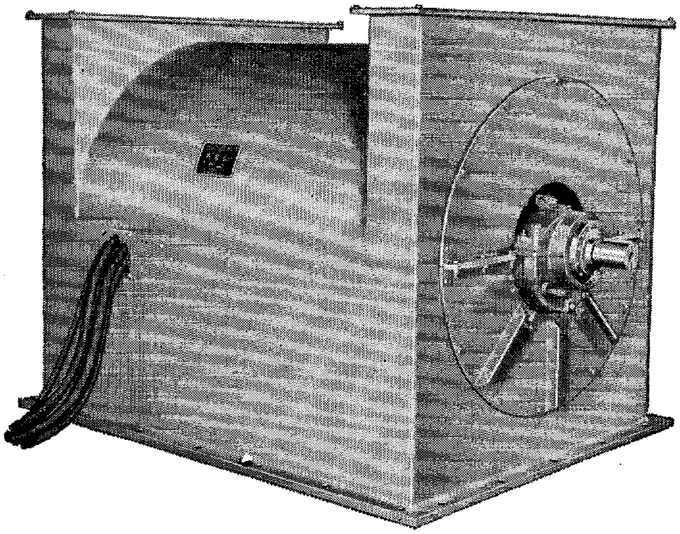


Fig. H-26. Pipe-ventilated motor with top air intakes and air discharge at bottom of yoke.

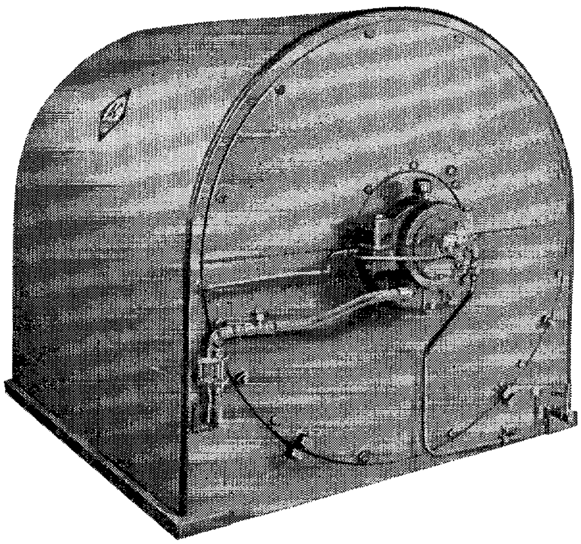


Fig. H-27. Base ventilated motor with air intakes and discharge at the bottom of the stator yoke.

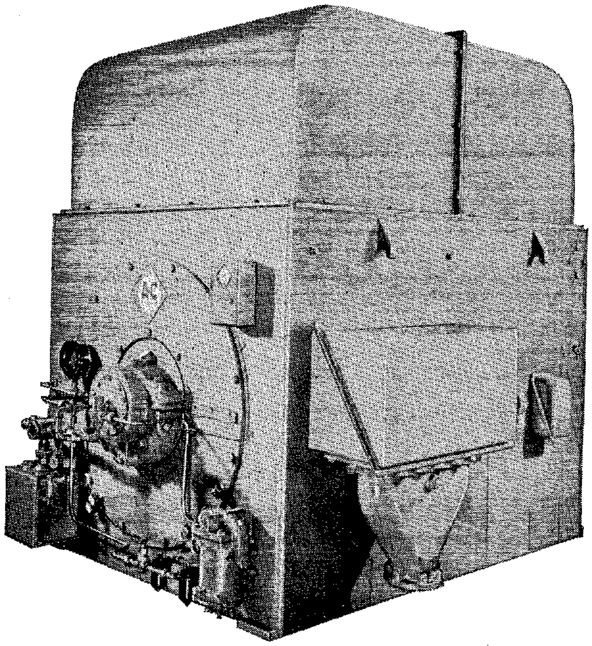


Fig. H-28. Completely assembled cage motor using recirculating ventilating system with air cooler.

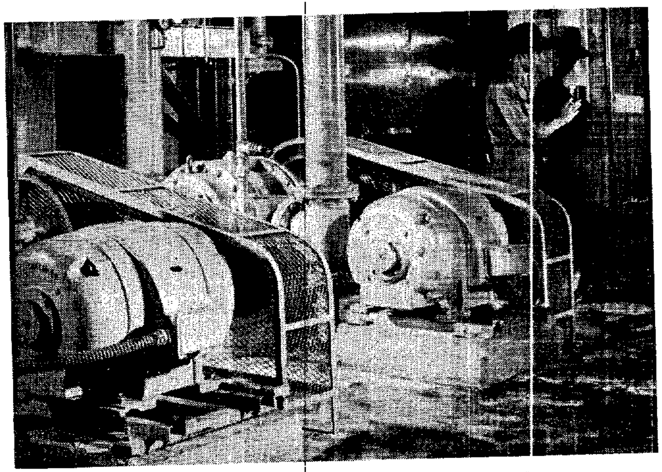


Fig. H-29. Splash-proof 75-hp cage motors were selected for chemical processing plant drive.

Fig. H-30. Dust in lime plant dictated selection of this 7½-hp, totally-enclosed fan-cooled motor.

5. An altitude not exceeding 3300 feet (1000 meters).
6. Location or atmospheric conditions as to dust, moisture or fumes which will not seriously interfere with the ventilation of the motor.
7. Solid mounting and all belt and chain drives and gearing in accordance with adopted standards.

In general, since the service conditions to which such motors are subjected are uncontrolled and not subject to exact determination, the basis of rating chosen, in accordance with NEMA standards, provides a factor of safety of 10 C in temperature rise at 100 percent loading.

Specific service conditions defined by NEMA as *special service conditions more favorable than usual* are:

1. Operation at rated voltage and frequency.
2. Individual application to a machine where the loads and duty cycle are accurately known and cannot be exceeded.

Unusual Service Conditions

Where apparatus is to be subject to any one or a combination of the following conditions, the manufacturer should be consulted to make sure that the proper motor is selected:

1. Exposure to steam or excessive moisture from other causes, such as vapor or excessive splashing and dripping, as may be encountered in parts of dye houses, bleacheries, packing plants, paper mills, metal mines, etc. These conditions may require special insulation, low-voltage designs, and/or enclosed motors.
2. Exposure to the corrosive action of salt-laden air usually requires special consideration of insulation and the use of non-corroding nuts, bolts and current-collecting parts.
3. Exposure to excessive amounts of acid or alkali vapors, fumes or dust, as encountered in chemical, fertilizer and similar plants. Where the ambient atmosphere contains corrosive or solvent agents harmful to the insulation or to current-collecting parts, the use of enclosed or separately ventilated motors may be necessary.
4. Exposure to conducting or abrasive dusts, such as coal, coke, carbon, graphite, iron, etc. Even in small amounts these may be extremely harmful to insulation, and the use of enclosed motors is preferable. Open motors with special insulation may suffice for lower voltages.

   A combination of conductive or abrasive dusts plus sulphur fumes and moisture is often encountered in power plant boiler rooms around ash-handling and coal-pulverizing equipment.
5. Exposure to hazardous atmospheres containing flammable or explosive gases or combustible or explosive dusts requires totally-enclosed explosion-proof motors.

   The *National Electrical Code* designates hazardous gas locations as Class I and hazardous dust-and-air locations as Class II. Class I is divided into Groups A, B, C, and D, Group A being the most hazardous and Group D being the least hazardous. Similarly, Class II is divided into Groups E, F, and G, Group E being the most hazardous and Group G being the least hazardous. Motors for Class I Groups A and B are generally not available.
6. Exposure to lint, such as encountered by textile mill motors, may quickly clog ventilating passages of open motors and make totally-enclosed motors desirable for looms, and special self-cleaning motors for spinning frames, etc.
7. Exposure to abnormal shock or vibration may make special structural materials necessary.
8. Exposure to ambient temperatures above 40 C (104 F). Where the windings will be subjected to an [illegible] ambient tempera-

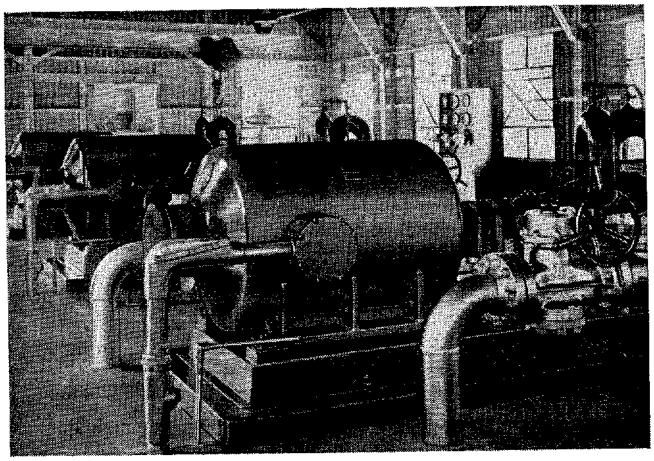


Fig. H-31. Explosion-proof, totally-enclosed fan-cooled motors were needed for oil pipe-line station.

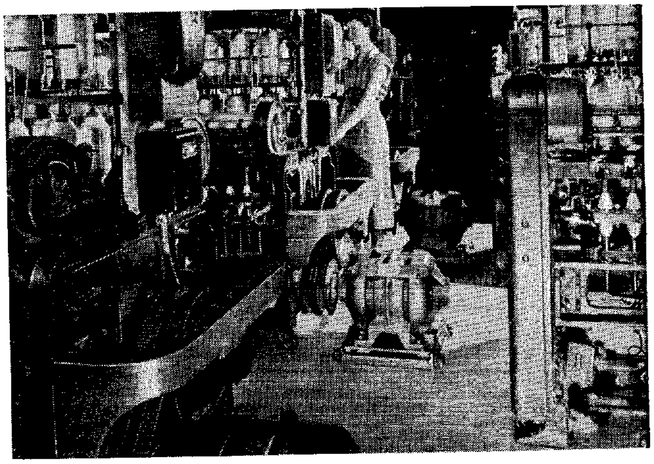


Fig. H-32. Special textile motors are available for applications like these cotton spinning frames.

ture plus operating temperature rise) above 90 C for open motors, or 95 C for enclosed motors, Class B insulation is required. Maximums for Class B are 110 and 115 C respectively.

9. Outdoor operation requires a degree of enclosure dependent on the climate involved. Usually totally-enclosed types are preferable. Splash-proof construction should be limited to the milder climates and lower voltages. Low ambient temperatures require special consideration of the bearing lubrication. In general, outdoor installations are not recommended under conditions of extreme cold and heavy snows.
10. Operation in poorly ventilated rooms or pits is undesirable. If such locations are unavoidable, means should be provided for separate forced ventilation to insure an ample volume of cooling air.

TABLE 3—COMPARISON OF DC AND AC MOTORS

	Direct Current	Alternating Current
Voltage	**Limited to 230 volts on ordinary circuits.**	**Any standard voltage available with use of transformers.**
Speed adjustment	**Simple.**	**Difficult.**
Efficiency	**High.**	**Good.**
Intermittent starting service	**Good.**	**Unsatisfactory and heavy current—except wound-rotor motors.**
Starting currents	**Generally low.**	**High for cage type.**
Maintenance	**Higher because of commutator.**	**Low.**
Constant speed	**Shunt motor.**	**Synchronous motor.**
Semi-constant speed	**Compound motor.**	**Induction motor.**
Speed adjustable but remaining constant	**Shunt motor with field control.**	**In combination with magnetic couplings.**
Speed varying with load	**Series motor.**	**Wound-rotor motor with drum control.**

SELECTING A MOTOR

There are many factors to be considered in selecting the right type of electric motor for a specific drive.

First, the requirements of the machine to be driven must be considered. This involves not only establishing the motor size (which may be a problem in itself) but also consideration of other characteristics of the load which have a direct bearing on the type of motor to be selected. What is the required operating speed? Should it be constant, adjustable or variable? What are the torque requirements? These and many other factors must be considered if an intelligent selection is to be made.

Second, there are questions of power supply. What current is available—direct or alternating? Should plant power factor be improved? Are there power company current limitations?

Third, ambient conditions must be considered. Will the motor need special protective enclosures? Special insulation? Separate ventilating equipment?

Fourth, the available forms of motors must be weighed in relation to the characteristics desired, and the economics of initial and future costs must be investigated.

Take a compressor for example. If initial cost is the main consideration and plant power factor can be ignored, a squirrel-cage induction motor is the obvious choice for small and medium sized compressors. For heavy-duty compressors requiring large motors, the smooth acceleration and low starting current of wound-rotor motors justifies their use. But if there are already numerous induction motors in the plant, the best choice may be a synchronous motor to provide corrective kva for plant power factor improvement.

Tables 3 and 4 are provided as a general guide for use in selecting motors. Whenever there is any question about an application, the motor manufacturer should be furnished with as complete information as possible. Failure to do so might result in misapplication. Table 5 gives an indication of the essential type of information

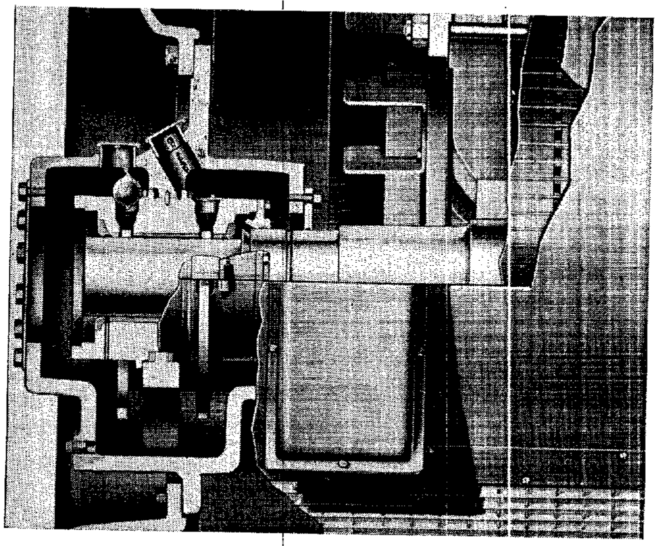


Fig. H-33. Sectional view through ring-oiled sleeve bearing used on large end-shield bearing motor.

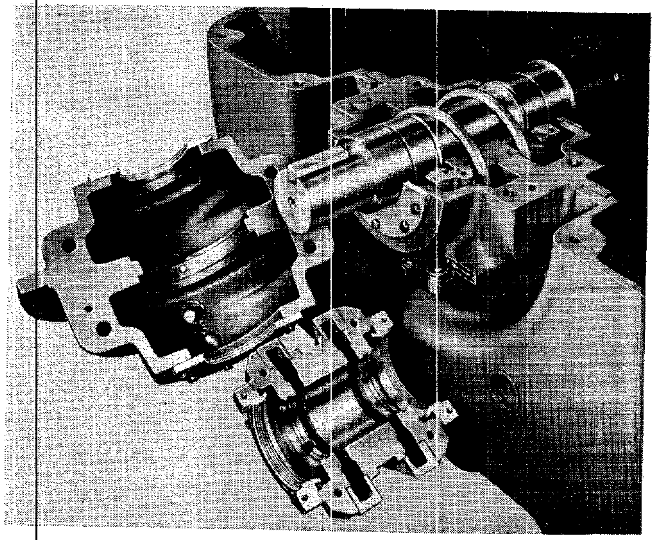


Fig. H-34. Partially dismantled capsule-type sleeve bearing of same type as that shown in Fig. H-33.

TABLE 4—MOTOR SELECTION TABLE

APPLICATION	MOTOR SYMBOL Alternating Current	Direct Current
Agitator	1A-1B-2B	6A
Baler (power)	1D	6B-7
Ball mill	1C-2B-3A	6B
Blower (positive pressure)	1A-1B-2B-3A-4	6A
Boring mill	2A-3A	6A-8
Buffer	1A-1B-2A	6A
Cement kiln	3A	8
Compressor	1A-1B-1C-3A-4	6B-8
Conveyor	1A-1C-2B-3A	6B-8
Crane	1D-2A-3B	7
Crusher	1A-1C-1D	6A-6B
Dough mixer	1A-1B-1C-2B	6A-6B
Drilling machine	1A-1B-2A	6A-8
Drying tumbler	1A-1B-1D	6A
Elevator	1D-1E-2B-3B	6B-8
Fan (centrifugal and propeller)	1A-1B-2C-3A-4	6A-8
Finishing stand	3B	8
Grinder	1A-1B-2A	6A
Hammer (power)	1D	6B
Hammer mill	1C	6A
Hoist	1D-2A-3B	7
Jordan	1A-1B-4	6A
Keyseater	1A-1B	6A
Lathe	1A-1B-2A	6A-8
Laundry extractor	1C-1D	6B
Laundry washer	1A-1B-1D	6A
Line shaft	1A-1B	6A
Metal grinder	1A-1B	6A
Metal saw	1A-1B	6A
Milling machine	1A-1B-2A	6A-8
Mill table	3A	8
Mine hoist	3B	8
Molder	1A-1B	6A
Ore grinder	3A	8
Pipe threader	1A-1B	6A
Planer	1A-1B	6A
Polisher	1A-1B-2A	6A
Printing press (job)	1A-1B-3A	6B-8
Printing press (rotary and offset)	3A	6B-8
Pulverizer	1C	6B
Pump (centrifugal)	1A-1B-2B-3A-4	6B
Pump (displacement)	1C-2B-3A	6B
Rock crusher	3A	6B-7
Sander	1A-1B	6B
Sand mixer (centrifugal)	1C	6A
Saw (circular)	1A-1B	6A
Saw (band)	1A-1B-1C-3A	6A-6B
Screw machine	1A-1B	6A
Shaper	1A-1B	6A
Spinning and weaving machinery	1A-1B	6A
Stoker	1A-1B-1C-2B	6A-8
Tumbling barrel	1C	6A
Winch	1D-3A	6B-8

EXPLANATION OF SYMBOLS

1. Squirrel-Cage, Constant-Speed
   - A. Normal torque, normal starting current
   - B. Normal torque, low starting current
   - C. High torque, low starting current
   - D. High torque, high slip
   - E. Elevator

2. Squirrel-Cage, Multi-Speed
   - A. Constant horsepower
   - B. Constant torque
   - C. Variable torque

   Note: Classes "A," "B" and "C" listed under "1" are also applicable to multi-speed motors. The listing ("A," "B" or "C") for the constant-speed motor indicates the form of motor to use under "2." For example: If the listing shows 1C-2B, then the multi-speed, constant torque motor should also be high torque, low starting current.

3. Wound-Rotor
   - A. General-purpose
   - B. Crane and hoist

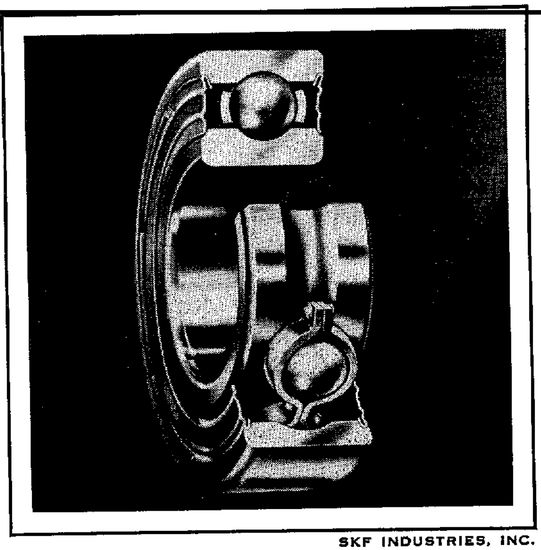
4. Synchronous

6. Direct-Current, Constant-Speed
   - A. Shunt-wound
   - B. Compound-wound

7. Direct-Current, Variable-Speed, Series-Wound

   Note: Series motors must be connected directly to the load (not belted).

8. Direct-Current, Adjustable-Speed



SKF INDUSTRIES, INC.

Fig. H-35. Various types of ball bearings are used on motors. Above unit is a double-shielded type.

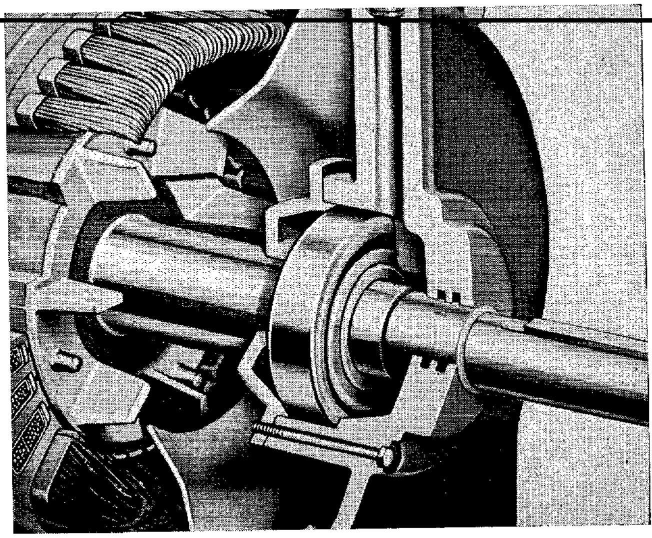


Fig. H-36. Cutaway view showing shielded ball bearing installed in a general-purpose cage motor.

required for various types of motors. To this the purchaser should, of course, add any other desired characteristics and features and indications of any unusual operating conditions.

MOTOR BEARINGS

Bearing design, including provision for lubrication and protection, forms one of the most vital features of motor construction. Bearings are one of the few wearing parts in electric motors; in cage motors they are, in fact, the only element that can be considered as a wearing part.

In properly designed sleeve bearings, the shaft rotates on a film of oil, which prevents actual contact between the shaft and the bearing during operation. With clean oil, free from abrasive materials, sleeve bearings should provide long years of service, and they are very quiet in operation. They do, however, normally require more attention than the anti-friction type. *Figs. 33* and *34* show typical sleeve bearing mountings.

The use of anti-friction bearings is usually confined to ratings in the general-purpose classification (200 hp and less). The type most commonly used is the grease-lubricated ball bearing, *Figs. 35* and *36*, which requires little attention except for checking grease about once a year. Most ball-bearing troubles in the smaller machines are, in fact, due to overgreasing.

Experience indicates that for ratings of 250 hp and larger, particularly for speeds above 1000 rpm, anti-friction bearings are not as reliable as oil-lubricated sleeve bearings. For lower speeds, anti-friction bearings are usually satisfactory in ratings up to 1 hp per rpm. The balls, or rollers, undergo cyclical compression and release with every revolution, so that high speeds and high loading cause fatigue and ultimate failure. Exceptional cases may permit the use of oil-lubricated ball bearings.

TABLE 5—INFORMATION REQUIRED FOR SELECTING MOTORS

Motor Data

GENERAL

Type of motor (cage, wound-rotor, synchronous, or dc)........
Quantity........ Hp........ Rpm........ Phase........
Cycles........ Voltage........
Time rating (continuous, short-time, intermittent)............
Overload (if any)......% for........ Service factor........%
Ambient temperature........C Temperature rise..........C
Class of insulation: Armature.. Field.. Rotor of w-r motor...
Horizontal or vertical.......... Plugging duty............
Full- or reduced-voltage or part-winding starting (ac)........
If reduced voltage—by autotransformer or reactor..........
Locked-rotor starting current limitations..................
Special characteristics....................................

INDUCTION MOTORS

Locked-rotor torque..........% Breakdown torque........%
or for general-purpose cage motor: NEMA Design (A, B, C, D)
....

SYNCHRONOUS MOTORS

Power factor.... Torques: Locked-rotor....% Pull-in....%
Pull-out....% Excitation......volts dc. Type of exciter......
If m-g exciter set, what are motor characteristics?..........
Motor field rheostat........ Motor field discharge resistor.....

DIRECT-CURRENT MOTORS

Shunt, stabilized shunt, compound, or series wound..........
Speed range........ Non-reversing or reversing..............
Continuous or tapered-rated.................................

MECHANICAL FEATURES

Protection or enclosure............ Stator shift............
Number of bearings.......... Type of bearings............
Shaft extension: Flanged...... Standard or special length.....
Press on half-coupling........ Terminal box................
NEMA C or D flange........ Round-frame or with feet.......
Vertical: External thrust load....lbs. Type of thrust bearing....
Base ring type............ Sole plates..................
Accessories...

Load Data

Type of load...
If compressor drive, give NEMA application number..........
Direct-connected, geared, chain, V-belt, or flat-belt drive.......
Wk^2 (inertia) for high inertia drives..................lb-ft^2
Starting with full load, or unloaded........................
If unloaded, by what means?...........................
For variable-speed or multi-speed drives, is load variable torque, constant torque, or constant horsepower?..................
Operating conditions.......................................

INDUCTION MOTORS

Applicable to a broad range of applications, induction motors are the most widely used because of their simple construction. As is true of practically every type of polyphase motor, the operation of an induction motor depends on the production of a revolving magnetic field in the stator; the rotor of the machine being pulled around by the revolving magnetic field.

This revolving field is produced by increasing and decreasing currents in the stator winding. In a two-phase motor, the magnetic field, at a given instant, is produced entirely by the first phase winding. As the instantaneous current decreases in the first phase and increases in the second, a slight shift of the magnetic field takes place. This shift continues to the point where the second phase is producing the entire magnetic field.

In a three-phase motor, the third-phase winding has a maximum field which is still further shifted around the stator. The windings are so distributed as to allow uniform continuous shifting or rotation of the magnetic field around the stator.

Beyond this, induction motors operate on the principle of magnetic induction; that is, the magnetic field in the rotor is induced by the current flow in the stator. The rotor may be (1) the squirrel-cage type, or (2) the wound-rotor type with the ends of the winding brought out through collector rings to an external circuit.

SQUIRREL-CAGE POLYPHASE INDUCTION MOTORS

Squirrel-cage motors, *Figs. 5* to *10*, the most commonly used type of polyphase induction motor, derive their name from the similarity of their rotor windings to squirrel cages. Since these motors operate by induction, the stator is sometimes called the *primary* because it receives power from the line, and the rotor, the *secondary* because its currents result from the action of the primary currents.

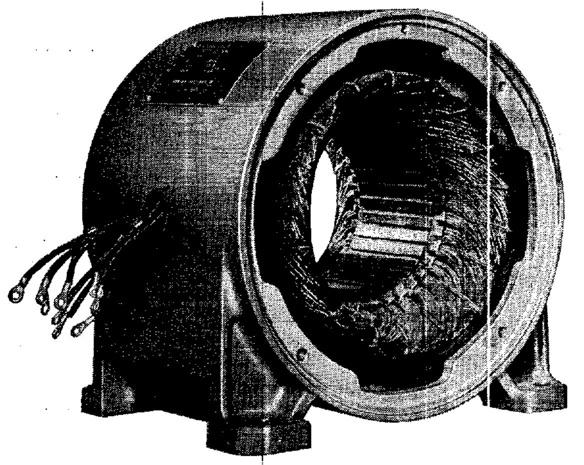


Fig. H-37. Wound stator for small general-purpose, squirrel-cage induction motor.

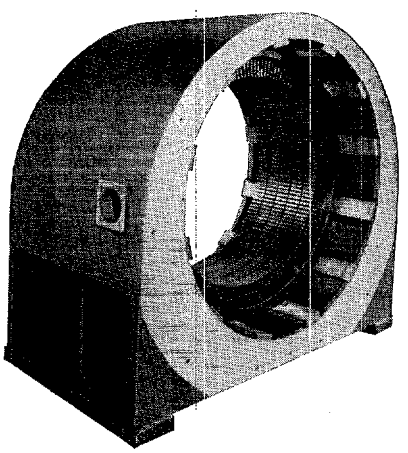


Fig. H-38. Stator yoke and core for large cage motor ready for winding.

The operation of a cage motor can best be explained by starting with the motor at rest. When current is supplied to the stator (primary) winding, a revolving magnetic field is set up as described above. This revolving field cuts the rotor conductors (cage bars) and thereby induces voltages in the bars.

As a result of the induced voltages, current flows in the cage winding. The current loops through the bars and short-circuiting end rings are distributed in such a manner as to create a magnetic field similar to that of the stator. Interaction of these two magnetic fields results in a force that tends to pull the rotor along with the revolving field of the stator. The motor therefore starts and gains speed.

The rotor cannot, however, rotate as rapidly as the revolving field of the stator. If it did, the cage bars, instead of being cut by the revolving field, would become magnetically stationary with respect to the revolving field. In that case, no voltage would be induced in the rotor, and there would be no attraction between the rotor and the rotating field in the stator.

In other words, the rotor constantly slips back and an induction motor cannot operate at synchronous speed. Obviously increasing the load will increase the *slip*, and the motor will run slower. However, at full load, the slip is small, and motors of this type are usually considered to be of constant speed.

Cage Motor Construction Features

The basic simplicity of cage motors is favorable to operational reliability, but careful engineering and quality construction are nevertheless essential to reliability and minimum maintenance.

The stator construction (*Figs. 37, 38, 39*) is the same for cage, wound-rotor and synchronous motors. It comprises a supporting yoke, a slotted laminated sheet-steel core, and insulated coils connected to provide definite polar areas providing the revolving magnetic field.

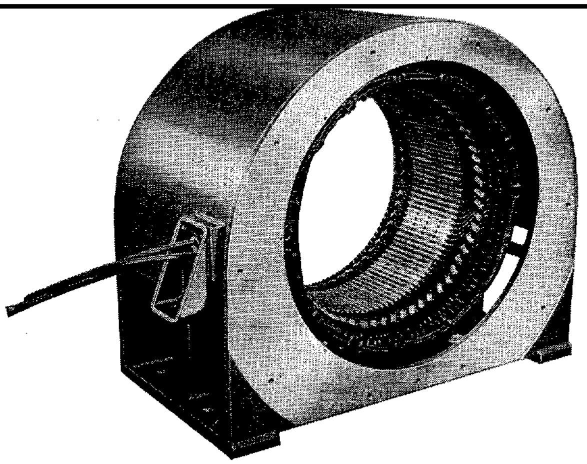


Fig. H-39. Wound stator for large, end-shield bearing, squirrel-cage induction motor.

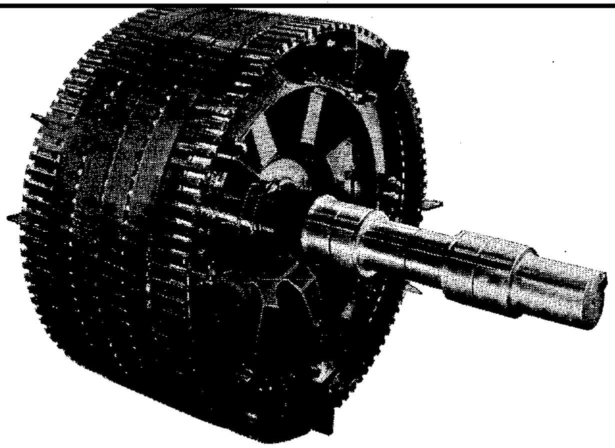


Fig. H-40. Squirrel-cage rotor construction typical of ratings beyond general-purpose sizes.

A cage motor rotor (*Figs. 40, 41, 42*) consists of a shaft, core, and cage winding. The core is built up of slotted laminated-steel punchings mounted directly on the shaft or supported by a spider mounted on the shaft (*Fig. 43*). The winding consists of bars short-circuited by end rings. In smaller motors, the winding is frequently cast in one operation, and aluminum is often used for this purpose. In larger motors, heavy copper bars or rods are used, and these are brazed or otherwise fastened to the end rings. Due to the very low voltage in the bars, insulation is not necessary between the bars and the rotor core.

End-shield or bracket bearing construction is used for most cage motors. Pedestal bearing construction is, however, commonly used for ratings above one hp per rpm. Ball bearings are generally confined to general-purpose sizes; sleeve bearings are available for both general-purpose and large motors.

Shaft rigidity and bearing quality are especially important in these motors because, to obtain good efficiency and power factor, the air gap between rotor and stator must be small. It should be noted, however, that too small an air gap can be detrimental to construction, to sound level, and, by producing parasitic torques, to efficiency.

Cage Motor Characteristics

Polyphase squirrel-cage induction motors are the most reliable and, with the exception of large synchronous motors, the most efficient motors available. This presupposes that the motor selected for any definite load is of such size that it can be operated at nearly full load because the power factor and efficiency

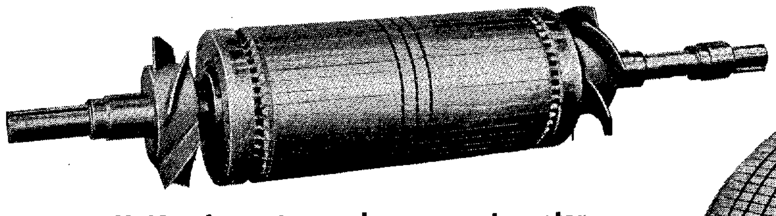


Fig. H-41. Large two-pole cage motor rotor.

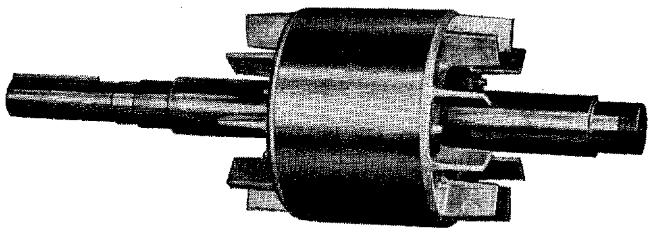


Fig. H-42. Die-cast aluminum squirrel-cage rotor.

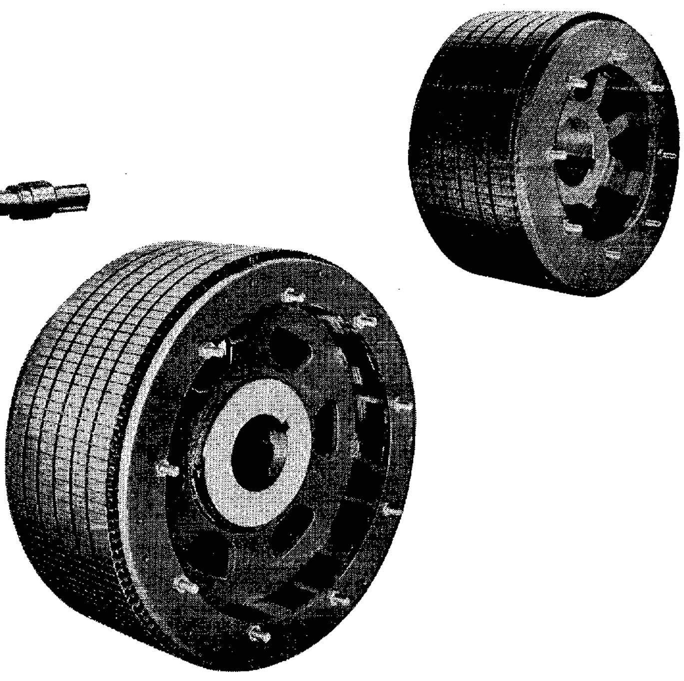


Fig. H-43. Rotor spider and core assemblies for large squirrel-cage induction motors.

is lower at light loads. It is also important to remember that high-speed motors have higher power factors than lower speed machines.

Under normal load and voltage conditions, squirrel-cage motor speeds are practically constant and, like those of synchronous motors, are dependent on the number of poles and the frequency of the power supply. But, as previously noted, the cage motor slows down sufficiently to produce the necessary torque when load is applied. This slip is expressed as a percentage of the synchronous speed. For example, if a motor with a synchronous speed of 1200 rpm is loaded until the speed drops to 1164 rpm, the slip is:

$$\frac{1200 - 1164}{1200} = \frac{36}{1200} = 3\%$$

A definite relationship exists between the slip and the efficiency of the motor; that is, the higher the slip, the lower the efficiency, for slip is a measure of the losses in the rotor winding. In the above example, about 3 percent of the total power input would be lost in the rotor winding. However, relatively high slip motors may be necessary if high starting (locked-rotor) torque is required by the application.

To provide the best starting torque consistent with high power factor and efficiency, cage motors must be of well-balanced design. Within limits, the amount of starting torque developed will depend on the resistance of the rotor winding. Increasing the rotor resistance will increase the starting torque—with a corresponding increase in slip and decrease in efficiency.

NEMA Design Classifications

To simplify the selection of motors by providing some uniformity of design, NEMA has divided polyphase squirrel-cage motors into classes based on electrical characteristics. While these classifications

TABLE 7—BREAKDOWN TORQUE

The break-down torque of Design B and C cage motors, with rated voltage and frequency applied, shall be in accordance with the following values which are expressed in percent of full-load torque and which represent the upper limit of the range of application for these motors.

Hp	Synchronous Speed in Rpm (60 and 50 Cycles)	Design B	Design C
1/2	900-750	250	. . .
	Lower than 750	200	. . .
3/4	1200-1000	275	. . .
	900-750	250	. . .
	Lower than 750	200	. . .
1	1800-1500	300	. . .
	1200-1000	275	. . .
	900-750	250	. . .
	Lower than 750	200	. . .
1-1/2	3600-3000	275	. . .
	1800-1500	300	. . .
	1200-1000	275	. . .
	900-750	250	. . .
	Lower than 750	200	. . .
2	3600-3000	250	. . .
	1800-1500	275	. . .
	1200-1000	250	. . .
	900-750	225	. . .
	Lower than 750	200	. . .
3	3600-3000	250	. . .
	1800-1500	275	. . .
	1200-1000	250	225
	900-750	225	200
	Lower than 750	200	. . .
5	3600-3000	225	. . .
	1800-1500	225	200
	1200-1000	225	200
	900-750	225	200
	Lower than 750	200	. . .
7-1/2	3600-3000	215	. . .
	1800-1500	215	190
	1200-1000	215	190
	900-750	215	190
	Lower than 750	200	. . .
10	3600-3000	200	. . .
	1800-1500	200	190
	1200-1000	200	190
	900-750	200	190
	Lower than 750	200	. . .
15-25	All Speeds	200	190
30 and Larger	All Speeds	200	190

Design A values are in excess of those for Design B.
Design D motors have no sharply defined breakdown torque

TABLE 6—LOCKED-ROTOR TORQUE

The locked-rotor torque of Design A, B and C motors, with rated voltage and frequency applied, shall be in accordance with the following values, which are expressed in percentage of full-load torque and represent the upper limit of the range of application.

		DESIGN A and B								DESIGN C		
	60 Cy	3600	1800	1200	900	720	600	514	450	1800	1200	900
Hp	50 Cy	3000	1500	1000	750	600	500	428	375	1500	1000	750
	Poles	2	4	6	8	10	12	14	16	4	6	8
1/2		. . .	. . .	. . .	150	150	115	110	105	. . .	. . .	. . .
3/4		. . .	. . .	175	150	150	115	110	105	. . .	. . .	. . .
1		. . .	275	175	150	150	115	110	105	. . .	. . .	. . .
1-1/2		175	265	175	150	150	115	110	105	. . .	. . .	. . .
2		175	250	175	150	145	115	110	105	. . .	. . .	. . .
3		175	250	175	150	135	115	110	105	. . .	250	225
5		150	185	160	130	130	115	110	105	250	250	225
7-1/2		150	175	150	125	120	115	110	105	250	225	200
10		150	175	150	125	120	115	110	105	250	225	200
15		150	165	140	125	120	115	110	105	225	200	200
20		150	150	135	125	120	115	110	105	200	200	200
25		150	150	135	125	120	115	110	105	200	200	200
30		150	150	135	125	120	115	110	105	200	200	200
40		135	150	135	125	120	115	110	105	200	200	200
50		125	150	135	125	120	115	110	105	200	200	200
60		125	150	135	125	120	115	110	105	200	200	200
75		110	150	135	125	120	115	110	105	200	200	200
100		110	125	125	125	120	115	110	105	200	200	200
125		100	110	125	125	120	115	110	105	200	200	200
150		100	110	125	125	120	115	110	105	200	200	200
200		100	100	125	125	120	115	110	105	200	200	200

The locked [illegible] upper limit [illegible] Design D [illegible] motors is 275%

TABLE 8—LOCKED-ROTOR CURRENT

Locked-rotor current, measured with rated voltage and frequency, shall not exceed the following values for 220-volt Design B (and C and D 60 cycle) cage motors.

Rated Hp	Amperes 60 Cy	Amperes 50 Cy
1/2	12	14
3/4	18	21
1	24	28
1-1/2	35	40
2	45	50
3	60	70
5	90	105
7-1/2	120	140
10	150	175
15	220	255
20	290	335
25	365	420
30	435	500
40	580	670
50	725	835
60	870	1000
75	1085	1250
100	1450	1670
125	1815	2090
150	2170	2495
200	2900	3335

Locked-rotor current at other voltages is inversely proportional to the voltage.

TABLE 9A—STANDARD HORSEPOWER RATINGS —INDUCTION MOTORS

GENERAL-PURPOSE MOTORS: 1/2, 3/4, 1, 1-1/2, 2, 3, 5, 7-1/2, 10, 15, 20, 25, 30, 40, 50, 60, 75, 100, 125, 150, 200.

LARGE MOTORS: 250, 300, 350, 400, 450, 500, 600, 700, 800, 900, 1000, 1250, 1500, 1750, 2000, 2250, 2500, 3000, 3500, 4000, 4500, 5000, 5500, 6000, 7000, 8000, 9000, 10,000, 11,000, 12,000, 13,000, 14,000, 15,000, 16,000, 17,000, 18,000, 19,000, 20,000, 22,500, 25,000, 30,000.

TABLE 9B—STANDARD VOLTAGES—INDUCTION MOTORS

Voltage	Approximate Hp Range	
110	1/2 — 20	
208, 220	1/2 — 200	
440, 550	1/2 — 1000	
2300	40 —	Any practicable rating.
4000	100 —	
4600	250 —	
6600	250 —	
13200	1000 —	

TABLE 9C—STANDARD SPEEDS—INDUCTION MOTORS

Speed in Rpm (60 Cycles)	Number of Poles	Approximate Hp Range	
3600	2	1-1/2 — 5000	
1800	4	1 — 5000	
1200	6	3/4 — 5000	
900	8	1/2 — 10000	
720	10	1/2 — 10000	
600	12	1/2 — 10000	
514	14	3 — 22500	
450	16	3 —	Any practicable required rating.
400	18	50 —	
360	20	50 —	
327	22	50 —	
300	24	50 —	
277	26	75 —	
257	28	100 —	
240	30	125 —	
225	32	150 —	
200	36	200 —	

NOTE: Some of the smaller ratings listed are not normally available in wound-rotor designs, and some of the largest ratings are not normally available for squirrel-cage designs.

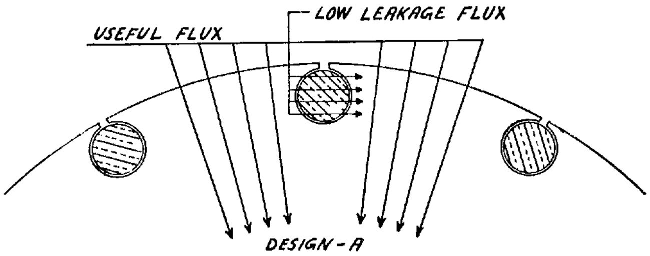
specify locked-rotor (starting) torque, breakdown torque, locked-rotor (starting) current, and slip, variations in practically all types can be obtained by changes in the design of the rotor slots and resistance of the rotor windings. Except for coil design, stator construction remains the same for all types.

It is, however, advantageous to specify motors meeting the NEMA standards, which are as follows:

A *Design A* motor is a squirrel-cage motor designed to withstand full-voltage starting and developing locked-rotor torque as shown in Table 6, breakdown torque as shown in Table 7, with locked-rotor current higher than the values shown in Table 8 and having a slip at rated load of less than 5 percent*. (See *Fig. 44.*) Standard horsepower ratings, voltages and speeds of induction motors are given in Tables 9A, B and C.

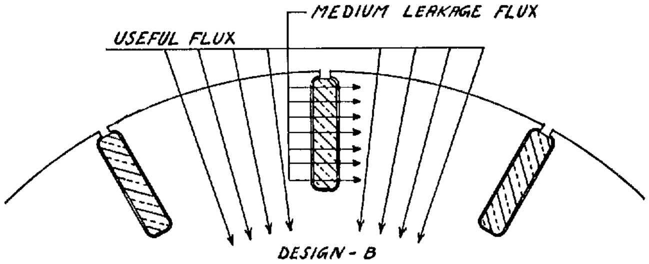
A *Design B* motor is a squirrel-cage motor designed to withstand full-voltage starting, developing locked-rotor and breakdown torques adequate for general application as specified in Tables 6 and 7, drawing locked-rotor current not to exceed the values shown in Table 8 and having a slip at rated load of less than 5 percent*. (See *Fig. 45.*)

A *Design C* motor is a squirrel-cage motor designed to withstand full-voltage starting, developing locked-rotor torque for special high-torque application up to the values shown in Table 6, breakdown torque up to the values shown in Table 7, with locked-rotor current not to exceed the values shown



To obtain normal torque with higher than normal starting current, rotor bars are placed close to surface of rotor. Rotor reactance is relatively low, resulting in high power factor and efficiency.

Fig. H-44.



To obtain normal torque with normal starting current, rotor bars are deep and narrow, producing relatively high reactance when frequency of magnetic flux is high.

Fig. H-45.

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*Motors with 10 and more poles may have slip slightly greater than 5 percent.

TABLE 10—PERFORMANCE DATA

SQUIRREL-CAGE, CONSTANT-SPEED, DESIGN B MOTORS
OPEN AND ENCLOSED[1] TYPES
3 PHASE, 60 CYCLES, 208-220-440-550 VOLTS

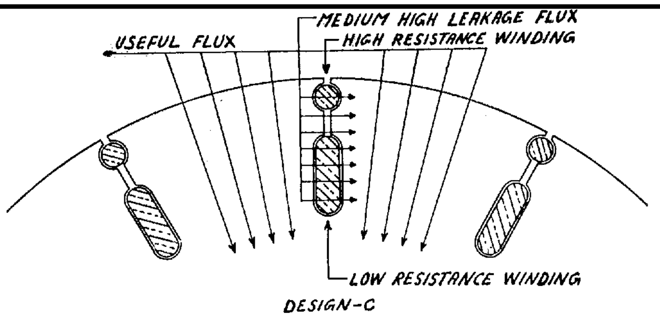
EFFICIENCIES AND POWER FACTORS WHICH MIGHT BE EXPECTED[2]

Hp	Rpm (Synchronous)	Efficiency			Power Factor			Full-Load Current[3] Amps per Phase 220 Volts, 3 Phase
		4/4	3/4	1/2	4/4	3/4	1/2	
1/2	900	66	60	53	54	45	37	2.74
3/4	1200	70	68	64	66	55	43	3.18
3/4	900	68	63	55	57	49	38	3.8
1	1800	76	74	68	71.5	62	48	3.6
1	1200	71	70	64	67	57	45	4.1
1	900	70	66	57	60	51	39	4.66
1-1/2	3600	79	76	69	84	78	67	4.48
1-1/2	1800	79	76.5	72	72.5	66	54	5.14
1-1/2	1200	76.5	76	71	70	61	49	5.5
1-1/2	900	74	73	67	63	52	40	6.3
2	3600	81.5	78	73	84.5	78.5	68	5.7
2	1800	80	78	73	76	68	54.5	6.44
2	1200	77	76	73	71	62	50	7.16
2	900	75	74	69	65	55	43	8.04
3	3600	82.5	82	80	85	79	69	8.4
3	1800	81	81.5	77.5	79	73	61	9.2
3	1200	80	79	75	75	66	51	9.8
3	900	78	76	70.5	65	56	44	11.6
5	3600	83.5	83.5	81	85	79	69	13.8
5	1800	85	85	83	81	75	64	14.2
5	1200	82	81.5	80	77	73	60	15.5
5	900	81	80.5	79	71	63	50	17.0
7-1/2	3600	85	85	82	87	82	75	19.9
7-1/2	1800	84	83.5	81	85.5	80	71	20.4
7-1/2	1200	83.5	83	80	80	74	62	22.0
7-1/2	900	82.5	82	79	71	63	50	25.0
10	3600	86	86	84	88	84	77	26
10	1800	85	85	84	87	83	76	26.5
10	1200	84	84	83	81.5	77	68	28.6
10	900	83.5	83.5	81	80	75	63	29.4
15	3600	86	86	84	90	87	81	38
15	1800	86	86	85	87	84	76	39.4
15	1200	87	87	86	82	77	67	41.2
15	900	84	84	82	81	75	64	43.2
20	3600	86	86	85	91	89	84	50
20	1800	87.5	87.5	86.5	87	84.5	79	51.6
20	1200	87	87	86	82	77	67	55.0
20	900	86	86	85	81	75	64	56.4
25	3600	87	86	85	90	87.5	83.5	62.6
25	1800	88.5	88.5	87.5	87	84.5	79	63.6
25	1200	88	88.5	87	86	83.5	72	64.8
25	900	87	87	86	82	76	66	68.8
30	3600	89	88	86	90	87.5	83.5	73.4
30	1800	89	89	88	88	85	80	75.0
30	1200	88.5	89	88	87.5	85.0	73.5	76
30	900	88	88	87	82	78	70	81.4
40	3600	89	88	86.5	90	87.5	83.5	98
40	1800	89	89	88	88.5	86	81	99.6
40	1200	89	89	88	88	84.5	78	100.0
40	900	88.5	89	88	82	79	71	108.0
50	3600	89	88	85.5	89	87	83.5	124.0
50	1800	89.5	89.5	88	89	87	82	123.0
50	1200	89.5	89.5	88	88	84.5	78	124.4
50	900	88.5	88.5	87	83	79.5	71	134.0
60	3600	90	89	87	90	89	85	145
60	1800	90	90	89.5	89	87	82	147
60	1200	89.5	89.5	88.5	87.5	84.5	76	150
60	900	88.5	88.5	87	83	79.5	71	160
75	3600	90.5	90	88	89.5	88.5	84.5	181
75	1800	90	90	89	89	87	82	184
75	1200	90	90	89	87.5	84.5	76	187
75	900	89	89	88	86	84.5	74	192

[1] For 2-pole, totally-enclosed fan-cooled motors, efficiency should be reduced 1% at 4/4 load, 2% at 3/4 load, and 3% at 1/2 load.

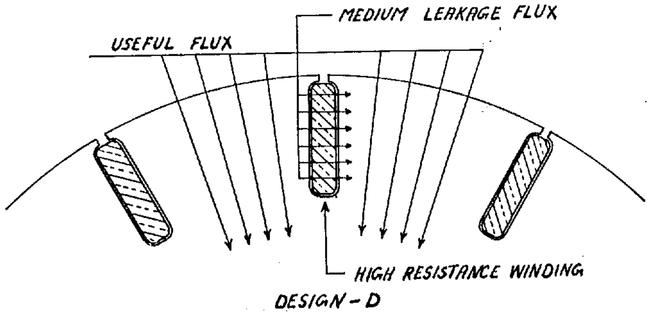
[2] Not to be used for guarantees; consult motor manufacturer.

[3] Full-load current not to be used for selecting heater elements. See nameplate rating of motor involved.



To obtain high starting torque with low starting current, two sets of rotor bars are used. The operation of this type is described under the heading "Double-Cage Motors."

Fig. H-46.



To obtain high starting torque with normal starting current, thin high-resistance bars are used, producing relatively high reactance.

Fig. H-47.

in Table 8 and having a slip at rated load of less than 5 percent. (See *Fig. 46.*)

A *Design D* motor is a squirrel-cage motor designed to withstand full-voltage starting, developing high locked-rotor torque as shown in Table 6, with locked-rotor current not greater than shown in Table 8 and having a slip at rated load of 5 percent or more. (See *Fig. 47.*)

NOTE: Standard speeds for most 25-cycle motors are 1500, 750 and 500 rpm for which no torque values have been established.

Typical Applications

Design A motors obtain higher breakdown torque than Design B motors, but they do this at the expense of higher locked-rotor current.

Design B motors are the standard, forming the basis for comparative motor performance of all other types. Their torque, starting current and slip characteristics make them suitable for most applications. Efficiency is relatively high—even under fractional loads. Power factor is also good at full load, although it does decrease quite rapidly with decrease in load. Both efficiency and power factor decrease as the number of poles increases. (See Table 10.)

Design A and B motors are used for such constant-speed applications as light conveyors, line shafts, blowers, fans, woodworking machines, rotary compressors, centrifugal pumps and machine tools.

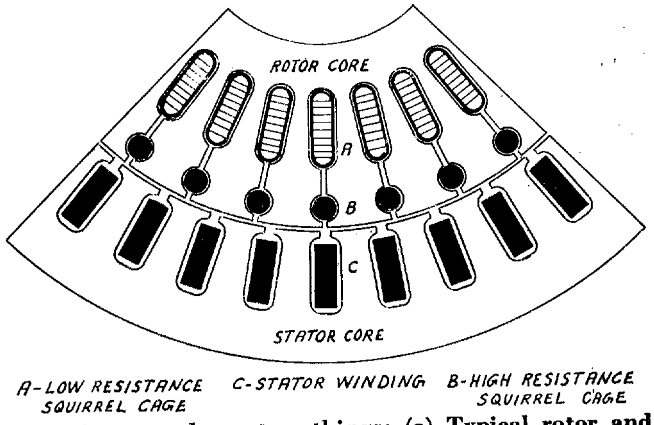
Design C motors have higher locked-rotor torque but lower breakdown torque than Design B motors, while locked-rotor current and slip are the same for the two designs. Design C is for applications requiring high initial torque to start, such as vibrating screens, conveyors, milling machines, pulverizers, reciprocating pumps, crushers, and compressors without unloading devices. It should be noted that while these motors develop high starting torque, they are not intended for applications requiring frequent starting and stopping.

Design D motors have high torque and high slip. They are generally used on applications involving high inertia and frequent load changes, such as flywheel-equipped punch presses. The high slip enables the motor to pick up the load when the excess energy stored in the flywheel has been released during the working stroke of the cycle. The high torque enables the motor to repeatedly accelerate the load to full speed, without overheating, to restore energy to the flywheel. This alternate supplying and releasing of power irons out the load peaks, that is, the maximum power demand. Other applications include elevators, metal drawing, shears, hoists, and bailers.

Double-Cage Motors

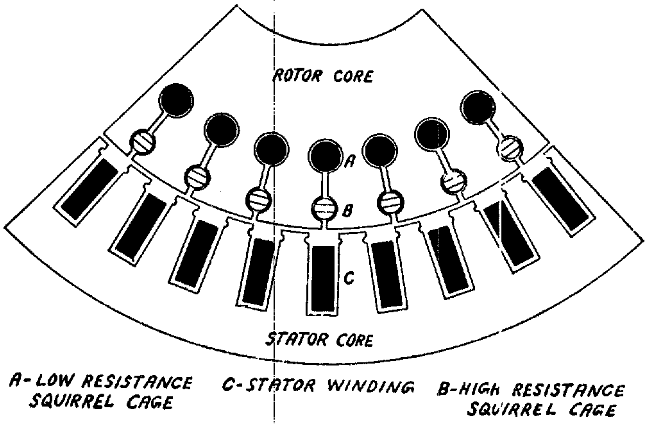
A double-cage motor is a polyphase induction motor having a rotor with two separate squirrel-cage windings, one within the other, as shown in *Figs. 48* and *49*. The stator is of standard construction. Double-cage construction is used only when it is necessary to obtain high starting torques with relatively low starting current. It provides higher starting torques than ordinary single-winding motors, but not as high torques as single high-resistance winding motors.

In a double-cage motor, the outer cage has high resistance and the inner cage has low resistance. The former provides high torque in starting, while the latter carries most of the current at full load.



This diagram shows two things: (a) Typical rotor and stator slot shapes used in small double-cage rotors. (b) Relative current flow at time motor is ready to start; most of current is carried by high-resistance outer cage bars, giving high starting torque with low starting current.

Fig. H-48.



(a) Typical rotor and stator slot shapes used in large double-cage motors. (b) Relative current flow when motor has reached normal speed; most of current is carried by low-resistance inner cage, giving high efficiency during operation.

Fig. H-49.

Figs. 48 and *49* show that the inner cage bars are more completely enclosed by stator core iron than are the outer cage bars. Thus the magnetic path around the inner cage bars is more satisfactory than that around the outer bars. This, however, means that the path around the inner bars has greater inductance.

Now, at the instant of starting, the revolving field produced by the stator current induces currents in both sets of rotor conductors—at full line frequency. But at full line frequency, the high inductance of the inner winding impedes the current in the inner conductors.

However, even at full line frequency, considerable current is set up in the outer conductors since they have relatively low inductance. But this is a high resistance winding, and this plus the choking action of self-induction at line frequency limits the current in starting.

In *Fig. 48*, the depth of shading indicates the comparative density of the currents in the two sets of conductors when the motor is ready to start.

As the rotor gains speed, the frequency of the currents induced in the rotor decreases, and the relationship between the currents in the two squirrel cages automatically changes. This is due to the fact that the frequency of the induced currents is proportional to the slip, and at normal speed this frequency becomes only a few cycles per second.

At this low frequency, the higher inductance of the inner cage windings produces only a small choking effect. Therefore the resistances of the two cages are the essential factors influencing the distribution of and limiting the flow of the rotor currents. Thus, at normal speed the greater part of the total rotor current is carried by the low-resistance inner cage, as indicated by the shading in *Fig. 49*.

WOUND-ROTOR MOTORS

A wound-rotor induction motor, sometimes called a *slip-ring* motor, is defined by NEMA as an induction motor in which the secondary circuit consists of a polyphase winding or coils whose terminals are either short-circuited or closed through suitable circuits. (*Fig. 50* shows a standard wound-rotor motor.)

The general principles of operation of the polyphase wound-rotor motor are quite similar to those of the polyphase squirrel-cage type.

The essential structural difference between the wound-rotor motor and the squirrel-cage motor is in the rotor. The wound-rotor motor has a distributed phase-wound rotor winding arranged for the same number of poles as the stator winding. The terminals of the rotor winding are connected to three collector rings (slip rings) mounted on the shaft (*Fig. 51*). From brushes riding on the collector rings, leads are brought out for connection to a secondary control—which provides resistance for starting or speed regulating purposes.

To increase the speed, the resistance is gradually cut out of the circuit until, for operation at full speed, the rotor winding is short-circuited through the control.

The torque of a polyphase induction motor is a function of its impedance, and the function of the wound-rotor motor secondary control is to change the impedance to an optimum value. By properly proportioning the external resistance, it is possible to obtain a locked-rotor torque that is nearly equal

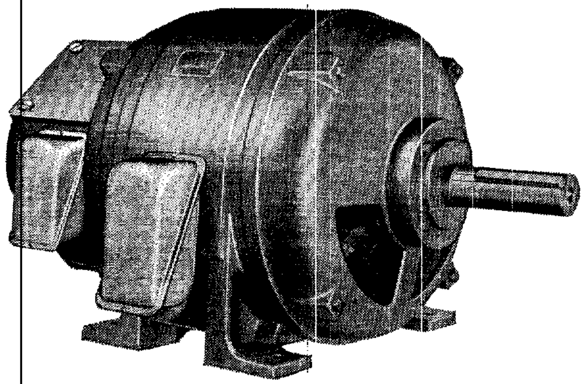


Fig. H-50. Open, drip-proof wound-rotor motor.

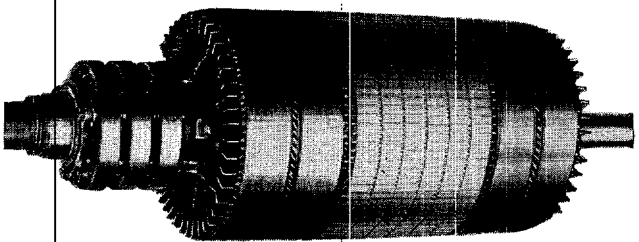


Fig. H-51. Representative wound-rotor.

to the breakdown torque, and this can be done with much lower locked-rotor (starting) current than with squirrel-cage motors.

Wound-Rotor Motor Advantages

The wound-rotor motor thus has some very distinct advantages over the squirrel-cage motor:

a) It can develop high starting torque with relatively low starting current. This characteristic makes it suitable for high load-torque drives where starting current must be limited.

As noted above, it is possible to obtain starting torques nearly equal to the breakdown torques. This depends on the external resistance in the rotor circuit and its method of distribution. The breakdown torque, with collector rings short-circuited, is not less than *200* percent for general-purpose ratings, and larger values can be obtained for special load requirements.

b) The major portion of the heat developed during starting can be dissipated in the external resistors (provided that they are suitably proportioned) instead of being concentrated in the rotor winding, as is the case in squirrel-cage motors. This makes the wound-rotor motor suitable for drives having such high load inertia as to be beyond the thermal capacity of the starting windings of squirrel-cage or synchronous motors.

c) The wound-rotor motor can be used for adjustable-varying speed regulating duty for such applications as fans, cranes, hoists, etc. It should be noted that this does not, however, provide good speed regulation on non-steady loads as the speed changes with changes in load, due to the *slip* inherent in induction motors. The percentage of speed reduction obtainable depends on the character of the load; a *50 percent reduction* is usually permissible on variable torque loads without producing unstable operation. The temperature of the motor will usually be higher at reduced speeds, due to the reduction in normal ventilation.

Other Characteristics

When a wound-rotor motor is operating at full speed with the secondary short-circuited through the control, its operating characteristics are very similar to those of a normal-torque, normal starting-current cage motor. The main differences are usually slightly lower slip (2 percent for larger sizes to 5 percent for smaller ones) and somewhat lower power factors (due to certain magnetic "leakage" factors inherent in the design).

MULTI-SPEED INDUCTION MOTORS

Multi-speed squirrel-cage motors can be designed to operate at two, three or four speeds—having constant-speed characteristics at each speed.

Wound-rotor motors are limited to two fixed speeds because of complications in rotor construction. However, each "fixed" speed is capable of further speed adjustment in the same manner as outlined above for single-speed motors of this type. For example, the speed can be adjusted from the higher one through the range to the lower fixed speed.

Multi-speed squirrel-cage construction constitutes the simplest form of adjustable-speed motor, since there are no brushes, commutators or collector rings involved. Its principal drawback lies in the fact that it provides only the two, three or four speeds for which it is designed—there are no intermediate speeds.

Construction Principles

The stator may have either one or two windings, each of which will produce either one or two of the desired rotor speeds—depending upon the ratios of the various speeds required.

Two-speed motors (for operation on 3-phase circuits) having a speed ratio of 2 to 1 (1800 and 900 rpm, or 1200 and 600 rpm, for example) are usually furnished with a single stator winding. The two speeds are obtained by means of a selector switch which renders either all or half of the poles effective. With all of the poles effective, the motor operates at the low speed; with half of the poles effective, it operates at the high speed. This is called a *consequent-pole* winding, and the low speed is always one-half of the high speed.

If the two speeds required are not in a 2 to 1 ratio, two separate stator windings are required. This applies to such speed ratios as 1200/900 rpm or 1800/1200 rpm.

When three or four speeds are required, the motor is built with two separate windings, with one or both of the windings being of the consequent-pole type. This permits speed ratings such as 1200/900/600 rpm or 1800/1200/900/600 rpm. Diagrams of windings and coil connections of consequent pole motors are shown on pages 124 and 125, Section F.

Torque Characteristics

Multi-speed motors are available with any one of the following three torque characteristics:

Constant-horsepower motors produce the same horsepower output at all speeds. They are used for lathes, boring mills and other machine tools where the torque demand decreases as the speed increases.

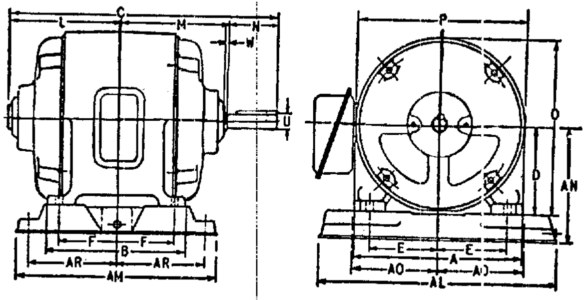
Constant-torque motors produce the same torque at all speeds and the horsepower is in direct proportion to the speed. These motors are used for conveyors, stokers, etc.

Variable-torque motors produce a torque that decreases with the speed, resulting in a horsepower output which decreases with the square of the speed. They are used principally for fans; the power require-

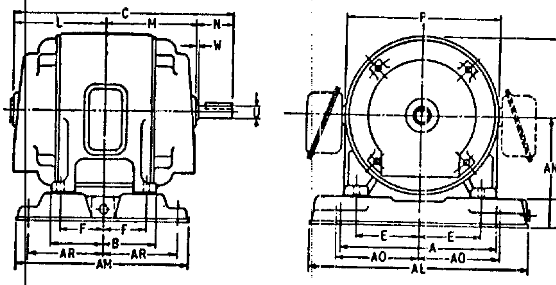
TABLE 11—SUMMARY OF PROTECTION AND ENCLOSURES—INDUCTION MOTORS

Type of Enclosure	Approximate Range of Sizes	Standard Temperature Rise Class A Insulation	Approximate Cost Increase	Application Information
Open, drip-proof	**1/2 hp and larger**	**40 C**	**0 to 10%**	**Protection against dripping liquids or falling particles.**
Semi-protected	**1/2 hp and larger**	**50 C**	**5%**	**Same as *protected.***
Protected	**1/2 hp and larger**	**50 C**	**10%**	**Protection against metal chips in machine shops, etc.**
Splash-proof	**Frame 224 and larger**	**50 C**	**10 to 15%**	**Protection against dripping and splashing liquids; used in breweries, food plants, dairies, etc.**
Enclosed, forced-ventilated	**Frame 364 and larger**	**40 C**	**4 to 20%**	**Same as *fan-cooled.***
Enclosed, self-ventilated	**Frame 364 and larger**	**40 C**	**15 to 40%**	**Same as *fan-cooled.***
Totally-enclosed, non-ventilated	**Frames 204 to 254**	**55 C**	**10 to 40%**	**Same as *fan-cooled.***
Totally-enclosed, fan-cooled	**Frame 254 and larger**	**55 C**	**40 to 115%**	**Used where abrasive dust, dirt, grit, or corrosive fumes are too severe for open motors—in metal-working plants, foundries, machine shops, etc.**
Explosion-proof	**Frame 225 and larger**	**55 C**	**10 to 20% higher than *fan-cooled***	**For oil refineries, varnish plants, lacquer plants, or others where flammable, volatile liquids are manufactured, used or handled.**

TABLE 12—REPRESENTATIVE CAGE MOTOR DIMENSIONS (IN INCHES)



Open Drip-Proof



Splash-Proof

Frame	A‡	B‡	C	D†	E†	F†	L	M	N	O	P	U†	W	AL	AM	AN	AO†	AR†	Key†
203	9¾	6¾	13⅞	5	4	2¾	5¾	5¾	2⅜	9 11/16	9⅝	.750	⅛	14	11	6¾	5	4¾	3/16x3/16x1⅜
204	9¾	7¾	14⅞	5	4	3¼	6¼	6¼	2⅜	9 11/16	9⅝	.750	⅛	14	12	6¾	5	5¼	3/16x3/16x1⅜
224	10¾	8¼	16⅝	5½	4½	3⅜	6¾	6¾	3⅛	10 11/16	10⅝	1.000	⅛	15½	12¼	7¼	5½	5⅜	¼x¼x2
225	10¾	9	17⅜	5½	4½	3¾	7⅛	7⅛	3⅛	10 11/16	10⅝	1.000	⅛	15½	13	7¼	5½	5¾	¼x¼x2
254	11¾	10	20	6¼	5	4⅛	8¼	8¼	3½	12 1/32	11 9/16	1.125	⅛	17¾	15⅓	8¼	6¼	6⅝	¼x¼x2⅜
284	12¾	11¼	22⅝	7	5½	4¾	9⅜	9⅜	3⅞	13 5/16	12⅝	1.250	⅛	19¾	16⅞	9	7	7½	¼x¼x2¾
324	14¾	12¾	25 11/16	8	6¼	5¼	10 5/16	10 5/16	5 1/16	15 5/16	14⅝	1.625	3/16	22¾	19¼	10½	8	8½	⅜x⅜x3¾
326	14¾	14¼	27 5/16	8	6¼	6	11 1/16	11 1/16	5 1/16	15 5/16	14⅝	1.625	3/16	22¾	20¾	10½	8	9¼	⅜x⅜x3¾
364	17½	14	28⅜	9	7	5⅝	11¼	11¼	5⅞	17¾	17⅝	1.875	¼	25½	20½	11½	9	9⅛	½x½x4¼
364-S	17½	14	26	9	7	5⅝	11¼	11¼	3½	17¾	17⅝	1.625	¼	....	....	....	....	....	⅜x⅜x1⅞
365	17½	15	29⅜	9	7	6⅛	11¾	11¾	5⅞	17¾	17⅝	1.875	¼	25½	21½	11½	9	9⅝	½x½x4¼
365-S	17½	15	27	9	7	6⅛	11¾	11¾	3½	17¾	17⅝	1.625	¼	....	....	....	....	....	⅜x⅜x1⅞
404	19½	15¼	31⅝	10	8	6⅛	12½	12½	6⅝	19 11/16	19 9/16	2.125	¼	28½	22	13	10	9⅞	½x½x5
404-S	19½	15¼	29	10	8	6⅛	12½	12½	4	19 11/16	19 9/16	1.875	¼	....	....	....	....	....	½x½x2
405	19½	16¾	33⅛	10	8	6⅞	13¼	13¼	6⅝	19 11/16	19 9/16	2.125	¼	28½	23½	13	10	10⅝	½x½x5
405-S	19½	16¾	30½	10	8	6⅞	13¼	13¼	4	19 11/16	19 9/16	1.875	¼	....	....	....	....	....	½x½x2
444	21½	17½	35⅞	11	9	7¼	14	14	7⅞	21⅝	21½	2.375	¾	31	24¼	14	11	11	⅝x⅝x5½
444-S	21½	17½	33	11	9	7¼	14	14	5	21⅝	21½	2.125	¾	....	....	....	....	....	½x½x2¾
445	21½	19½	37⅞	11	9	8¼	15	15	7⅞	21⅝	21½	2.375	¾	31	26¼	14	11	12	⅝x⅝x5½
445-S	21½	19½	35	11	9	8¼	15	15	5	21⅝	21½	2.125	¾	....	....	....	....	....	½x½x2¾
504-U	24½	19	40⅞	12½	10	8	15¾	15¾	9⅛	24⅞	24⅝	2.875	¾	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	¾x¾x7¼
505	[illegible]	[illegible]	42⅞	12½	[illegible]	[illegible]	16¾	16¾	9⅛	24⅞	24⅝	2.875	¾	34½	29¼	16	12½	13½	¾x¾x7¼

TABLE 13—REPRESENTATIVE CAGE MOTOR FRAME SIZES

STANDARD OPEN DRIP-PROOF AND SPLASH-PROOF MOTORS (60 CYCLES)

Hp	3600	1800	1200	900	720	600
1/2	....	....	....	204	224	225
3/4	....	....	203	224	225	254
1	....	203	204	225	254	254
1-1/2	203	204	224	254	254	284
2	204	224	225	254	284	324
3	224	225	254	284	324	326
5	225	254	284	324	326	364
7-1/2	254	284	324	326	364	365
10	284	324	326	364	365	404
15	324	326	364	365	404	405
20	326	364	365	404	405	444
25	364S	364	404	405	444	445
30	364S	365	405	444	445	504U
40	365S	404	444	445	504U	505
50	404S	405S	445	504U	505	....
60	405S	444S	504U	505	....	....
75	444S	445S	505	....	....	....
100	445S	504S	....	....	....	....
125	504S	505S	....	....	....	....
150	505S	....	....	....	....	....

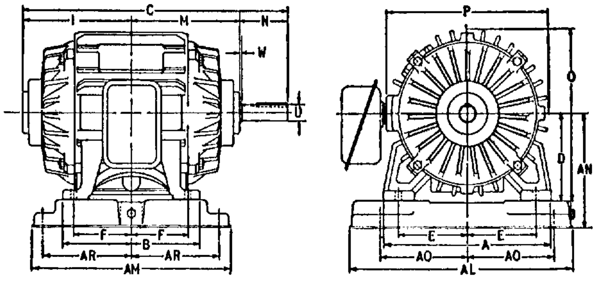
STANDARD TOTALLY-ENCLOSED MOTORS (60 CYCLES)

Motors above line are non-ventilated.

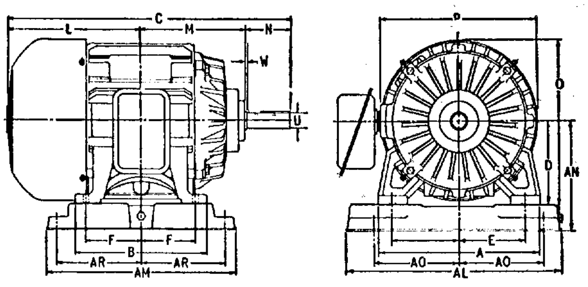
Motors below line are fan-cooled.

Hp	3600	1800	1200	900	720	600
1/2	....	....	....	204	224	225
3/4	....	....	203	224	254	254
1	....	203	204	225	254	254
1-1/2	204	204	224	254	254	284
2	204	224	225	254	284	324
3	224	225	254	284	324	326
5	225	254	284	324	326	365
7-1/2	254	284	324	326	365	404
10	284	324	326	364	404	405
15	324	326	364	365	405	444
20	326	364	365	404	444	445
25	365S	365	404	405	445	504U
30	404S	404	405	444	504U	505
40	405S	405	444	445	505	
50	444S	444S	445	504U		
60	445S	445S	504U	505		
75	504S	504S	505			
100	505S	505S				

TABLE 12—REPRESENTATIVE CAGE MOTOR DIMENSIONS (IN INCHES)—Continued



Totally-Enclosed Non-Ventilated and Explosion-Proof



Totally-Enclosed Fan-Cooled and Explosion-Proof

Frame	A‡	B‡	C	D†	E†	F†	L	M	N	O	P	U†	W	AL	AM	AN	AO†	AR†	Key†
203*	9¾	6¾	13⅞	5	4	2¾	5¾	5⅝	2½	9¾	9½	.750	¼	14	11	6¾	5	4¾	3/16x3/16x1⅜
204*	9¾	7¾	14⅞	5	4	3¼	6¼	6⅛	2½	9¾	9½	.750	¼	14	12	6¾	5	5¼	3/16x3/16x1⅜
224*	10¾	8¼	16⅝	5½	4½	3⅜	6¾	6⅝	3¼	10 13/16	10⅝	1.000	¼	15½	12¼	7¼	5½	5⅜	¼x¼x2
225*	10¾	9	17⅜	5½	4½	3¾	7⅛	7	3¼	10 13/16	10⅝	1.000	¼	15½	13	7¼	5½	5¾	¼x¼x2
254	11¾	10	22 1/16	6¼	5	4⅛	10 5/16	8⅛	3⅝	12	11½	1.125	¼	17¾	15⅛	8¼	6¼	6⅝	¼x¼x2⅜
284	12¾	11¾	24¾	7	5½	4¾	11½	9¼	3⅝	13¼	12½	1.250	¼	19¾	16⅞	9	7	7½	¼x¼x2¾
324	14¾	12¾	28¼	8	6¼	5¼	12⅞	10¼	5⅛	15⅝	15¼	1.625	¼	22¾	19¼	10½	8	8½	⅜x⅜x3¾
326	14¾	14¼	29¾	8	6¼	6	13⅝	11	5⅛	15⅝	15¼	1.625	¼	20¾	22¾	10½	8	9¼	⅜x⅜x3¾
364	17½	14	31⅛	9	7	5⅝	14	11¼	5⅞	18½	19	1.875	¼	25½	20½	11½	9	9⅛	½x½x4¼
364-S	17½	14	28¾	9	7	5⅝	14	11¼	3½	18½	19	1.625	¼	....	....	....	....	....	⅜x⅜x1⅞
365	17½	15	32⅛	9	7	6⅛	14½	11¾	5⅞	18½	19	1.875	¼	25½	21½	11½	9	9⅝	½x½x4¼
365-S	17½	15	29¾	9	7	6⅛	14½	11¾	3½	18½	19	1.625	¼	....	....	....	....	....	⅜x⅜x1⅞
404	19½	15¼	34⅜	10	8	6⅛	15¼	12½	6⅝	20⅜	20⅝	2.125	¼	28½	22	13	10	9⅞	½x½x5
404-S	19½	15¼	31¾	10	8	6⅛	15¼	12½	4	20⅜	20⅝	1.875	¼	....	....	....	....	....	½x½x2
405	19½	16¾	35⅞	10	8	6⅞	16	13¼	6⅝	20⅜	20⅝	2.125	¼	28½	23½	13	10	10⅝	½x½x5
405-S	19½	16¾	33¼	10	8	6⅞	16	13¼	4	20⅜	20⅝	1.875	¼	....	....	....	....	....	½x½x2
444	21½	17½	39⅝	11	9	7¼	17¾	14¼	7⅝	22⅝	23¼	2.375	½	31	24¼	14	11	11	⅝x⅝x5½
445	21½	19½	41⅝	11	9	8¼	18¾	15¼	7⅝	22⅝	23¼	2.375	½	31	26¼	14	11	12	⅝x⅝x5½
445-S	21½	19½	38¾	11	9	8¼	18¾	15¼	4¾	22⅝	23¼	2.125	½	....	....	....	....	....	½x½x2¾
504-U	24½	21	44⅛	12½	10	8	19	16¼	8⅞	24½	24½	2.875	¼	34½	27¼	16	12½	12½	¾x¾x7¼
505	24½	23	46⅛	12½	10	9	20	17¼	8⅞	24½	24½	2.875	¼	34½	29¼	16	12½	13½	¾x¾x7¼

*Dimensions shown for these frames are for totally-enclosed non-ventilated construction.

†These are NEMA standard dimensions. Other dimensions may vary, depending upon the manufacturer.

‡These are representative dimensions well within maximums listed by NEMA.

ments of a fan decrease approximately as the cube of the speed.

Squirrel-cage multi-speed motors are built to the same NEMA design standards for torques and starting currents as single-speed motors.

MOTOR PROTECTION

Classification of machines by types of mechanical protection and methods of cooling will be found in the definitions of pages 4 to 9. Accompanying illustrations, *Figs. 5* to *28*, inclusive, show the construction employed for the various types, and Table 11 gives a brief summary of such features. This table shows (a) the approximate range of sizes or ratings in which each type is built, (b) the maximum temperature rise for Class A insulated machines, (c) the approximate increase in cost over the standard open type, and (d) application suggestions.

STANDARD DIMENSIONS

Table 12 gives representative dimensions for foot-mounted motors, while Table 13 shows representative frame sizes for various horsepower and speed ratings in open drip-proof and totally-enclosed motors.

GEARMOTORS

Gearmotors meet the demand for a highly efficient, economical and dependable source of power for low-speed drives. Basically, a gearmotor consists of a 1750-rpm motor and a double-, triple- or quadruple-reduction gear unit. The standard motor is the squirrel-cage type, but wound-rotor and direct-current motors are occasionally used.

Construction

The gear units use precision-cut gears, some manufacturers using the helical type and others the planetary type. The gear efficiency usually is not less than 97 percent.

High efficiency and, in the case of induction motors, good power factor results from the use of high-speed motors. Motors usually are of the standard open drip-proof type, but in most cases splash-proof or totally-enclosed types are also available, as well as vertical types.

Performance and cost are usually consistently better than for direct-connected motors of the same output speeds. For smaller ratings, gearmotor construction is the only practical answer for low output speeds. *Figs. 52* and *53* show two types of gearmotors.

Ratings and Classifications

Units of this type are available in ratings up to 50 hp for all applications and up to 75 hp for some applications. Table 14 gives output speeds listed in the NEMA Recommended Standards, but it should be noted that some of these speeds, namely 1430, 1170, 950, 6, 5, and 4 rpm, are seldom used and are not always available.

TABLE 14—OUTPUT SPEEDS FOR INTEGRAL-HORSEPOWER GEARMOTORS OF PARALLEL CONSTRUCTION

Nominal Gear Ratios	Output Speeds	Nominal Gear Ratios	Output Speeds
1.225	1430	25.628	68
1.500	1170	31.388	56
1.837	950	38.442	45
2.250	780	47.082	37
2.756	640	57.633	30
3.375	520	70.623	25
4.134	420	86.495	20
5.062	350	105.934	16.5
6.200	280	129.742	13.5
7.594	230	158.900	11.0
9.300	190	194.612	9.0
11.390	155	238.350	7.5
13.950	125	291.917	6.0
17.086	100	357.525	5.0
20.926	84	437.875	4.0

These output speeds are based on an assumed operating speed of 1750 rpm and certain nominal gear ratios and will be modified:

1. By the variation in individual motor speeds from the basic operating speed of 1750 rpm.

   (The same list of output speeds may be applied to 25- or 50-cycle gearmotors when employing motors of 1500 rpm synchronous speed if an assumed motor operating speed of 1430 rpm is used.)

   (This list of output speeds may be applied to 60-cycle gearmotors when employing motors of 1200 rpm synchronous speed if an assumed motor operating speed of 1165 rpm is used.)

2. By a variation in the exact gear ratio from the nominal, which variation will not change the output speed by more than plus or minus 3 per cent.

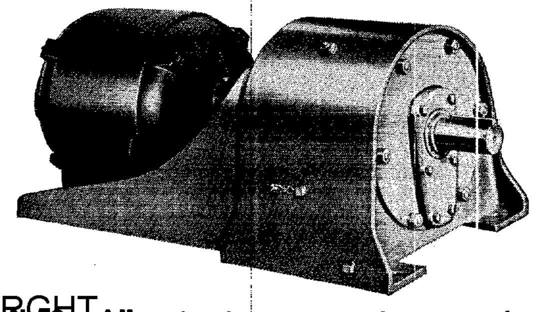


Fig. H-52. All-motor type gearmotors use standard foot-mounted motors—recommended when space permits.

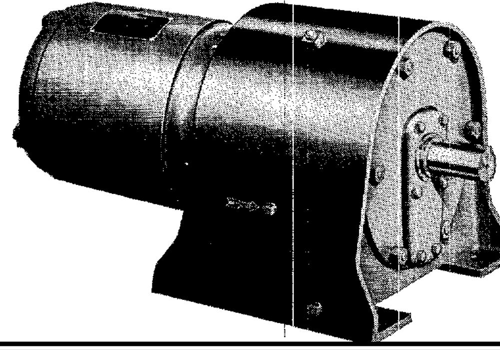


Fig. H-53. Integral-type gearmotor uses round-frame C-flange motor, resulting in shorter over-all length.

AGMA recommended practice calls for three classifications of gearmotors as follows:

Class I—For steady loads not exceeding normal rating of motor and 8 hours a day service. Moderate shock loads where service is intermittent.

Class II—For steady loads not exceeding normal rating of motor and 24 hours a day. Moderate shock loads for 8 hours a day.

Class III—Moderate shock loads for 24 hours a day. Heavy shock loads for 8 hours a day.

As shown by Table 15, gearmotors in these various classifications are available for most applications. To assure proper selection of units, it is essential that the manufacturer be given complete application data.

TABLE 15—COMMONLY AVAILABLE GEARMOTOR RATINGS

Output Rpm (1750 Rpm Motors)	Hp		
	Class I	Class II	Class III
520, 420, 350	**1 to 50**	**1 to 50**	**1 to 40**
280, 230, 190, 155	**1 to 50**	**1 to 50**	**1 to 50**
125	**1 to 50**	**1 to 50**	**1 to 40**
100	**1 to 50**	**1 to 50**	**1 to 30**
84	**1 to 50**	**1 to 30**	**1 to 25**
68	**1 to 40**	**1 to 30**	**1 to 20**
56	**1 to 40**	**1 to 25**	**1 to 30**
45	**1 to 30**	**1 to 20**	**1 to 15**
37	**1 to 25**	**1 to 20**	**1 to 10**
30	**1 to 20**	**1 to 15**	**1 to 10**
25, 20	**1 to 15**	**1 to 10**	**1 to 7.5**
16.5, 13.5	**1 to 10**	**1 to 7.5**	**1 to 5.0**
11.0, 9.0	**1 to 7.5**	**1 to 5.0**	**1 to 3.0**
7.5	**1 to 5.0**	**1 to 3.0**	**1 to 3.0**

TABLE 16—OPERATION ON OFF-STANDARD VOLTAGES AND FREQUENCIES

VALUES SHOWN ARE FOR GENERAL-PURPOSE DESIGN B CAGE MOTORS AND WILL VARY SOMEWHAT FOR DIFFERENT RATINGS AND DESIGNS.

Characteristic	Voltage (in percent of rated)		Frequency (in percent of rated)	
	110%	90%	105%	95%
***Torque**				
Locked-rotor and breakdown	**Increase 21%**	**Decrease 19%**	**Decrease 10%**	**Increase 11%**
†Speed				
Synchronous	**No change**	**No change**	**Increase 5%**	**Decrease 5%**
Full load	**Increase 1%**	**Decrease 1.5%**	**Increase 5%**	**Decrease 5%**
Percent slip	**Decrease 17%**	**Increase 23%**	**Little change**	**Little change**
Efficiency				
Full load	**Increase 0.5 to 1**	**Decrease 2**	**Slight increase**	**Slight decrease**
3/4 load	**Little change**	**Little change**	**Slight increase**	**Slight decrease**
1/2 load	**Decrease 1 to 2**	**Increase 1 to 2**	**Slight increase**	**Slight decrease**
Power factor				
Full load	**Decrease 3%**	**Increase 1%**	**Slight increase**	**Slight decrease**
3/4 load	**Decrease 4%**	**Increase 2 to 3%**	**Slight increase**	**Slight decrease**
1/2 load	**Decrease 5 to 6%**	**Increase 4 to 5%**	**Slight increase**	**Slight decrease**
Current				
Locked-rotor	**Increase 10 to 12%**	**Decrease 10 to 12%**	**Decrease 5 to 6%**	**Increase 5 to 6%**
Full load	**Decrease 7%**	**Increase 11%**	**Slight decrease**	**Slight increase**
Temperature rise	**Decrease 3 to 4 C**	**Increase 6 to 7 C**	**Slight decrease**	**Slight increase**
Maximum overload capacity	**Increase 21%**	**Decrease 19%**	**Slight decrease**	**Slight increase**
Magnetic noise	**Slight increase**	**Slight decrease**	**Slight decrease**	**Slight increase**

*The locked-rotor and breakdown torque of ac induction motors will vary as the square of the voltage.

†The speed of ac induction motors will vary directly with the frequency.

OPERATION ON OFF-STANDARD VOLTAGES AND FREQUENCIES

Guarantees of motor characteristics (torque, power factor, efficiency, etc.) are based on operation of the motor at rated (nameplate) voltage and frequency. As explained earlier, under the heading *Service Conditions*, motors will operate successfully despite some deviation from rated values, but not necessarily in accordance with the standards established for operation under rated conditions. Table 16 shows the *approximate* effects of variations in voltage and frequency on motor performance. The values will vary somewhat with the rating of the motor.

SYNCHRONOUS MOTORS

A synchronous motor is defined by NEMA as a synchronous machine which transforms electrical power from an alternating-current system into mechanical power. Synchronous motors usually have direct-current field excitation.

A synchronous motor consists essentially of a stationary armature (stator) and a revolving field with windings arranged for excitation from a source of direct current. Fields of motors with four or more poles are of the salient pole type. Two-pole motors, which are seldom used except in very large sizes, are usually of the non-salient pole type and are similar to steam-turbine-driven synchronous generators.

The speed of a synchronous motor is a function of the number of poles. It remains in synchronism with the supply frequency and is unaffected by the load. (See Table 1.)

Efficiencies are generally higher than for induction motors of corresponding ratings. This is particularly so

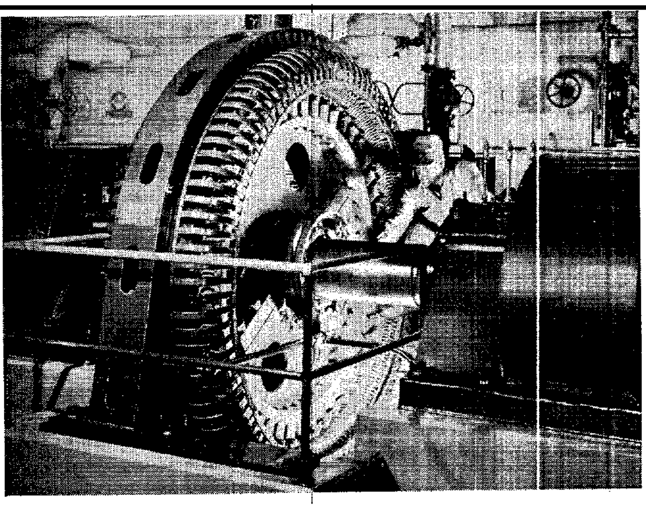


Fig. H-54. Engine-type, 600-hp, 150-rpm synchronous motor driving 450-ton-per-day ammonia compressor.

in the case of unity power factor motors and/or lower speeds.

Application of synchronous motors requires careful consideration of all factors involved, especially:

- Power factor.
- Locked-rotor (static) torque.
- Pull-up (accelerating) torque.
- Pull-in torque.
- Pull-out torque.
- Effect of load inertia on pull-in torque and thermal capacity of the amortisseur winding.
- Effect of voltage variation on torques.

POWER FACTOR

Normally, one does not think of induction motors as requiring excitation, but actually they do. The fact is, the exciting current is supplied from the line. And because the magnetizing component lags 90 degrees, the result is that the line current lags at all loads to an extent depending on the magnitude of the magnetizing current.

In synchronous motors, the excitation is supplied to the field from a separate dc source. Thus, by varying the field strength, the phase relationship (power factor) of the armature current and voltage may be changed. With a given field strength the power factor is unity; that is, the armature current is a minimum and in phase with the voltage.

Decreasing the field strength causes the increasing current to lag, increasing the field strength causes the increasing current to lead the voltage. In other words, lagging or leading power factor results. Synchronous motors can therefore be made suitable for power-factor correction purposes.

The above should not be interpreted to mean that any such motor is necessarily suitable for operation at other than its rated power factor and rated load.

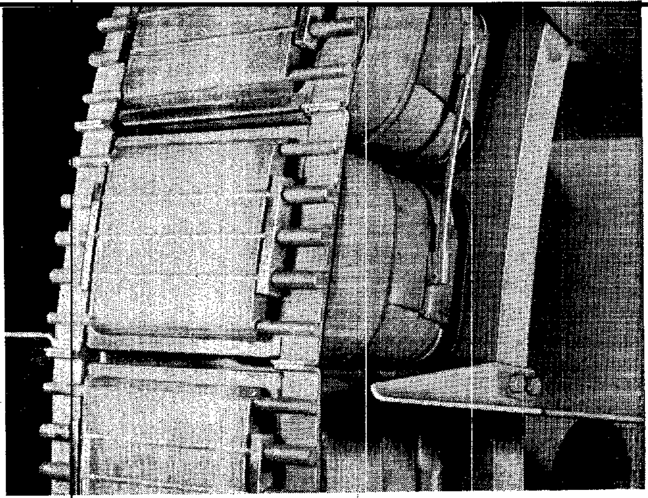


Fig. H-55. Close-up of synchronous motor rotor showing details of field and amortisseur windings.

STARTING

Amortisseur Winding

The armature (stator) winding is wound for operation from a polyphase (2 or 3-phase) source. When voltage is applied at the terminals, a revolving magnetic field is produced in the stator; its speed is proportional to the frequency and number of poles.

The rotor assembly contains an amortisseur winding in the pole faces. This winding is similar to the cage winding of an induction motor. It is shown in *Fig. 55.*

The revolving field of the armature acting on the amortisseur winding produces (a) the static torque that causes the motor to break from rest and (b) the pull-up torque for acceleration. Depending upon the type of load and the resistance of the amortisseur winding, the motor will accelerate to a speed of from 2 to 5 percent below synchronous speed.

Pull-in Torque

Thus, the synchronous motor is actually started and brought up to near synchronous speed as a squirrel-cage motor. Then the field excitation is applied. If the motor is properly designed for the application, the field of the rotor will "pull in" and lock in step with the rotating magnetic field of the stator.

Effect of Load Wk^2

Certain types of drives are characterized by high load inertia (load Wk^2), as indicated by Table 18. The load inertia which a synchronous motor can accelerate is definitely limited by the thermal capacity of its amortisseur winding.

Smaller motors can accelerate relatively higher load Wk^2 than larger motors, until a point may be reached in the very large sizes where the motor may be capable of accelerating only a relatively small load Wk^2.

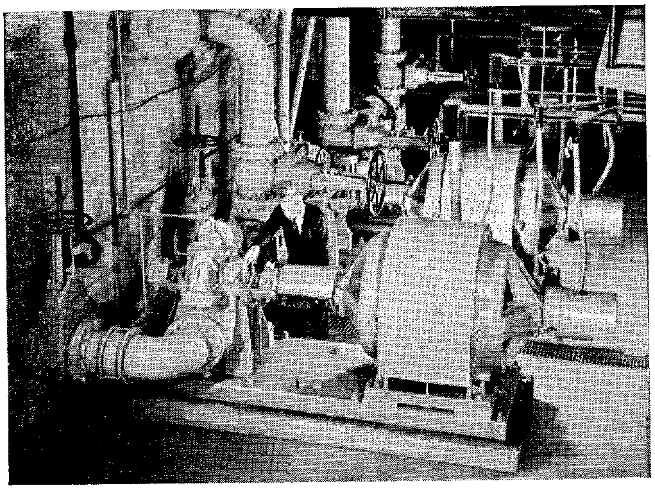


Fig. H-56. Besides driving 3000-gpm pumps, these 500-hp synchronous motors improve plant power factor.

As indicated by the NEMA definition of pull-in torque on page 4, the matter of load Wk² has a most important effect on the pull-in capabilities of synchronous motors.

Effect of Voltage on Torques

It must be remembered that all torque values listed are based on full voltage at the motor terminals. Hence, if the voltage at the terminals is below rated voltage, the starting and pull-in torques should be based on values adjusted to compensate for the reduction in voltage so that the required torques will be obtained with the actual voltage at the terminals.

This condition exists when reduced-voltage starting is used and/or when the line voltage drops below rated voltage during the starting period.

Starting and pull-in torques vary approximately as the square of the voltage.

For example, suppose you have an application that requires 100 percent starting torque (static torque) and 100 percent pull-in torque. Suppose also that reduced voltage starting on 85 percent tap and pull-in on full voltage is to be used but that line voltage will drop to 95 percent during the starting and pull-in period. You would then require a motor with rated starting and pull-in torques as follows:

$$\text{Starting torque} = \frac{100}{0.85^2 \times 0.95^2} = 153\%$$

$$\text{Pull-in torque} = \frac{100}{0.95^2} = 111\%$$

PULL-OUT TORQUE

When a synchronous motor is operating at no-load, the individual field poles of the motor have a fixed position with respect to the revolving magnetic field of the armature. A load applied to the motor develops a torque that balances the requirements of the load torque. The increased torque requirement is produced by a backward shift or lag in the position of the field poles with respect to the revolving magnetic field. The motor, however, still maintains its synchronous speed.

The motor develops its maximum torque when the field poles have shifted backward approximately one-half the distance between adjacent poles. Any further increase in load will cause the motor to pull out of step and stop.

The maximum torque that a motor will develop without pulling out of step is called its pull-out torque. Typical pull-out torque requirements for various

SYNCHRONOUS MOTORS

TABLE 17A—STANDARD HORSEPOWER RATINGS

GENERAL-PURPOSE MOTORS: 30, 40, 50, 60, 75, 100, 125, 150, 200*.

LARGE HIGH-SPEED: 200, 250, 300, 350, 400, 450, 500, 600, 700, 800, 900, 1000, 1250, 1500, 1750, 2000, 2250, 2500, 3000, 3500, 4000, 4500, 5000, 5500, 6000, 7000, 8000, 9000, 10,000, 11,000, 12,000, 13,000, 14,000, 15,000, 16,000, 17,000, 18,000, 19,000, 20,000, 22,500, 25,000, 27,500, 30,000.**

LOW-SPEED: 20, 25, 30, 40, 50, 60, 75, 100, 125, 150, 175, 200, 225, and larger ratings as listed above for large highspeed motors.

*At 1.0 pf. **At 0.8 pf.

TABLE 17B—STANDARD VOLTAGES

Voltage	Approximate Hp Range—1.0 Pf
208, 220	20 — 200
440, 550	20 — 1000
2300	20 — 10000
4000	75 — 17000
4600	75 — 20000
6600	400 — 30000
13200	1000 — Any

TABLE 17C—STANDARD SPEEDS

Speed in Rpm (60 Cycles)	Number of Poles	Approximate Hp Range—1.0 Pf
3600	2	1000 & Larger
1800	4	30 — 5000
1200	6	30 — 10000
900	8	30 — 30000
720	10	40 — 30000
600	12	50 — 30000
514	14	100 — 30000
450	16	20 — 10000
400	18	20 — 10000
360	20	20 — 10000
327	22	20 — 10000
300	24	20 — 10000
277	26	20 — 10000
257	28	20 — 10000
240	30	20 — 10000
225	32	20 — 10000
200	36	20 — 10000
180	40	20 — 10000
164	44	20 — 10000
150	48	50 — 10000
138	52	60 — 10000
128	56	75 — 10000
120	60	100 — 10000
109	66	100 — 10000
100	72	100 — 10000
95	76	150 — 10000
90	80	150 — 10000
86	84	150 — 10000
80	90	150 — 10000

Standard speeds for other frequencies will be proportionate to the frequency using the pole groupings listed above for 60 cycles.

TABLE 18—TYPICAL TORQUE REQUIREMENTS OF SYNCHRONOUS MOTOR APPLICATIONS

The following, taken in the main from NEMA MG1-8.9, represent typical locked-rotor, pull-in and pull-out torque requirements of various synchronous motor applications.

In individual cases, lower values may be satisfactory or higher values may be necessary, depending upon the characteristics of the particular machine and the effect of locked-rotor kva on the line voltage.

APPLICATION	TYPICAL TORQUE REQUIREMENTS In Percent of Full-Load Torque: Locked-Rotor (Static)		Pull-In		Pull-Out	Max. "Load Wk^2" Ratio (Approx.)
	Unloaded	Loaded	Unloaded	Loaded		
1—CENTRIFUGAL MACHINERY—Blowers, Compressors, Fans and Pumps						
[1] [2] **Blowers**	.....	.....	.....	.....	.....	10-15
[1] [3] **Compressors**	.....	.....	.....	.....	.....	15-25
[1] **Fans—(except sintering)**	.....	.....	.....	.....	.....	20-50
[4] **Inlet or discharge valve closed**	40%	.....	60%	.....	150%	.....
[5] **Inlet or discharge valve open**	.....	40%	.....	100%	150%	.....
[5] **Sintering—Inlet gates either open or closed**	.....	40%	.....	100%	150%	25-60
Propeller-type Discharge open	.....	40%	.....	100%	150%	25
Pumps—Centrifugal (Horizontal)	.....	.....	.....	.....	.....	1
[4] **With discharge valve closed**						
High-and medium-speed	40%	.....	50-60%	.....	150%	.....
Low-speed	40%	.....	70-100%	.....	150%	.....
With discharge valve open	.....	40%	.....	100%	150%	.....
—Centrifugal (Vertical)						
[4] **With discharge valve closed**						
High-and medium-speed	50%	.....	60-70%	.....	150%	.....
Low-speed	50%	.....	75-100%	.....	150%	.....
With discharge valve open	.....	50%	.....	100%	150%	.....
[4] **Adjustable-blade—Vertical**	50%	.....	40%	.....	150%	1
Screw-type	.....	.....	.....	.....	.....	1
Started dry	40%	.....	30%	.....	150%	.....
Primed, discharge open	.....	40%	.....	100%	150%	.....
Axial-flow type	.....	.....	.....	.....	.....	1
With discharge open	.....	40%	.....	100%	150%	.....
With discharge closed	.....	40%	.....	200-300%	Same	.....
2—CEMENT, ROCK PRODUCTS AND MINING MACHINERY						
Grinding Mills						
[1] **Attrition**	100%	.....	60%	.....	175%	12
Ball and *Compeb*						
Rock and coal	.....	150%	.....	110%	150%	2
Ore	.....	175%	.....	110%	175%	2
Rod and tube mills—Ore	.....	175%	.....	110%	175%	3
Crushers						
B. and W.	200%	.....	100%	.....	250%	3
Bradley-Hercules	100%	.....	80-100%	.....	250%	3
Cone	100%	.....	100%	.....	250%	6
Gyratory	100%	.....	70-100%	.....	250%	4
Jaw	100%	.....	70-100%	.....	250%	2
Roll	100%	.....	70-100%	.....	250%	3
[1] **Hammer mills**	120%	.....	100%	.....	250%	15-40
Flotation machines	.....	150-175%	.....	110%	175%	1
Fuller mills	.....	125-150%	.....	110%	175%	.....
3—METAL ROLLING MILLS						
Structural and rail—Roughing	40%	.....	30%	.....	300%	1
—Finishing	40%	.....	30%	.....	250%	
Plate	40%	.....	30%	.....	300%	
Merchant trains	60%	.....	40%	.....	250%	
Billet, skelp and sheet bar—(Continuous with lay-shaft drive)	60%	.....	40%	.....	250%	
Hot-strip, continuous, individual drive roughing stands	50%	.....	40%	.....	250-300%	
Tube-piercing and expanding	60%	.....	40%	.....	300-350%	
Tube-rolling (plug)	60%	.....	40%	.....	250%	
Tube-reeling	60%	.....	40%	.....	250%	
Sheet and tin (cold-rolling)	.....	200%	.....	150%	250%	
Brass and copper—Roughing	50%	.....	40%	.....	250%	
—Finishing		150%		125%	[illegible]	

TABLE 18—TYPICAL TORQUE REQUIREMENTS OF SYNCHRONOUS MOTOR APPLICATIONS—Continued

APPLICATION	TYPICAL TORQUE REQUIREMENTS In Percent of Full-Load Torque					Max. "Load Wk^2" Ratio (Approx.)
	Locked-Rotor (Static)		Pull-In		Pull-Out	
	Unloaded	Loaded	Unloaded	Loaded		
4—PULP AND PAPER MACHINERY						
Beaters—Standard	.....	125%	.....	100%	150%	5
—Breaker	.....	125%	.....	100%	200%	5
[1] Chippers (empty)	60%	.....	50%	.....	250%	30-100
Hydraupulpers	.....	125%	.....	125%	150%	.....
Jordans (plug out)	50%	.....	50%	.....	150%	1
Pulp grinders—Magazine type	50%	.....	50%	.....	150%	5
—3 or 4 Pochet type	40%	.....	30%	.....	150%	4
Screens—Centrifugal	.....	50%	.....	100%	150%	1
Vacuum pumps—(Hytor)	.....	60%	.....	100%	200%	4
[1] Wood Hogs	60%	.....	60%	100%	225%	30
5—RECIPROCATING MACHINERY						
Blowing Engines	40%	.....	50%	.....	150%	.....
Compressors						
Air and gas	40%	.....	30%	.....	150%	10
Ammonia (discharge pressures 100 to 250 psi)	40%	.....	30%	.....	150%	7
[1] Ammonia boosters[7]						
Freon	40%	.....	50%	.....	150%	4
Carbon dioxide (with piston rod diameter of 30% to 60% of piston diameter):						
[1] Single-cylinder, double acting	40-120%	.....	40%	.....	150%	5-10
Two-cylinder, double acting	40-90%	.....	40%	.....	150%	4-7
Pumps—Positive displacement	.....	.....	.....	.....	.....	1
Started dry	40%	.....	30%	.....	150%	.....
By-passed	40%	.....	40%	.....	150%	.....
Not by-passed (3-cylinder)	.....	150%	.....	100%	150%	.....
[1] Vacuum pumps	40%	.....	60%	.....	150%	10
6—RUBBER MILLS						
Banbury mixers	.....	125%	.....	100%	250%	1
Line shafts	.....	125%	.....	110%	225%	1
Plasticators	.....	125%	.....	100%	250%	1
Individual drive	.....	125%	.....	100%	250%	1
7—SAWMILLS						
Saws—Band mill[1]	80%	.....	40%	.....	250%	100
—Edger	40%	.....	30%	.....	250%	5
—Gang[1]	60%	.....	30%	.....	200%	10
—Trimmer	40%	.....	30%	.....	200%	1
[1] Wood hogs	60%	.....	60%	100%	225%	30
8—MISCELLANEOUS						
[1] Blowers—Positive displacement, rotating, cycloidal type	40%	.....	40%	.....	150%	8
[6] Bowl mills—(coal pulverizer) (with common motor for pulverizer and exhaust fan)	.....	150%	.....	125%	150%	.....
Compressors—Positive displacement, rotating, sliding-vane type:						
By-pass open	60%	.....	30%	.....	150%	.....
Inlet open, by-pass closed	.....	60%	.....	100%	150%	.....
[1] Flour mill line shafts	.....	175%	.....	110%	150%	5-15
[1] Gas cleaners—(Thiessen)	40%	.....	60%	.....	150%	25
[1] Vacuum pumps—(Hytor) In other than paper mill service	40%	.....	60%	.....	150%	4

[1] These applications have high inertia, and the Wk^2 of the load may require a motor design which cannot be determined from the torque requirements alone. For these applications the motor manufacturer should always be provided with the actual value of the Wk^2 of the load.

[2] [3] [4] The torque requirements may vary for the individual machine. The manufacturer should be consulted

[5] May require higher torques under certain conditions; such as starting with cold air when rating is based upon normally warm air.

[6] On some mills the exhaust fan may be separately driven and different torque values will apply; in either case the mill manufacturer should be consulted.

[7] Torque requirements will vary widely with different pressure-differential operating conditions and starting method.

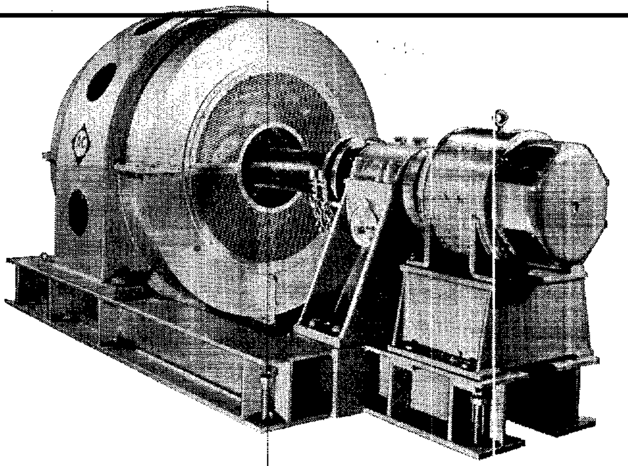


Fig. H-57. This pedestal-bearing, 1000-hp, 720-rpm synchronous motor has direct-connected exciter.

synchronous motor applications are given in Table 18. Standard horsepower ratings, voltages and speeds of synchronous motors are given in Tables 17A, B and C.

CONSTRUCTION OF SYNCHRONOUS MOTORS

Synchronous motors may be divided into two general classifications: (a) High-speed motors, operating at speeds of 500 rpm or more, and (b) low-speed motors, having speeds below 500 rpm.

High-Speed Motors

For high-speed synchronous motors, the temperature rise, based on an ambient temperature of 40 C, normal conditions of ventilation, and an altitude of 3300 feet (1000 meters) or less, will not exceed:

Unity power factor motors:

Armature..............40 C by thermometer
Field.................50 C by resistance

Leading power factor motors and all motors having greater than normal torques:

Armature..............40 C by thermometer
Field.................60 C by resistance

End-shield bearing construction is generally considered standard up to and including the following ratings; these limitations may be exceeded for certain steady-load applications, such as centrifugal compressors, at speeds from 500 to 900 rpm:

	Hp per Rpm	
Rpm	*1.0 Pf*	*0.8 Pf*
500 to 900.........	1.0	1.0
1200...............	1.0	0.8
1800...............	0.7	0.5

Larger motors are generally furnished with a base and two pedestal-type bearings. Provision for stator shift (to facilitate inspection and repair of windings) is not standard but can be obtained at slight extra cost in most ratings, except that it is usually impractical in four and six-pole motors.

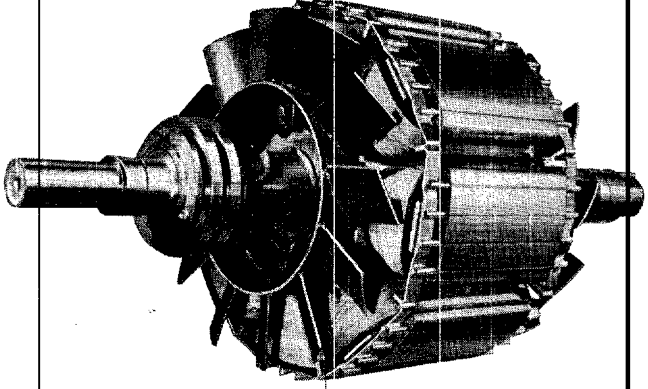


Fig. H-58. Rotor for 900-hp, 0.8-pf, 900-rpm synchronous motor shows collector ring details.

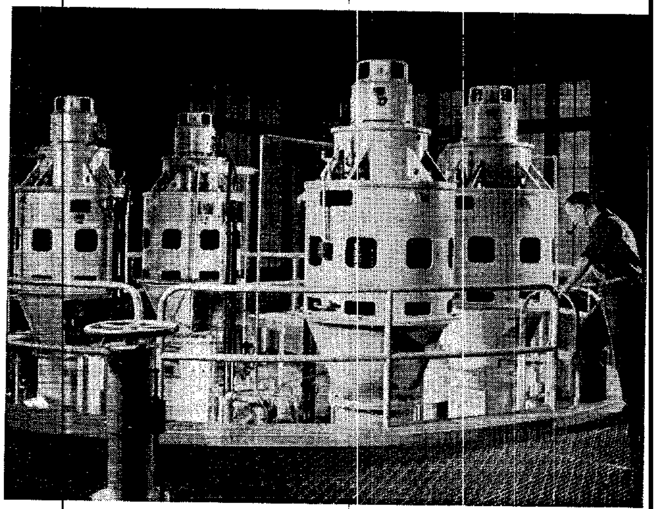
Low-Speed Motors

The temperature rise for standard low-speed motors is 50 C, that is, 10 C higher than for high-speed motors. However, the use of motors with this temperature rise is usually confined to such applications as reciprocating compressors and other non-overloading drives. Motors with the same temperature rise as high-speed units are available and essential for many types of applications such as metal rolling mills, ball mills, etc.

Low-speed motors are available in engine-type, end-shield bearing, and pedestal-bearing construction. (*Figs. 54* to *62*.) Engine-type units, which are furnished without shaft, base or bearings, are widely used for applications such as reciprocating compressors. End-shield bearing construction is limited to some smaller ratings. Pedestal-bearing construction, with base arranged for stator shift optional, is available in all larger sizes.

Vertical Motors

Vertical construction is generally available for most ratings and is widely used for pump drives.



ALLIS-CHALMERS MFG. CO.

Fig. H-59. Vertical synchronous motors are frequently used for driving pumps. These are 350 hp, 720 rpm.

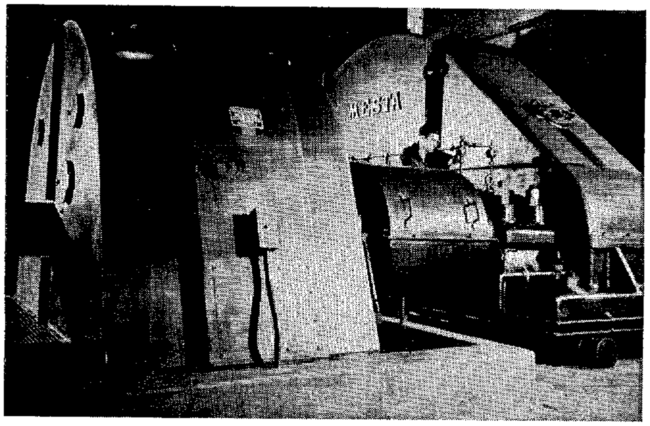


Fig. H-60. Enclosed synchronous motor rated 4500 hp driving roughing stand in eastern steel mill.

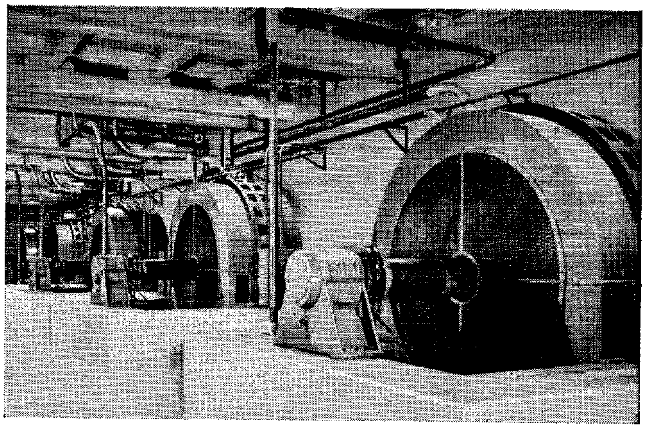


Fig. H-61. Five 3500-hp, 11,200-volt, 257-rpm synchronous motors driving paper mill pulp grinders.

Excitation

Field excitation should be provided from a source that is not subject to circuit interruption. Direct-connected exciters are preferable for high-speed motors. For low-speed units, belted exciters or separate motor-generator sets are recommended.

MOTOR PROTECTION

Classification of machines by types of mechanical protection and methods of cooling will be found in the definitions on pages 4 to 9. Accompanying illustrations show some of the types applicable to synchronous motors, and Table 19 gives a brief summary of such features. Because synchronous motors are not built in ratings as small as induction motors, some types (such as totally-enclosed non-ventilated construction) are not practical.

DATA ON COMPARISON

As a further aid to motor selection, the various characteristics of synchronous and induction motors have been summarized in Table 20.

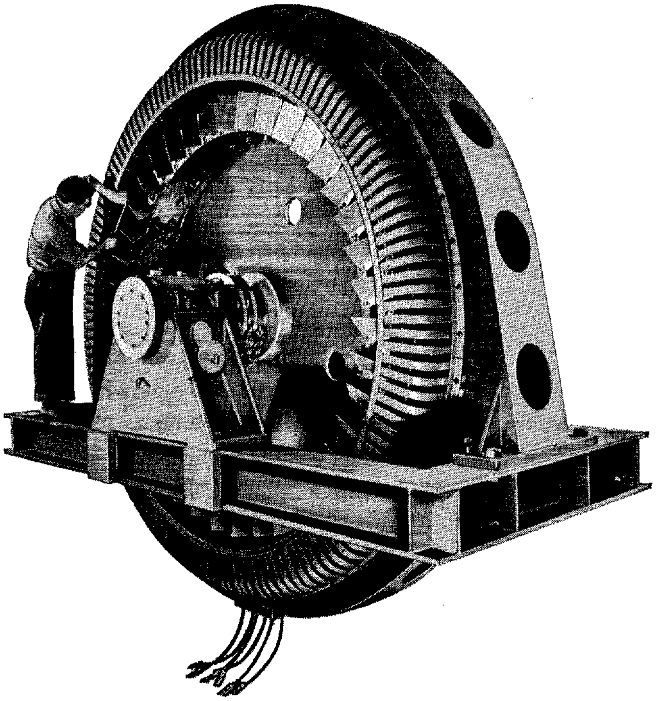


Fig. H-62. Built for cement grinding mill use, this synchronous motor is rated 1500 hp, 180 rpm.

TABLE 19—SUMMARY OF PROTECTION AND ENCLOSURES—SYNCHRONOUS MOTORS

Type of Enclosure	Approximate Range of Sizes	Standard Temperature Rise Class A Insulation	Approximate Cost Increase	Application Information
Drip-proof	**All ratings**	**Same as open motor**	**4 to 10%**	**Protection against dripping liquids or falling particles.**
Splash-proof	**All ratings**	**50 C**	**15%**	**Protection against dripping and splashing liquids.**
Enclosed collector rings	**All ratings**	**Same as open motor**	**4 to 30%**	**Used in both explosive and non-explosive atmospheres.**
Enclosed, forced-ventilated	**All ratings**	**Same as open motor**	**4 to 20%**	**Same as *fan-cooled.***
Enclosed-self-ventilated	**High-speed only**	**40 C**	**40%**	**Same as *fan-cooled.***
Totally-enclosed, fan-cooled	**High-speed only**	**55 C**	**135%**	**Used where abrasive dust, dirt, grit, or corrosive fumes are too severe for [illegible]**

TABLE 20—COMPARISON OF GENERAL CHARACTERISTICS OF SYNCHRONOUS AND INDUCTION MOTORS

	Synchronous Motors	Induction Motors
Power Factor	Operates at unity (1.0) power factor with current in phase with voltage, or at leading power factor with current leading voltage. Hence, eminently suitable for power factor correction or improvement.	Power factor is always lagging due to magnetizing current requirements. It is higher in high-speed and large motors than in low-speed and smaller motors. It is highest at full load and decreases with decreasing load.
Speed	The speed is an inverse function of the number of poles and the power supply frequency, with which the motor is synchronized. The speed is constant and cannot be changed unless the frequency is changed (except in the case of two-speed motors, which are available in the larger sizes only).	Because of slip, standard motor speed is a few percent below synchronous speed but remains constant under constant load conditions. Special high-torque motors have higher slip. Motors can be designed as high-slip machines, with slip of 5 to 12 percent depending on size. Wound-rotor motors with external adjustable resistance in rotor circuit can provide a wide range of speed.
Construction	Salient poles, an amortisseur winding, and a field winding with a collector assembly replace the simpler cage rotor of the induction motor. Motor is started with the field circuit closed through a resistor to prevent injury from high voltages due to transformer action. When excitation is removed, on shutting down the motor, the field is closed through a resistor to protect windings from high discharge voltages. With present control, failure from these sources seldom occurs.	The polyphase squirrel-cage motor is the simplest in construction and for that reason it is the most reliable of all motors. The wound-rotor type has a phase-wound rotor winding, collector rings and brush rigging, but these do not affect its dependability. However, wound-rotor motors for plugging duty require special attention in design because of the double normal voltage when plugging on full voltage.
Auxiliary Apparatus	Requires a separate exciter with shunt field rheostat, or a motor field rheostat if excited from a source common to several motors. Requires additional metering and field switches on the auxiliary control.	No auxiliary apparatus is required for squirrel-cage motors. Wound-rotor motors require secondary control.
Torques and Starting Kva	Starting, pull-up, pull-in, and pull-out torques ample for nearly all types of constant-speed applications are obtainable. High-speed motor torques have been standardized by NEMA for common applications, but other values can also be obtained. Locked-rotor (starting) current is proportional to torque requirements. It ranges from 250 percent for low-speed, low-torque compressor motors to 600 percent or more for high-speed, high-torque motors.	Motor design classification determines variation of cage motor torques from starting to breakdown. Locked-rotor (starting) current for general-purpose ratings is in accordance with NEMA standards, and ranges from 400 to 650 percent for large ratings. Starting currents for wound-rotor motors depend on secondary resistance and nature of the load. Starting current may be as low as 25 percent for first step and usually will not exceed 250 to 300 percent for full-load torque. Average accelerating current for average conditions is 125 percent.
Starting Methods	May be designed for starting (1) on full voltage, (2) on reduced voltage by means of an autotransformer or a reactor, or (3) by the part-winding method, in which full voltage is applied successively to each of several sections of the stator winding. With present-day controls providing at least some automatic functions, such as automatic field application, starting has become nearly as simple as for cage motors. Some precautions must, of course, be observed in selecting the control; for example, a motor designed to start a machine wholly or partially unloaded should not have a control arranged for automatic resynchronization unless the driven machine also has an automatic unloading device. Controls are usually semi- or fully-automatic and provide protection for various causes of failure.	A squirrel-cage motor may be started on reduced or full voltage. In the latter case a push-button-operated magnetic line contactor may be all that is needed. Manual or fully automatic magnetic controls are available for both the primary of cage and wound-rotor motors and the secondary of wound-rotor motors.
Sizes and Efficiencies	Not extensively used in ratings below 40 or 50 hp. In ratings smaller than this, it is always a good idea to consider induction motors for high speeds and gearmotors for low speeds. For high speeds, weights and dimensions are comparable to those of squirrel-cage motors except as added to by the exciters. For lower speeds, the synchronous type gradually becomes smaller than the induction type; this is particularly true at unity power factor. Efficiencies for unity power-factor motors are somewhat better than, and for 0.8 leading power-factor motors are approximately the same as, those for the induction type.	Table 10 shows the efficiencies of standard induction motors. Polyphase induction motors can be built in any practical size and speed. The only limit to size is the capacity of the supporting power system, starting current limitations, and effect of lagging power factor on the system. For very large sizes at low speeds, such as large pump motors for irrigation projects, the synchronous motor usually warrants preference.

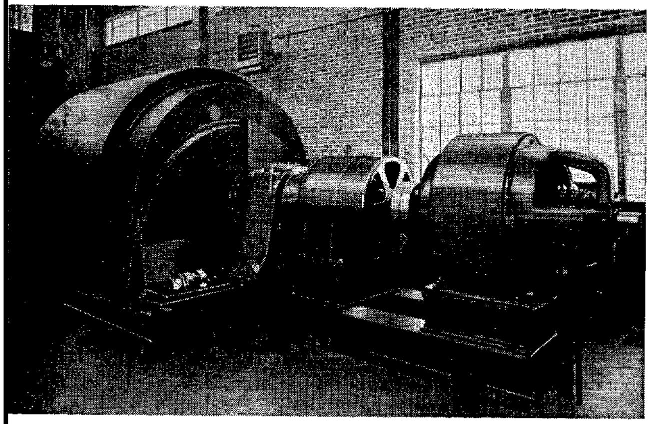


Fig. H-63. Air-cooled synchronous condenser with wound-rotor induction starting motor.

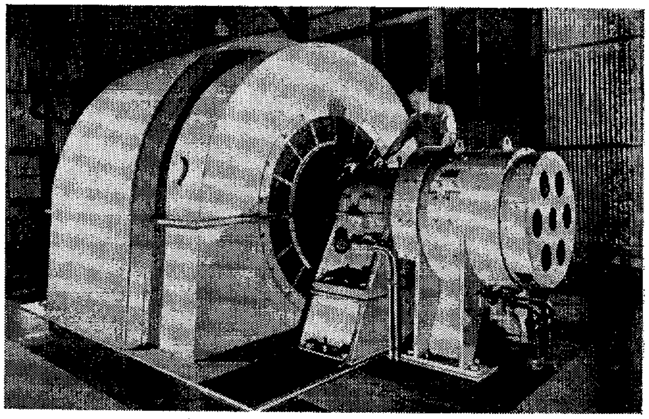


Fig. H-64. Air-cooled synchronous condenser rated 25,000/12,500 kva is used in a southern steel plant.

SYNCHRONOUS CONDENSERS

A synchronous condenser is essentially a synchronous motor running without load while connected to an electrical system. From an economic standpoint their use is confined to the larger systems where correction values are 1000 kva and over. These condensers can also be described as synchronous phase modifiers running without mechanical load, whose field excitation can be varied so as to modify the power factor of the system, or through such modification to serve as voltage regulators. *Fig. 63* shows a 12,500/6250-kva, 4160-volt, 900-rpm air-cooled synchronous condenser with its wound-rotor starting motor.

Small condensers are mainly used for their corrective effect on system power factor, by supplying reactive kva to the system. The condenser may be controlled to maintain a given system power factor, or it may be operated at full leading kvar to supply all or part of the system reactive kva. If the condenser is over-excited it supplies leading kva, and if under-excited it supplies lagging kva. In either case, system losses are reduced, and capacity is released for useful work.

Synchronous condensers are also much used for system voltage regulation. This function is especially important on long high-voltage transmission systems with high line charging capacity and loading. The inertia of a synchronous condenser improves the speed regulation and overall stability of the system. The flywheel effect (Wk^2) enables the condenser to act momentarily as a generator to reduce system disturbances caused by sudden load increases.

System improvement depends upon the inertia ratio

TABLE 21A—NEMA STANDARD KVA, SPEED AND VOLTAGES, AIR-COOLED SYNCHRONOUS CONDENSERS

Leading Kva	Lagging Kva	Speed 60 Cycles	Voltage Ratings 240	480	600	2400	4160	6900	*11,500	13,800
100	50	1200	x	x	x	x	x			
200	100	1200	x	x	x	x	x			
250	125	1200	x	x	x	x	x			
300	150	1200	x	x	x	x	x			
400	200	1200	x	x	x	x	x			
500	250	1200	x	x	x	x	x			
750	375	1200		x	x	x	x			
1000	500	1200		x	x	x	x	x		
1500	750	1200		x	x	x	x	x		
2000	1000	900			x	x	x	x	x	x
2500	1250	900			x	x	x	x	x	x
3000	1500	900				x	x	x	x	x
4000	2000	900				x	x	x	x	x
5000	2500	900				x	x	x	x	x
7500	3750	900				x	x	x	x	x
10000	5000	900				x	x	x	x	x
15000	7500	900					x	x	x	x
20000	10000	720						x	x	x
25000	12500	720							x	x
30000	15000	720							x	x
40000	20000	600							x	x
50000	25000	600							x	x
60000	30000	600								x
75000	37500	514								x

*This rating is recognized for use on established systems but is not preferred for new systems.

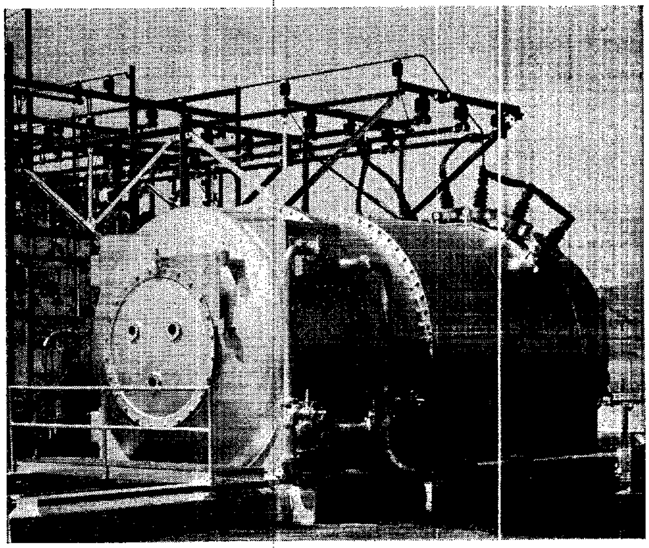


Fig. H-65. Outdoor installation of 40,000/16,800-kva, hydrogen-cooled synchronous condenser.

of the system and the condenser, which is influenced by the size of the condenser. For example, the inertia constant H ranges from 1.0 for a 5000-kva condenser to 2.0 for a 75,000-kva condenser, in the case of air-cooled condensers rated at 13,800 volts.

Synchronous condensers are available in two forms, air cooled, including indoor and outdoor types, and hydrogen cooled. The construction of the indoor air-cooled condensers is very similar to that of an ordinary synchronous motor. They depend for cooling on the free circulation of air through and back of the core and windings of the stator. Outdoor air-cooled condensers may be either self-ventilated, or they may be totally enclosed, using a recirculating ventilating system with coolers in the foundation. Ratings 3,000 kva and larger are available in the completely enclosed type.

Table 21A gives the NEMA ratings for air-cooled synchronous condenser.

Major operating advantages of hydrogen-cooled condensers can be summarized as follows. First, the windage loss drops about 90 percent for average operating conditions, with a consequent drop in leading kva load losses. Second, the higher heat transfer coefficient of hydrogen makes for better output from a given rating, and permits operating under overloads. Finally, maintenance is reduced because damage to the insulation from corona-produced ozone is practically eliminated, and so is overheating caused by the accumulation of dirt in the ventilating passages.

Fig. 65 shows a hydrogen-cooled condenser installed in a substation, and Table 21B gives the NEMA ratings of such condensers.

TABLE 21B—NEMA STANDARD KVA, SPEED AND VOLTAGES

HYDROGEN-COOLED SYNCHRONOUS CONDENSERS

Leading Kva	Lagging Kva	Speed 60 Cycles	Voltage Ratings 4,160	6,900	*11,500	13,800
15,000	6,300	900	X	X	X	X
20,000	8,400	900		X	X	X
25,000	10,500	720			X	X
30,000	12,600	720			X	X
40,000	16,800	720			X	X
50,000	21,000	600			X	X
60,000	25,200	600				X
75,000	31,500	514				X

*This rating is recognized for use on established systems but is not preferred on new systems.

Excitation

Exciters are usually of the direct connected type. In cases where condensers are serving as voltage regulators, the condensers must be able to deliver both lagging and leading kvar, possible variations ranging from 40 percent lagging to 100 percent of the leading capacity.

An excitation system that acts accurately and rapidly is necessary to obtain a smooth variation of kvar over the entire operating ranges. The system recommended for both large air-cooled condensers and hydrogen-cooled condensers consists of the following equipment:

1. Direct connected stabilized main exciter.
2. Standard motor-operated main exciter field rheostat (for manual control in emergencies).
3. Motor driven *Regulex* exciter set.
4. Static impedance type automatic voltage regulating control, using a saturated transformer and a discriminating circuit.

Starting

There are several ways available for starting synchronous condensers, but reduced voltage starting from autotransformers is the one most commonly used. Taps are provided for from approximately 20 to 33 percent of rated voltage, depending on the requirements of the system. As the larger condensers are provided with high pressure lubrication, which reduces the breakaway torque, most machines can be started with no more than full load line current when autotransformers are used.

If minimum starting kva is desirable for any reason, a direct connected wound-rotor induction motor can be used. The motor is designed with two poles less than the condenser in order to accelerate the latter to synchronous speed, and the condenser is synchronized with the power supply in the same manner as a synchronous generator. The motor and control are usually based on a starting time of about 2-1/2 minutes for a 5000-kva condenser, and up to 5 minutes for the larger sizes.

Condensers as Power Factor Correctors

The application and effect of a synchronous condenser for power factor correction can probably be best shown by taking a concrete example. This case is [illegible] determination of the condenser required to improve the power factor of a 300-kw system operating at 0.75 pf.

The first step is to express the components of the system as shown in *Fig. 66*.

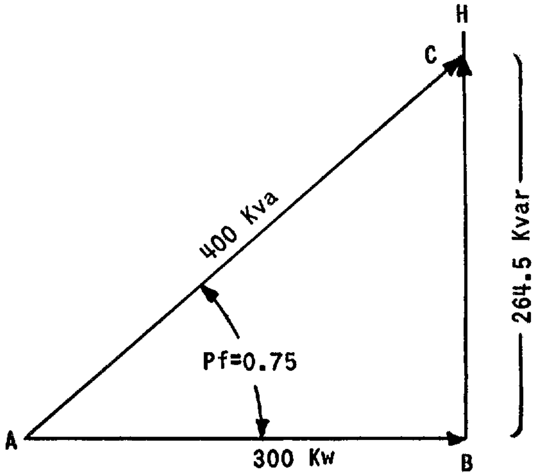


Fig. H-66. Vector presentation of a system delivering 300 kw at 0.75 power factor.

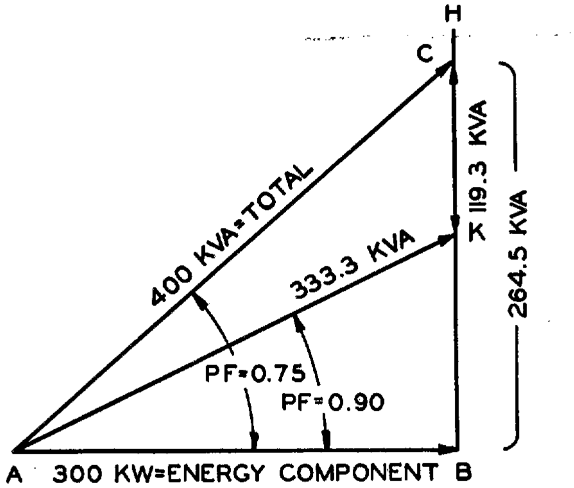


Fig. H-67. Determination of condenser output needed to raise power factor from 0.75 to 0.9.

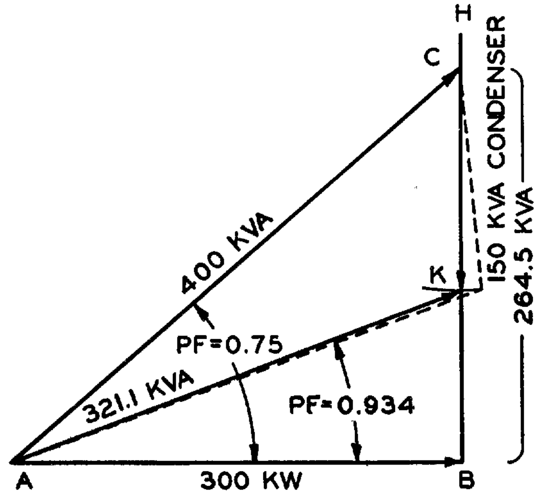


Fig. H-68. Effect of adding a 150-kva synchronous condenser to the system.

Using the equation $\text{pf} = \frac{\text{kw}}{\text{kva}}$ and solving for kva we have $\frac{300}{0.75}$ or 400 kva.

In *Fig. 66* line AB equals 300 kw. Since kvar is always at right angles to kw, the perpendicular BH is erected at B on AB. With A as a center, and a radius equal to 400 kva an arc is described that cuts BH at C.

The triangle ABC shows graphically the total kva (AC) of the generator, its energy component (AB) and the wattless component (BC), which is 264.5 kvar. The triangle also shows the phase relation between AB and AC: angle A. This angle need not be determined because its cosine $\left(\frac{AB}{AC}\right)$ equals the power factor, 0.75.

As the next step, using the same equation $\text{pf} = \frac{\text{kw}}{\text{kva}}$, and assuming that a power factor of 0.9 is desired, solving for kva shows that the system must be altered so that it delivers only 333.3 kva $\left(\text{kva} = \frac{300}{0.9}\right)$. Then using the triangle already developed, with A as a center, and 333.3 kva as a radius an arc is described that cuts BC at E (*Fig. 67*). By scale, or otherwise, BE = 145.2 kvar, and EC = 119.3 kvar.

Therefore, a synchronous condenser with an output of 119.3 kva at zero pf leading would correct the system power factor to 0.9.

To take another phase of the problem, assume that it is desired to find out what the effect would be of adding a 150-kva condenser; 150 kvar is laid off on line CB. The value of AK can be found by scale measurement, or by solving the triangle, ABK, to be 321.1 kvar. (*Fig. 68.*)

The resultant power factor is $\frac{300}{321.1} = 0.93.4$.

DIRECT-CURRENT MOTORS

Direct-current motors are used for applications that require continuous operation under fairly constant load (such as fans, blowers, line shafting) in plants having direct-current rather than alternating-current power service. In addition, they are used for applications such as machine tools when fine speed adjustment and other characteristics of dc motors are so necessary that the cost of conversion equipment is warranted when the source of electrical power supplies alternating current.

Direct-current motors are divided into three classes: series, shunt and compound wound. These terms refer to the relationship of the connections between the armature and fields. Each type is explained briefly below, while Table 22 on page 36 provides a ready comparison of the applications and operating characteristics.

TABLE 22—COMPARISON OF GENERAL CHARACTERISTICS OF DC MOTORS

	Series Motors	Shunt Motors	Compound Motors
Applications	Where speed can be regulated and where high starting torque is necessary. Car retarding, traction, car dumpers, hoists, gates, etc.	Where starting conditions are not severe and where constant or adjustable speed is necessary. Metal working machines, elevators, centrifugal pumps, line shafts, woodworking machines, blowers, conveyors, fans, etc.	Required where high starting torque combined with fairly constant speed is necessary. Conveyors, plunger pumps, bending rolls, punch presses, elevators (geared), shears, hoists, etc.
Starting Torque	High. Varies as square of voltage. Limited by commutation and heating.	Good. Constant field, varies directly as voltage applied to armature.	Higher than for shunt motors, according to amount of compounding.
Pull-Out Torque	High. Limited by commutation and heating.	High. Limited by commutation and heating.	High. Limited by commutation and heating.
Speed Control	Zero to maximum, according to load and control.	Any range desired, according to type of motor and system.	Any range desired, according to type of motor and control.
Speed Regulation	Speed varies inversely with the load. Races on light loads and full voltage.	Varies with size and speed range from 2 to 25 percent. Close regulation obtainable with special control.	Drops 7 to 25 percent from no load to full load, according to type of motor and control.

TABLE 23A—STANDARD HORSEPOWER RATINGS —DC MOTORS

GENERAL-PURPOSE MOTORS: 1/2, 3/4, 1, 1-1/2, 2, 3, 5, 7-1/2, 10, 15, 20, 25, 30, 40, 50, 60, 75, 100, 125, 150, 200.

LARGE MOTORS: 250, 300, 350, 400, 500, 600, 700, 800, 900, 1000, 1250, 1500, 1750, 2000, 2250, 2500, 3000, 3500, 4000, 4500, 5000, 5500, 6000, 7000, 8000.

TABLE 23B—STANDARD VOLTAGES—DC MOTORS

Voltage	Approximate Hp Range
115	1/2 — 30
230	1/2 — 200
250	250 — 1000
600	250 — 8000

TABLE 23C—STANDARD SPEEDS—DC MOTORS

Speed in Rpm	Approximate Hp Range
3500	1-1/2 — 40
1750	1 — 200
1150	3/4 — 800
850	1/2 — 1750
690	1/2 — 2250
575	3/4 — 2500
500	3/4 — 3000
450	1 — 3500
400	1 — 4000
350	1 — 4500
300	10 — 5000
250	20 — 5000
225*	250 — 5000
200	75 — 5000
175*	250 — 6000
150	75 — 7000
140**	7000 — 8000
130**	7000 — 8000
125*	250 — 6000
120**	7000 — 8000
110*	250 — 8000
100	75 — 8000
90	500 — 8000
80	600 — 8000
70	700 — 8000
65	800 — 8000
60	800 — 8000
55	900 — 8000
50	1000 — 8000

*These speeds standard for motors larger than 200 hp only.
**These speeds standard only for the ratings indicated.

SERIES MOTORS

The armature and fields of the series motor are connected in series (*Fig. 69*), and the speed of the motor varies inversely with the load; that is, the speed increases as the load decreases. This is due to the change in field strength with changes of current in the field caused by the load on the motor.

For this reason, a series motor should never be applied to a drive which can become unloaded. In general, a series motor should be direct-coupled to its load, for with full voltage applied and without load, its speed increases to the destruction point.

Modifications of the series motor include a small shunt winding of sufficient strength to prevent the motor reaching dangerous speed but not materially changing its series characteristic.

SHUNT MOTORS

The armature and fields of the shunt motor are connected in "shunt" or parallel (*Fig. 70*), and the speed of the motor is practically constant. This is due to the constant strength of the field.

Modifications of the shunt motor include a small series winding of sufficient strength to assure a drooping speed characteristic over a field weakening range.

This type of motor is commonly called a *stabilized shunt motor*. Connections are the same as shown for compound-wound motors.

COMPOUND MOTORS

The compound-wound motor has both series and shunt windings (*Fig. 71*), resulting in the characteristics of both series and shunt motors. That is, it provides high starting torque and constant speed. The exact characteristics of a compound-wound motor will

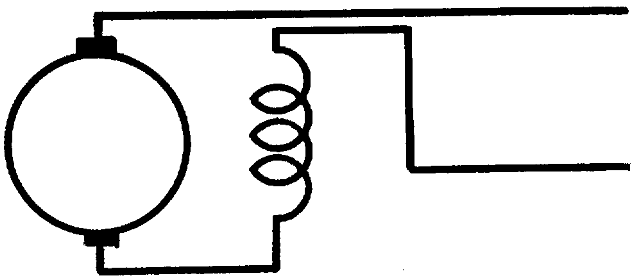


Fig. H-69. Field and armature relationship in a series-wound dc motor.

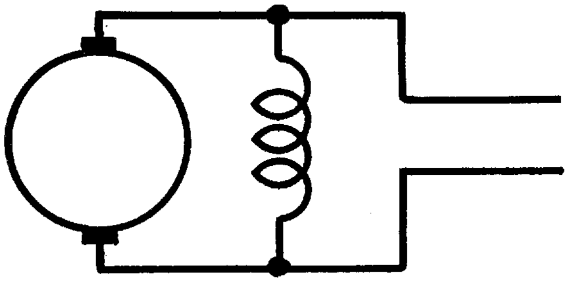


Fig. H-70. Field and armature relationship in a shunt-wound dc motor.

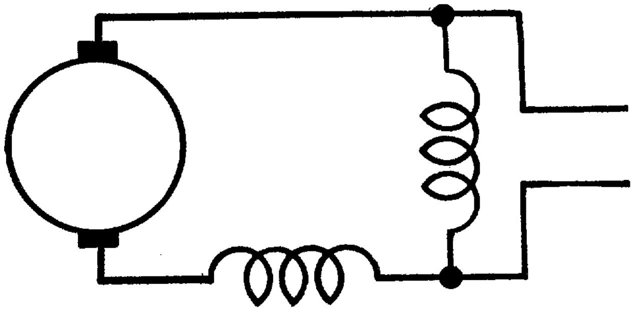


Fig. H-71. Field and armature relationship in a compound-wound dc motor.

depend upon the relationship of the series and shunt fields.

Standard horsepower ratings, voltages and speeds of direct-current motors are given in Table 23.

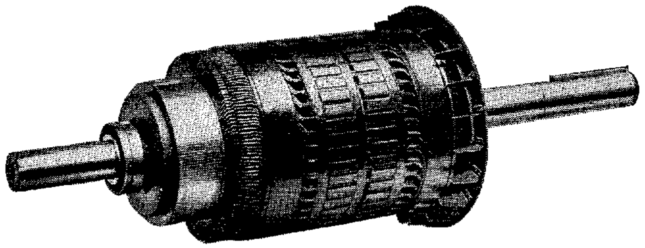


Fig. H-72. Armature for small dc motor.

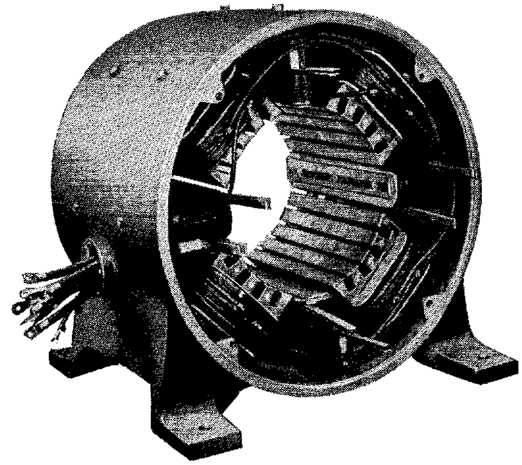


Fig. H-73. Field yoke ready for insertion of special compensating winding in pole faces.

MOTOR PROTECTION

Classification of machines by types of mechanical protection and methods of cooling will be found in the definitions on page 4. Illustrations on pages 5 to 9 show the construction employed for various types, and Table 24 gives a brief summary of such features. This table shows (a) the approximate range of ratings in which each type is built, (b) the maximum temperature rise for Class A insulated machines, (c) the approximate increase in cost over the standard open type, and (d) application suggestions.

TABLE 24—SUMMARY OF PROTECTION AND ENCLOSURES—DC MOTORS

Type of Enclosure	Approximate Range of Sizes	Temperature Rise	Approximate Cost Increase	Application Information
Drip-proof	**All sizes**	**50 C** **40 C**	**2%** **10 to 17%**	**Protection against dripping liquids or falling particles.**
Protected	**All sizes**	**50 C** **40 C**	**5%** **12 to 20%**	**Protection against metal chips in machine shops, etc.**
Drip-proof, fully protected	**All sizes**	**55 C** **40 C**	**5%** **12 to 20%**	**Combines above features.**
Splash-proof	**All sizes**	**50 C** **40 C**	**8 to 15%** **16 to 27%**	**Protection against dripping and splashing liquids.**
Separately ventilated	**All sizes**	**40 C**	**9 to 15%**	**Same as totally-enclosed.**
Self-ventilated	**All sizes**	**40 C**	**15 to 30%**	**Same as totally-enclosed.**
Totally-enclosed:				
Non-ventilated	**1/2 to 15 hp**	**55 C**	**35 to 110%**	**Used where abrasive dust, dirt, grit, or corrosive fumes are too severe for open motors. Metal-working plants, foundries, machine shops, etc.**
Fan-cooled	**1 to 100 hp**	**55 C**	**35 to 90%**	

EFFECTS OF VOLTAGE VARIATION

Direct-current systems, like alternating-current systems, are subject to variations in voltage above or below the rated value. Standard-voltage motors will operate successfully, but not necessarily in accordance with standard guarantees, at voltages 10 percent above or below the nameplate stamping.

Table 25 shows the general effects of operating shunt and compound-wound motors at voltages above and below normal.

ADJUSTABLE-SPEED CONTROL

In many plant operations adjustable-speed control is essential to production efficiency and product quality. In metal-working shops, rubber mills, paper mills, and textile finishing plants, for example, the advantages of having operating speeds that can be exactly adjusted to suit the dimensions, materials and conditions that affect quantity and quality of production can hardly be overemphasized.

Where dc power is available, obtaining adjustable speed presents few difficulties, for dc motors have the characteristics most desirable for adjustable-speed service. And a wide variety of control equipment makes it possible to select a suitable drive for practically any application.

Where only the more widely used 3-phase ac power is available adjustable-speed operation is not as readily obtainable, but neither is it impossible of attainment.

In either case, it is important not to overlook the fact that selection of a satisfactory method of speed control, when required, can quickly pay for itself with even a slight increase in daily output. Following is a summary of the principal methods available for plants having direct current and for those limited to alternating current:

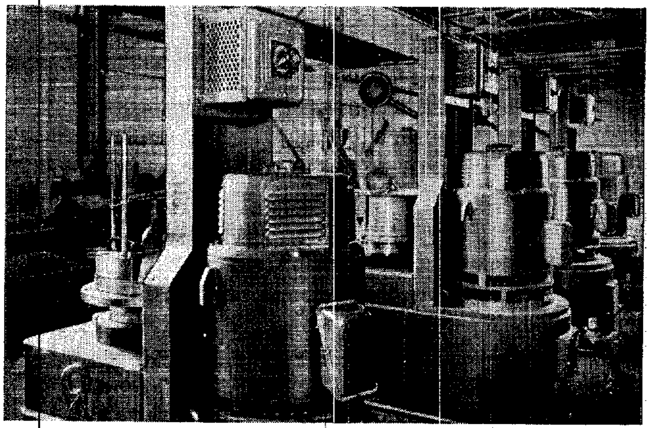


Fig. H-74. Test assembly of shunt-field controlled wire-drawing machinery with 30/40-hp dc motors.

Direct-Current Plants

1. Shunt-field control.
2. Armature control.
3. Combined shunt-field and armature control.
4. Variable-voltage control.

Alternating-Current Plants

1. Wound-rotor induction motors.
2. Multi-speed induction motors.
3. Use of conversion equipment to provide dc power. Page H-48.
4. Variable-pitch V-belt drives.
5. Magnetic or hydraulic couplings.

SHUNT-FIELD CONTROL

Variation in the speed of a shunt-wound or stabilized shunt-wound motor is obtained by inserting an adjustable resistor in the shunt-field circuit of the motor. This provides adjustable-speed control because the speed of the motor varies inversely with the strength

TABLE 25—EFFECTS OF VOLTAGE VARIATION ON DC MOTORS

STANDARD SHUNT MOTORS

Voltage Variation from Normal	EFFICIENCY Full Load	EFFICIENCY 75% Load	EFFICIENCY 50% Load	Percent Full Load Speed	Full Load Current	Starting Maximum Running Torque	Maximum Overload Capacity	Temperature Rise, Full Load
10% low	**Slightly lower**	**No change**	**Slightly higher**	−5%	+11-1/2%	−16%	−16%	**Main field higher. Commutator, field and armature higher.**
10% high	**Slightly higher**	**No change**	**Slightly lower**	+5%	−8-1/2%	+15%	+15%	**Main field higher. Commutator, field and armature lower.**
20% high	**Slightly higher**	**No change**	**Slightly lower**	+10%	−17%	+30%	+30%	**Main field higher. Commutator, field and armature lower.**

STANDARD COMPOUND-WOUND MOTORS

Voltage Variation from Normal	EFFICIENCY Full Load	EFFICIENCY 75% Load	EFFICIENCY 50% Load	Percent Full Load Speed	Full Load Current	Starting Maximum Running Torque	Maximum Overload Capacity	Temperature Rise, Full Load
10% low	**Slightly lower**	**No change**	**Slightly higher**	−6%	+11-1/2%	−16%	−16%	**Main field lower. Commutator, field and armature higher.**
10% high	**Slightly higher**	**No change**	**Slightly lower**	+6%	−8-1/2%	+15%	+15%	**Main field higher. Commutator, field and armature lower.**
20% high	**Slightly higher**	**No change**	**Slightly lower**	+12%	−17%	+30%	+30%	**Main field higher. Commutator, field and armature lower.**

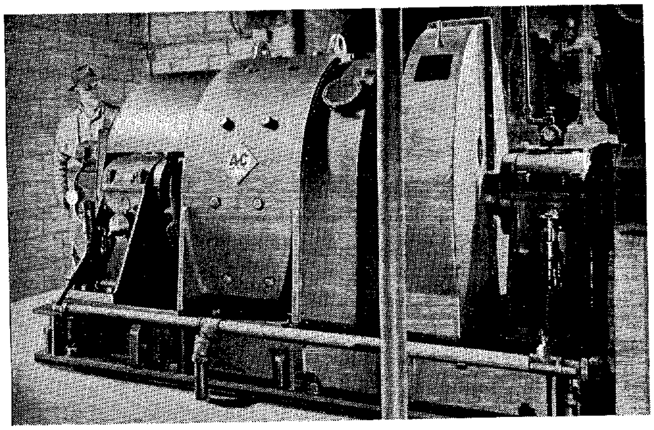


Fig. H-75. Variable-voltage and shunt-field control are used for 600-hp, flywheel-type tube-mill motor.

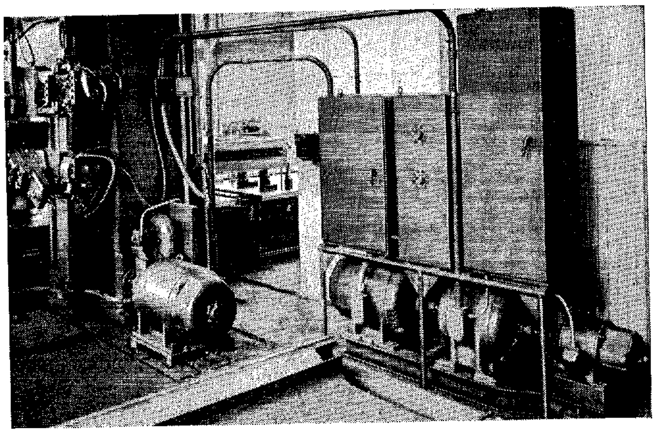


Fig. H-76. Planer drive with 30-hp motor also has combined variable-voltage and shunt-field control.

of the fields. That is, the stronger the fields the lower the speed; as the fields are weakened the speed increases.

As the strength of the field is decreased, the torque delivered by the motor also decreases; but since the speed increases proportionately, the horsepower output of the motor would be expected to remain constant. However, due to increased ventilation at the higher speeds, the horsepower capacity will actually be slightly more than at the low speeds. This increase in capacity can be used to advantage in providing an economical drive.

The efficiency is relatively high at all speeds, and the speed regulation from no-load to full-load can be held within close limits. Motors with speed ranges of 4 to 1 are regularly supplied, and ranges of 6 to 1 are sometimes practicable. The limitation to the speed increase is the ability of the motor to carry the load at the high speeds without sparking.

Compound-wound motors are sometimes used for this method of speed adjustment, but the results are not as satisfactory as with shunt or stabilized shunt-wound motors. When the compound-wound motor has its shunt fields weakened to too great an extent, it more nearly approaches the characteristics of the series motor—with the inherently poor speed regulation of the series type.

ARMATURE CONTROL

Speed control using this method is obtained by inserting a variable resistor in the armature circuit. A shunt-wound motor is generally used. Speeds obtained are below the normal motor speed, and the horsepower output decreases directly with the speed. Armature control is not usually employed for speed reductions greater than 50 percent below normal: The efficiency of the motor is reduced at the low speeds, and the speed regulation, while satisfactory at the high speeds, becomes poor as the speed decreases.

Nevertheless, the armature control method can be used for [illegible] applications where the load at low speeds is so small that the low efficiency is not important, and where a constant-horsepower output with close speed regulation is not required. This system is frequently used for fans and blowers, especially where the unit operates at the low speeds for only a few hours a day.

By using a compound-wound motor it is possible to obtain better starting characteristics for heavy loads than with the shunt-wound motor; but because of poor speed regulation, adjustment should be limited to about 30 percent below normal.

Series-wound motors are occasionally used with armature control for adjustable-speed service. Of course, with this type of motor, increased load will result in decreased speed, and decreased load will result in increased speed. Their principal use is for hoisting machinery in which some load is always present. While the load is being lifted, the speed can be adjusted fairly closely by regulating the amount of resistance introduced into the circuit. Series motors are useful where heavy starting loads are involved, since the torque developed is, up to the stalling point of the motor, determined by the load imposed.

COMBINED SHUNT-FIELD AND ARMATURE CONTROL

Combined shunt-field and armature control provides a wider speed range than can be obtained by either system alone. The speed is reduced below normal by armature control and increased above normal by field control.

Such a combination is used on printing presses, fans, blowers, and similar applications. That is, it is used where low speeds without close regulation are required at times but with most of the operation above normal, since the efficiency by field control is much better than by armature control.

VARIABLE-VOLTAGE CONTROL

As the name implies, this method makes use of the fact that the speed of the motor will vary in direct proportion to the voltage of the current supplied to the motor armature. This system is widely used where a smooth, gradual increase in speed is needed—over a wider range than can usually be obtained by other methods.

In its simplest form this system consists of (a) an adjustable-speed dc motor, (b) a motor-generator set to supply the power—at variable voltage—to drive the motor, and (c) a constant-potential source of direct current for exciting the fields of both the adjustable-speed motor and the motor-generator set generator.

The armature of the generator is connected electrically to the armature of the adjustable-speed motor. Since the motor has its fields separately excited at a permanent flux value, its speed will be in direct proportion to the voltage supplied by the generator. The torque imparted to the motor armature will remain practically constant at all times. Thus the horsepower output of the motor will vary with the motor speed, being greatest at the highest speed.

Speed control is just as simple as for shunt-field control. It is accomplished with a field rheostat in the shunt field of the generator. Speeds of 10 to 1 are frequently used, while a 15 to 1 or even 20 to 1 range may be obtained under favorable circumstances.

Speed regulation is at its best at the higher speeds; at the lowest speeds it is close enough to be satisfactory for most applications. The efficiency at high speed is not as high as with other forms of control; at low speed the efficiency is higher than with armature control but lower than with shunt-field control. It is more economical in the use of power than either of the other two methods.

Motor field weakening above base speed may be employed along with variable-voltage control to provide a very wide speed range of dc motor operation.

The variable-voltage system can be used in both ac and dc plants. When used on alternating current, the generator is usually driven by a squirrel-cage induction motor; larger sets may be driven by synchronous motors, and flywheel sets for reversing hoist or metal rolling mill motors are driven by wound-rotor motors. Excitation is usually provided by an exciter direct-connected to the motor-generator set.

For the smaller horsepower drives, the last few years have seen increasing use of electronic tubes to rectify alternating current to direct current to power dc motors. See Section Q. A wide motor speed range may be obtained by varying the output voltage of the power tubes. Excitation for the field of the motor is also obtained from electronic tubes. In addition, by suitably controlling the power tube output, motor IR drop compensation may be obtained, providing very good motor speed regulation even at very low speeds. Table 26 gives a summary of the principal methods of speed control.

METHODS DISCUSSED ELSEWHERE

The use of wound-rotor and multi-speed squirrel-cage motors is discussed in the section on induction motors (see pages 20 and 21, respectively). Equipment for converting alternating current to direct current is discussed in various sections of this book, including the preceding section on variable-voltage control and a subsequent section on motor-generator sets.

TABLE 26. SUMMARY OF PRINCIPAL METHODS OF SPEED CONTROL

Method	Range of Hp Ratings	Speed Range	Speed Regulation	Torque Characteristics	Remarks
Shunt-field control	**1/2 hp and larger**	**4 to 1, sometimes 6 to 1**	**Can be held within close limits.**	**Reduction of torque as speed increases.**	**Most frequently used of all for dc adjustable-speed motors.**
Armature control	**1/2 hp and larger**	**2 to 1**	**Satisfactory at high speeds, not so good at low speeds.**	**Horsepower decreases directly with speed.**	**Used principally for smaller motors and where operation at low speeds is for only a few hours a day. Series motors used for hoist drives.**
Combined shunt-field and armature control	**1/2 hp and larger**	**6 to 1**	**See above listings.**	**See above listings.**	**Used where most operation will be above normal speed.**
Variable voltage	**1 hp and larger**	**10 to 1, sometimes 15 or 20 to 1**	**Good at high speeds, satisfactory at low speeds.**	**Torque remains constant.**	**Requires separate motor-generator set.**
Wound-rotor motor	**3/4 hp and larger**	**2 to 1**	**Poor at reduced speeds.**	**Horsepower decreases with speed.**	**High starting torques; low efficiencies.**
Multi-speed motor	**1/2 hp and larger**	**2 to 1, 3 to 1, or 4 to 1**	**Same as single-speed motor.**	**Constant horsepower, constant torque, or variable torque.**	**Gives 2, 3, or 4 fixed speeds, except when wound-rotor motors are used.**

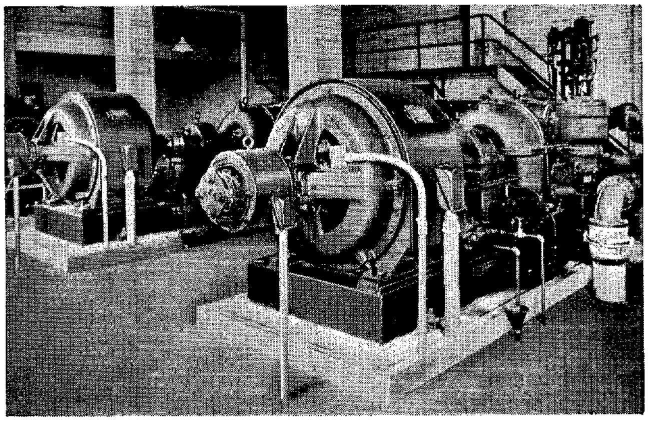


Fig. H-77. Geared turbine-driven, 250-kw, 312-kva, 1200-rpm synchronous generators.

GENERATORS

The rapid growth of power-generating central stations and power-transmission systems has provided industry with an abundant supply of electric power. Development of water power, which accounts for about 25 percent of the total, and refinements in the design of steam-generating equipment have resulted in the production of power at remarkably low cost.

Since utilities generate power with large and consequently more efficient units, purchased power is economically satisfactory for most industrial purposes.

However, there are cases where industry finds it desirable to generate its own power: Where steam is essential in manufacturing processes, it may be advantageous to install a non-condensing turbine-generator unit. In some locations, the advantages of large-scale generation may be unobtainable; on shipboard it is obviously impossible. If continuous operation is imperative, it may be essential to provide standby power.

The advantages and disadvantages must be carefully weighed, both from the standpoint of cost and manufacturing efficiency. If the decision favors power generation, the selection must be made between alternating current and direct current.

There are fields where only direct current will meet the requirements, such as extra-wide speed range or severe accelerating or reversing duty. For most applications, alternating current is satisfactory, since suitable performance can usually be obtained with ac motors and control, and there are many fields in which alternating current is the only suitable choice.

ALTERNATING-CURRENT (SYNCHRONOUS) GENERATORS

Synchronous generators are generally divided into three groups, as follows:

1. Two-pole, 3600-rpm (60-cycle) generators direct-driven by steam turbines.

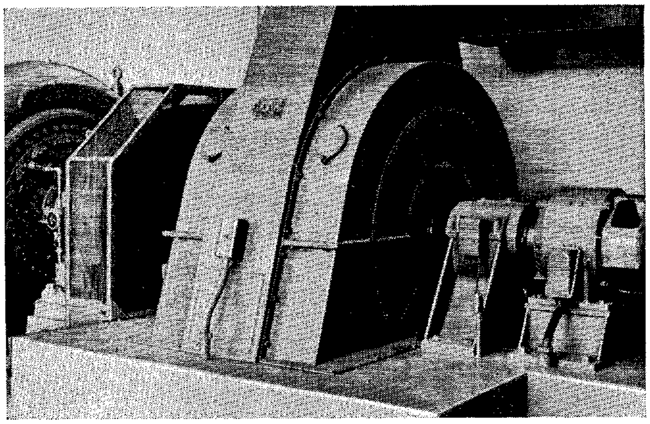


Fig. H-78. Horizontal hydraulic-turbine driven, 3000-kva, 720-rpm synchronous generator.

2. High-speed generators, operating at 500 to 1800 rpm.
3. Low-speed generators, operating at less than 500 rpm.

As the problems involved in the selection and operation of two-pole turbine-generators are so closely related to those of the steam turbine, it has been considered advisable not to attempt to describe this class of equipment here. The following information applies to Groups 2 and 3 only.

AC Generator Ratings

Alternating-current generators are rated at the load they are capable of carrying continuously without exceeding their temperature guarantees. Each rating is expressed in kilovolt-amperes available at the terminals at 0.8 power factor. Standard ratings for 0.8 pf lagging generators are shown in Table 27A, B and C.

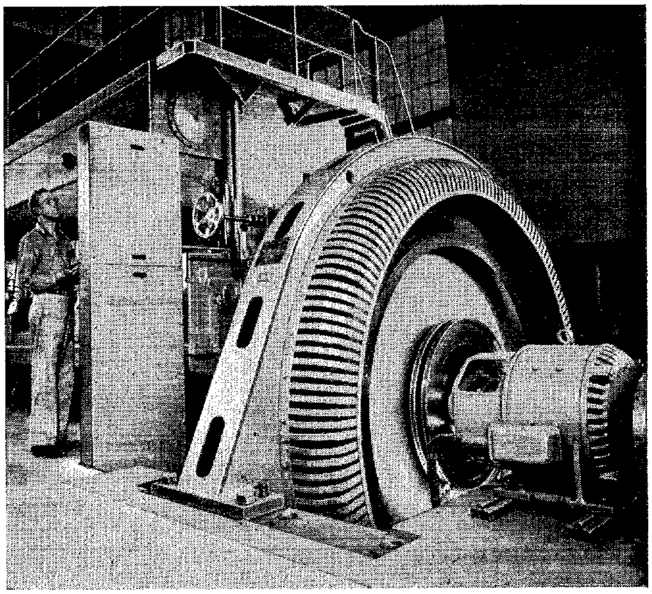


Fig. H-79. Diesel-driven engine-type, 1875-kw, 2345-kva, low-speed synchronous generator.

TABLE 27A—STANDARD KILOWATT RATINGS—SYNCHRONOUS GENERATORS

The following are NEMA listings for 60, 50 and 25-cycle, 0.8 power factor lagging, polyphase synchronous generators exclusive of turbine-driven, water-wheel and inductor synchronous generators.

Kva	Kw	Kva	Kw	Kva	Kw
1.25	1	250	200	4375	3500
2.5	2	312	250	5000	4000
3.75	3	375	300	5625	4500
6.25	5	438	350	6250	5000
9.4	7.5	500	400	7500	6000
12.5	10	625	500	8750	7000
18.7	15	750	600	10000	8000
25	20	875	700	12500	10000
31.3	25	1000	800	15625	12500
37.5	30	1125	900	18750	15000
50	40	1250	1000	25000	20000
62.5	50	1563	1250	31250	25000
75*	60*	1875	1500	37500	30000
93.8	75	2188	1750	43750	35000
125	100	2500	2000	50000	40000
156	125	2812	2250	62500	50000
187	150	3125	2500	75000	60000
219	175	3750	3000		

*The standard speeds for this rating shall be 500 to 1800 rpm, inclusive.

For standard generators, the temperature rise, based on an ambient temperature of 40 C, normal conditions of ventilation, and an altitude of 3300 feet (1000 meters) or less, will not exceed:

Armature (stator)	50 C by thermometer, or 60 C by temperature detector
Field (rotor)	50 C by thermometer, or 60 C by resistance

AC Generator Construction

High-speed generators are usually available with shaft and bearings for coupled duty. End-shield construction is, in general, standard for the smaller sizes, while pedestal-bearing construction is available for the larger ratings. Engine-type and belt-driven generators are also available in the high-speed range.

For speeds below 500 rpm, engine-type generators are commonly furnished (*Fig. 80*); that is, the shaft, bearings and base are supplied by the engine builder. Sole plates for the stator are, however, included as standard equipment with engine-type generators. When required, two-bearing coupled-type or three-bearing belted-type generators can be furnished in the low-speed ratings.

Generator field rheostats are normally furnished with ac generators, but may be omitted under the following circumstances:

1. When the generator is excited from its own individual exciter and the exciter is used for no other purpose. (For operation without a generator field rheostat, the exciter must be of the stabilized type, stable down to the voltage corresponding to the field voltage required by the generator at no load.)

TABLE 27B—STANDARD VOLTAGES—SYNCHRONOUS GENERATORS

Voltage	Approximate Kva Range—0.8 Pf
120	Up to 93.8
240	Up to 875
480, 600	6.3 — 1875
2400, 2500	25 and larger
4160	62.5 and larger

NOTE: Higher voltages (4330, 6900, 11,500, and 13,800 volts) are available, at additional cost, for large generators.

TABLE 27C—STANDARD SPEEDS—SYNCHRONOUS GENERATORS

Speed in Rpm (60 Cycles)	Number of Poles	Approximate Kva Range — 0.8 Pf	
1800	4	Up to 625	
1200	6	12.5 — 3125	
900	8	31.3 — 5000	
720	10	31.3 —	Any practicable required rating.
600	12	31.3 —	
514	14	31.3 —	
450	16	125 —	
400	18	125 —	
360	20	125 —	
327	22	125 —	
300	24	125 —	
277	26	125 —	
257	28	125 —	
240	30	125 —	
225	32	187 —	
200	36	187 —	
180	40	187 —	
164	44	187 —	
150	48	250 —	
138	52	312 —	
129	56	438 —	
120	60	438 —	
109	66	438 —	
100	72	438 —	

2. When the exciter will never be paralleled with other exciters.
3. When certain forms of automatic voltage regulators (which have rheostats or their equivalent contained in the mechanism) are used.

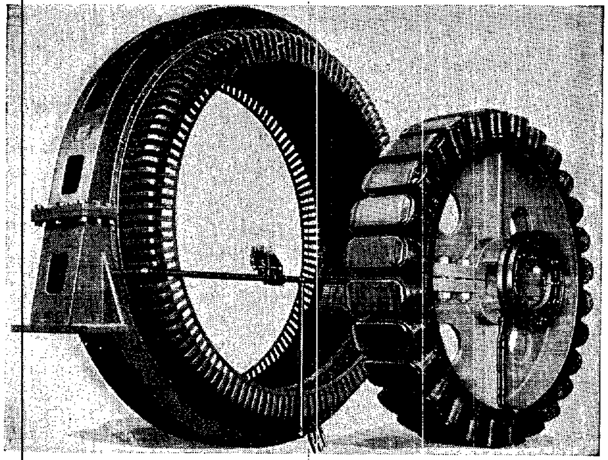


Fig. H-80. Stator and rotor assemblies for a large engine-type synchronous generator

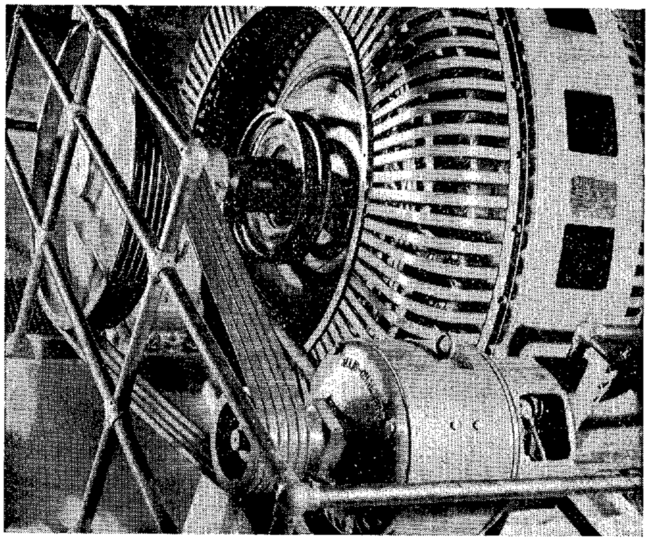


Fig. H-81. V-belt drive is used for exciter economy on this low-speed ac generator.

The recommended practice is to include a generator field rheostat, as the same refinement of voltage control cannot be expected when the rheostat is omitted.

Exciters

Direct-connected exciters (*Fig. 82*) are preferable for high-speed generators. Standard construction provides for overhanging the exciter armature on the generator shaft, with the field frame supported from the generator end-shield or by an extension of the generator base. Occasionally, two-bearing coupled-type exciters are used.

Belted exciters, either V-belt or flat-belt driven, are commonly used for the low-speed generators.

Parallel Operation

Successful parallel operation of ac generators driven by steam or internal-combustion engines is dependent upon the following:

1. Laminated-pole generators must be equipped with damper windings when one of the prime movers is an internal-combustion engine.
2. The speed characteristics of the prime movers must be similar so that there will be a proper division of load.
3. The governors of the prime movers must be designed and adjusted to prevent hunting, with interchange of power between the generators.
4. The value of the flywheel effect of the units in parallel must be such that: (a) The varying turning effort of the engine does not produce more than 0.5 to 0.6 percent variation in speed when the unit is operating alone. (b) The natural frequencies of oscillation of the units are far enough from the impulse frequencies so that objectionable oscillations are not set up; usually 20 percent difference between impulse and natural frequencies is sufficient.

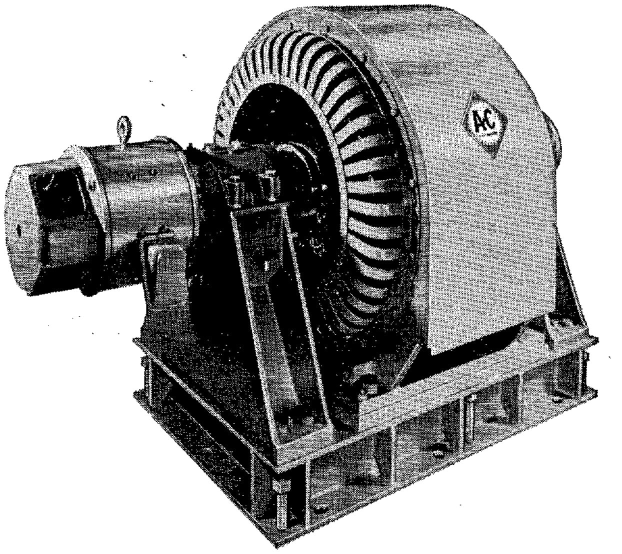


Fig. H-82. Small, high-speed synchronous generator has direct-connected overhung exciter.

Impulse frequencies are: four-cycle engines—one-half the speed of the engine and any multiple thereof; two-cycle engines—the speed of the engine and any multiple thereof.

For any given unit the natural frequency, at which the generator rotor tends to oscillate, can be changed by changing the flywheel effect.

Successful parallel operation calls for cooperation between the engine and generator builders. The generator manufacturer can be of assistance by furnishing technical information and by providing the requisite flywheel effect in the generator.

Voltage Regulation

When an ac generator is furnishing power to a steady load, both its speed and voltage remain constant. Any sudden increase in load, such as might be caused by starting a large motor, will affect both voltage and speed.

The effect on the voltage is an instantaneous drop, the extent of which depends on the magnitude of the load change and the inherent characteristics of the generator. After this instantaneous drop, a further and more gradual decrease takes place before the automatic voltage regulator can act to bring back normal voltage by strengthening the generator field. The subsequent rise in voltage is more gradual than the drop, due to the reactance of the field windings (magnetic inertia) of the exciter and main generator rather than the time required for the voltage regulator to act.

Should there be a sudden reduction instead of an increase in load, there will be a sudden rise in voltage followed by a gradual decrease to normal.

Such voltage fluctuations due to change of load are unavoidable; there is no device available at present that can prevent them. The degree of voltage fluctuation will depend on:

1. Kva capacity and pf rating of the generator.
2. Inherent regulation of the generator.
3. Kva and pf of the load change.
4. Kva and pf of the load the generator is carrying when the load change occurs.

If the above data is available, it is possible to calculate the amount of the resulting voltage change and thereby determine the effect on the quality of the service.

In general, voltage disturbances are caused by two classes of applications:

1. Starting and stopping of motors or other power loads, particularly:
    a) Alternating-current elevator motors—for both passenger and freight service.
    b) Pump and compressor motors started and stopped frequently by automatic starters controlled by pressure or liquid levels.
    c) Crane and hoist motors.
    d) Drives requiring frequent reversal of motors.
    e) Motors using full-voltage starting—particularly high-speed motors.
    f) Induction or electric-arc furnaces.
    g) Spot welders.
2. Variation in motor loads, such as:
    a) Air or refrigeration compressors with automatic loading and unloading devices.
    b) Punch presses and similar machines with intermittent loads.
    c) Compressors with insufficient flywheel effect.

Voltage fluctuations must be given particular attention in the case of hotels, apartments, clubs, schools, libraries, office buildings, hospitals, and other places where reading or close work calls for steady lighting. Even a 2-volt drop will cause an observable flicker in a 120-volt lamp, and the degree of flicker will increase with greater voltage drop. Of course, how objectionable the flicker is depends to some extent on its frequency.

In considering the degree to which voltage fluctuation may be tolerated, there are several classes of equipment other than lamps which require unusually good voltage regulation:

X-ray equipment.
Motion-picture sound projectors.
Teletype machines.
Continuous-tube seam welders.

Magnetic brakes on some elevator motors may set if the voltage drops more than 10 or 15 percent. In general, motor control requires a voltage drop of 40 to 60 percent to shut down motors under their control, [illegible] momentary [illegible] to

25 percent where better regulation is not required for other reasons.

Selection of AC Generators

The intelligent selection of ac generating equipment to meet the needs of a particular installation fully and economically requires mature engineering judgment based on experience and on complete information about the amount and character of the loads to be carried.

Included in this information should be: amount of lighting load; amount of power load and its average power factor; number and size of motors, with details of control showing whether across-the-line or reduced-voltage starting is used and the frequency of starting; degree of voltage fluctuation that can be tolerated; load curve showing the variation of total load throughout the day and night.

Because of the limited capacity of smaller systems compared to large central-station systems, the question of voltage fluctuation is of great importance. If consideration of the class of service indicates that the probable voltage fluctuations would be objectionable, consideration must be given to:

1. Reduction of motor starting currents through the use of reduced-voltage starting of squirrel-cage motors, or even further by the use of wound-rotor motors.
2. Use of flywheel m-g sets for part of the load—for cushioning the frequent starting of elevator motors, for example.
3. Use of separate generators for lighting and for power.
4. Use of generators with better than standard regulation.

Load curves are required to permit the determination of the number and size of units which will provide efficient operation at times of light load, to provide sufficient standby capacity for emergencies, and to allow periodic inspection and cleaning.

When full data is not already available, it can frequently be obtained from a study of monthly power bills. Demand charges will give the peaks to supplement average load data, and in many cases power factor data will also be available. These figures will, however, usually have to be supplemented by readings from recording or indicating wattmeters and ammeters.

If such readings cannot be obtained, the various motor loads may be tabulated, and the lighting load may be estimated from the number and wattage of lamps and their usual hours of use.

In plants not already electrified, the required data can be obtained to some extent from engine indicator cards, by comparison with similar plants which have been electrified, and from figures obtainable from the manufacturers of the various drives.

TABLE 28—INFORMATION REQUIRED FOR SELECTING AC GENERATORS

GENERAL

Type of generator (engine, coupled, belted)................
Quantity.......... To be driven by......................
Kva.... Pf.... Rpm.... Phase.... Cycles.... Voltage....
Ambient temperature.........C Temperature rise..........C
Class of insulation: Armature (stator)...... Field (rotor)......
Is special insulation treatment required?.................
Are damper windings required?............................
Excitation......volts dc. Type of exciter........... ......
Special characteristics (special efficiencies, etc.)..............

MECHANICAL FEATURES

Protection or enclosure (drip-proof, splash-proof, etc.)........
Number of bearings........ Type of bearings..............
Coupling (half, whole, none)........ Sole plates............
Engine type: Is shaft to be pressed into rotor?..............
Is split stator required?...... Split rotor?...... Split hub?....

LOAD DATA

Division of load (motors, lighting, etc.).....................
Voltage regulation required................................
Make and type of voltage regulator, is used.................
Will generator run in parallel with other generators?..........
If so, give make and kind..................................
Motive power of other generators.........................
Are there any formal specifications?........................
Additional information.....................................

While the foregoing material does not provide a means for solving specific problems, it does indicate the importance of providing complete information to the builders of the power generating equipment. Where consulting engineers draw up specifications, these will usually give all of the required information. A brief outline of the information required will be found in Table 28.

DIRECT-CURRENT GENERATORS

The standard kilowatt ratings of standard direct-current generators and the approximate kw ranges available at the various standard speeds are indicated in Table 29. These speeds are approximately the same as for 60-cycle synchronous generators so that the dc machines can be used with the same prime movers.

Speeds of generators direct-connected to internal-combustion engines may range from 164 rpm for a 5000-kw unit to 1200 rpm or more for a 25 or 50-kw unit. The lower speeds listed were originally set up for the once popular Corliss-type steam engine. Vertical multi-cylinder steam engines may have speeds up to 500 or 600 rpm in moderate capacities.

Since steam turbines perform most economically at high speeds, they are usually geared to dc generators with the maximum permissible speeds for the kw and voltage ratings required.

TABLE 29A—STANDARD KILOWATT RATINGS —DC GENERATORS

GENERAL-PURPOSE GENERATORS AND EXCITERS: 1, 1-1/2, 2, 3, 5, 7-1/2, 10, 15, 20, 25, 30, 40, 50, 60, 75, 100, 125, 150.

LARGE GENERATORS: 175*, 200, 250, 300, 350*, 400, 500, 600, 700*, 750, 800*, 900*, 1000, 1250, 1500, 1750, 2000, 2250*, 2500, 3000, 3500, 4000, 4500, 5000.

*Available only at the low speeds.

TABLE 29B—APPROXIMATE KW RANGES AT STANDARD SPEEDS AND VOLTAGES—DC GENERATORS

	125 Volts		250 Volts		600 Volts
Speed in Rpm	General-Purpose Generators and Exciters	Large Generators	General-Purpose Generators and Exciters	Large Generators	Standard Large Generators
		High-Speed			
1800-1750*	**¾ to 150**	**——**	**¾ to 150**	**——**	**——**
1200-1150*	**¾ to 150**	**200 to 250**	**¾ to 150**	**200 to 250**	**200 to 500**
900-850*	**¾ to 150**	**200 to 300**	**¾ to 150**	**200 to 750**	**200 to 750**
720-700	**1 to 150**	**200 to 500**	**1 to 150**	**200 to 1250**	**200 to 1250**
600-575*	**1 to 150**	**200 to 600**	**1 to 150**	**200 to 1250**	**200 to 1250**
514-500	**1 to 150**	**200 to 1000**	**1 to 150**	**200 to 1250**	**200 to 2500**
		Low-Speed			
450	**2 to 125**	**150 to 1000**	**2 to 125**	**150 to 2000**	**200 to 2500**
400	**2 to 100**	**125 to 1000**	**2 to 100**	**125 to 2000**	**200 to 2500**
360	**2 to 100**	**125 to 1000**	**2 to 100**	**125 to 2500**	**200 to 3500**
327	**2 to 75**	**100 to 1000**	**2 to 75**	**100 to 2500**	**200 to 4000**
300	**2 to 75**	**100 to 1000**	**2 to 75**	**100 to 3000**	**200 to 4500**
277	**3 to 75**	**100 to 1000**	**3 to 75**	**100 to 3000**	**200 to 4500**
257	**3 to 75**	**100 to 1000**	**3 to 75**	**100 to 3500**	**200 to 5000**
240	**5 to 60**	**75 to 1000**	**5 to 60**	**75 to 3500**	**200 to 5000**
225	**5 to 60**	**75 to 1000**	**5 to 60**	**75 to 3500**	**200 to 5000**
200	**5 to 60**	**75 to 1000**	**5 to 60**	**75 to 3500**	**200 to 5000**
180	**7½ to 50**	**60 to 1000**	**7½ to 50**	**60 to 3500**	**200 to 5000**
164	**10 to 40**	**50 to 1000**	**10 to 40**	**50 to 3500**	**200 to 5000**
150	**10 to 40**	**50 to 1000**	**10 to 40**	**50 to 3500**	**200 to 5000**
138	**10 to 40**	**50 to 1000**	**10 to 40**	**50 to 3500**	**200 to 5000**
128	**10 to 30**	**40 to 1000**	**10 to 30**	**40 to 3500**	**200 to 5000**
120	**10 to 30**	**40 to 1000**	**10 to 30**	**40 to 3500**	**200 to 5000**

*Applies only to belted general-purpose generators and exciters.

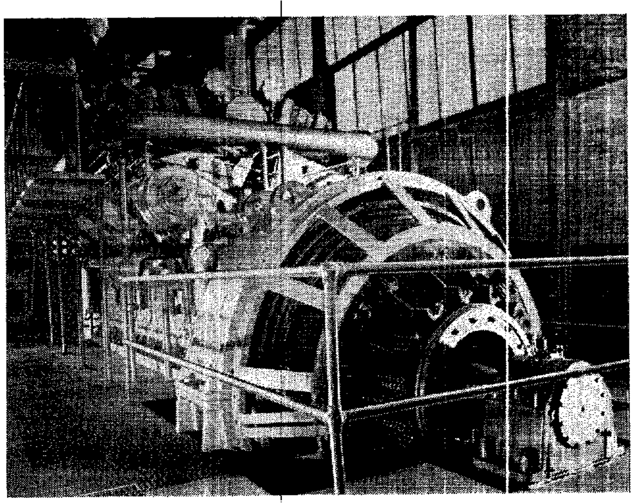


Fig. H-83. Diesel-driven 1700-kw, 327-rpm, engine-type direct-current generator.

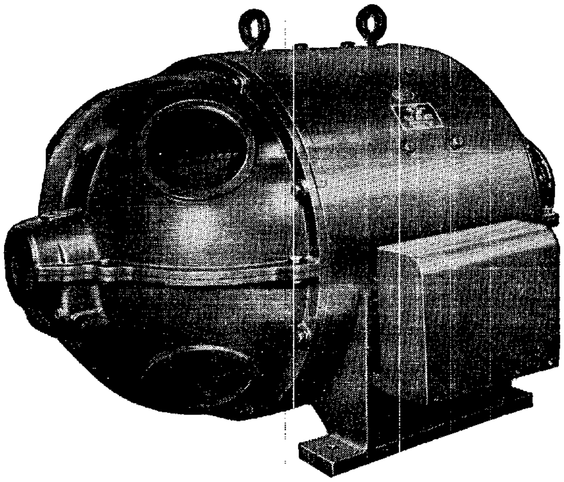


Fig. H-84. End-shield bearing design is used for the smaller dc generator ratings.

Standard voltages are 125, 250 and 600 volts for 2-wire units—125/250 volts for 3-wire units. Special voltage generators are procurable, but the cost is usually higher because of the added development expense.

Standard open-type general-purpose generators are rated 40 C rise for full-load continuous duty. However, when operated at rated voltage and speed they will carry continuously 1.15 times the rated load without injurious temperature rise, provided the ambient temperature does not exceed 40 C.

Standard open-type low-speed generators and large high-speed machines will carry 1.25 times their rated load for two hours and meet the following temperature guarantees:

	Full-Load Continuous Duty	*25% Overload for Two Hours*
Core and windings.......	40 C	55 C
Commutator..........	55 C	65 C
Bare copper windings...	50 C	65 C

DC Generator Construction

High-speed generators in the general-purpose class, that is, up through 150 kw, are usually furnished for coupled service, with one or two end-shield type bearings. Small sizes can be furnished for close-coupled service. These generators have the same external appearance as general-purpose dc motors (see pages H-6, H-7, H-38 and H-39) and are available with the same types of protective features.

For some speeds, such as 1200 rpm, end-shield construction usually can be furnished for ratings up to 300 kw at 250 or 600 volts. Larger high-speed generators generally are furnished with one or two pedestal bearings for mounting on an extension of the prime mover base.

Low-speed generators (below 500 rpm) are usually furnished in the engine type, that is, without shaft, bearings or base. The armature is mounted on the engine shaft, and the bearings, and base if required, are supplied by the engine builder. However, coupled-type parts, including shaft, bearings, and sole plates or base, can be furnished if required.

Parallel Operation

If two or more dc generators are to be operated in parallel, it is essential that they have the same characteristics. That is, the terminal voltage drop from no load to full load (with constant rheostat setting) must be the same for all generators to be paralleled, and the generator voltage regulation curves must have similar shapes.

Shunt-wound generators in parallel form a stable condition under all ordinary circumstances. To obtain exact division of the load, the percentage terminal voltage drop for a given percentage load change should be the same for all machines. Ordinarily, division of the load is controlled by adjustment of the respective field rheostats.

When *compound-wound generators* are operated in parallel, equalizer connections must be used except in cases, such as street railway systems, where the generators are located quite a distance apart. In such cases, the distances involved would make equalizer connections ineffective, but at the same time the unavoidably high resistances of the transmission lines make such connections unnecessary; generator characteristics must, of course, be suited to this type of operation.

The purpose of the equalizer is to maintain the proper current in the series windings of the machines so that each armature will carry its proportionate share of the load. Compound-wound generators can usually be adjusted at the factory for parallel operation with other generators of similar characteristics provided the station wiring is such that the voltage drop from the equalizer through the series field to the bus bars at normal load is the same for all generators.

Paralleling of *generators with and without interpoles* may be satisfactory under certain conditions but is generally not recommended. Generators without interpoles have more rapidly drooping characteristics than those with interpoles. At best, the interpole generators will probably require external resistances in the series circuits.

To parallel with *standby storage battery systems,* generators should have a rapidly drooping voltage characteristic from no load to full load. The generators should be either shunt or differentially compound-wound. If the batteries are to take the peak load, the differential winding should be used so that the generator voltage will drop faster with load than the battery voltage.

From the foregoing it is obvious that *the manufacturer must be supplied with complete information* if a generator is to be built to parallel with existing generators. The information furnished should include the nameplate data together with compounding and regulation data and the voltage drop in the series winding.

With this information, the machines can usually be fully adjusted at the factory for parallel operation. If the information is not available, or if the existing generators have very unusual electrical characteristics, it will be necessary to make final adjustments in the field.

Three-Wire Distribution

In three-wire dc systems, the lower voltage between the neutral and outside wires is used for lighting service, and the higher voltage between the outside wires is used for power. This provides an economical dc distribution system. Its use is usually limited to 120/240 or 125/250 volts. There are two methods commonly used to meet the demands for three-wire service.

One method uses the so-called *three-wire generator,* with the voltage obtained by means of external autotransformers connected through collector rings to the armature windings.

Basically, the construction of three-wire generators differs from that of standard two-wire generators only in the addition of two collector rings and suitable brush rigging. The rings, which are usually mounted on the shaft near the commutator, are connected to suitable points of the armature winding. The lead from each ring is connected to one leg of a balance coil, which is usually separately mounted.

To make the compounding of the generator independent of the unbalance of the load, the series fields of three-wire generators are split into two circuits. One circuit, consisting of the north poles, is connected to one side of the armature, and the other, consisting of the south poles, is connected to the other side of the armature.

Standard construction provides for an unbalanced load of 10 percent. Generators can, however, be built for 25 or 50 percent unbalance.

The other three-wire system commonly used is the *rotary-balancer system,* which consists of a two-wire single-voltage generator operating with a rotary-balancing set.

The rotary-balancer system has several advantages that should be carefully considered. Regulation is better than in other systems because the balancers can be compounded to give full voltage at any desired load. Any amount of unbalance can be handled, as this depends solely on the size of the balancer. And the full capacity of the generator is always available whatever the condition of unbalance.

Table 30 gives an idea of the data required before an intelligent selection of a dc generator can be made.

TABLE 30—INFORMATION REQUIRED FOR SELECTING DC GENERATORS

GENERAL

Type of generator (engine, coupled, belted)..................
Quantity............ To be driven by....................
Kw.... Rpm.... Voltage: Rated.... No load.... Full load...
Overload rating (if special)................................
Ambient temperature......C Temperature rise.............
Class of Insulation: Armature... Field... Special treatment...
Two-wire or 3-wire...... Percent unbalance (if 3-wire).......

MECHANICAL FEATURES

Protection or enclosure (drip-proof, splash-proof, etc.)........
Number of bearings........ Type of bearings.............
Coupling (half, whole, none)...... Sole plates.............
Engine type: Is shaft to be pressed into armature?...........

LOAD DATA

Nature of load..
Working voltage of plant................................
Make and type of voltage regulator, if used................
Will generator run in parallel with other generators?..........
If so, give data..
Are there any formal specifications?.......................
Additional information..................................

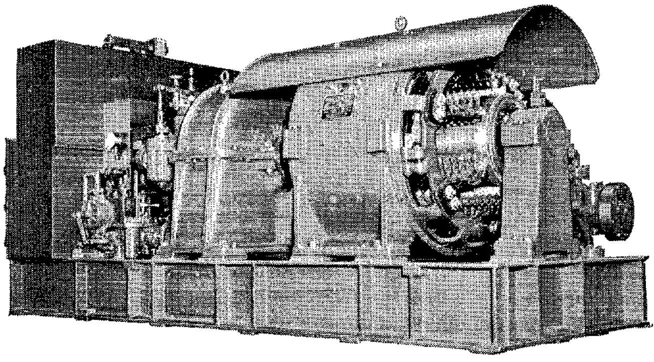


Fig. H-85. Geared 250-kw turbine-generator for auxiliary power aboard cargo vessel.

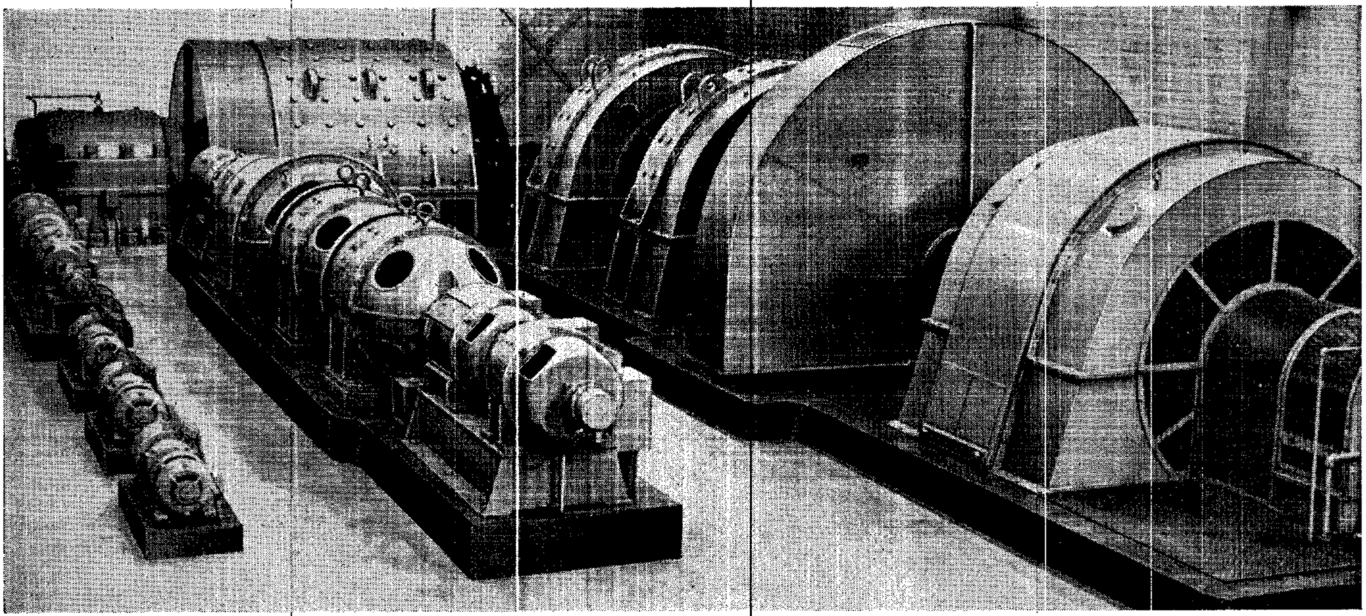


Fig. H-86. Four *Regulex* exciter sets, an 844-kw auxiliary synchronous m-g set, and 3500-kw flywheel m-g set supporting 4000-hp, 0-50/120-rpm dc reversing blooming mill motor in background.

MOTOR-GENERATOR SETS

Motor-generator sets, consisting of a motor and one or more generators, are used to transform electrical energy from one form to another as follows:

1. From alternating current to direct current.
2. From direct current to alternating current.
3. From direct current to direct current at different voltages.
4. From alternating current to alternating current at different frequencies.

Wherever practicable, motor-generator sets are built up of units of standard designs; but where this is not feasible, special combinations are designed to suit the requirements.

Alternating Current to Direct Current

Most electrical systems supply alternating current because it can be more economically transmitted and distributed than direct current. Where direct current is desirable or essential, it can be obtained from an ac system by means of an m-g set consisting of an induction or synchronous motor driving a dc generator. The choice of motor depends upon the conditions to be met.

Induction Motor-Generator Sets

Alternating-current/direct-current motor-generator sets rated less than 50 kw are almost invariably of the induction motor-driven type, and most of these have squirrel-cage induction motors. (*Fig. 87.*) They are used to supply excitation, lighting, and general power.

Under some conditions, the induction motor is preferable to the synchronous motor for driving generators of larger capacities. This is true, for example, where the load on the generator is of a widely fluctuating nature. While the induction motor has the advantage of not requiring excitation, its effect on the power factor of the system may be undesirable, especially when the circuit supplies other apparatus taking a lagging current.

A flywheel may be used to advantage with an induction set required to supply high peak loads of short duration. Since the motor slows down when the load is applied, the stored energy in the flywheel then drives the generator. This greatly reduces the temporary excess load on the m-g set motor and on the main generating system.

Wound-rotor motors are also used on flywheel m-g sets. The control can be arranged to produce a greater speed drop in the wound-rotor motor and thereby further limit peak loads on the line supplying the m-g set motor.

Synchronous Motor-Generator Sets

The chief advantage of using synchronous motors to drive the dc generators of m-g sets lies in the power-factor corrective effect that can be obtained by over-exciting the field of the motor. In other words, synchronous m-g sets can advantageously be used even in fairly small ratings to correct poor power factor resulting from induction motors, transformers, arc lights, and other inductive apparatus on the circuit.

Synchronous motors do, however, require direct current for excitation of the motor fields for m-g sets, this is not a particularly significant disadvantage though, since the set can readily be supplied with a direct-connected exciter. In fact, the m-g set generator can, if its voltage is not much above 250 volts, supply the required excitation. *Fig. 88* shows a large synchronous motor driven motor-generator set.

Direct Current to Alternating Current

Although m-g sets for conversion of direct current to alternating current are not in great demand, they can readily be supplied if required. Such a combination includes a dc driving motor coupled to an ac generator.

Direct Current to Direct Current

Motor-generator sets consisting of dc motors driving dc generators are used to furnish a circuit with a voltage different from that of the main power circuit or with a voltage that can be varied independently. Where a set supplies a special voltage circuit, the set also serves to insulate the main and special circuits from each other if their requirements differ.

Boosters sets are used when the load on some feeders in a dc distribution system requires a voltage regulation for which the main generator cannot be adjusted without disturbing the potential at other parts of the system. The booster, connected in series with one wire of the feeder, keeps the voltage constant or varying to suit local conditions.

This method frequently has been used by central stations to compensate for line loss in long runs. It is also used to raise the voltage for battery charging. Booster generators are usually driven at constant speed by shunt-wound motors receiving power from the line.

A three-unit *balancer* is sometimes employed in connection with a standard single-voltage dc generator to produce a multi-voltage supply from which dc motors may be operated at various speeds.

For example, a three unit balancer generating 40, 80 and 120 volts used in connection with a 240-volt generator would supply six voltages to the motors so that they could be run at six different speeds. In addition, field and armature control can be used to

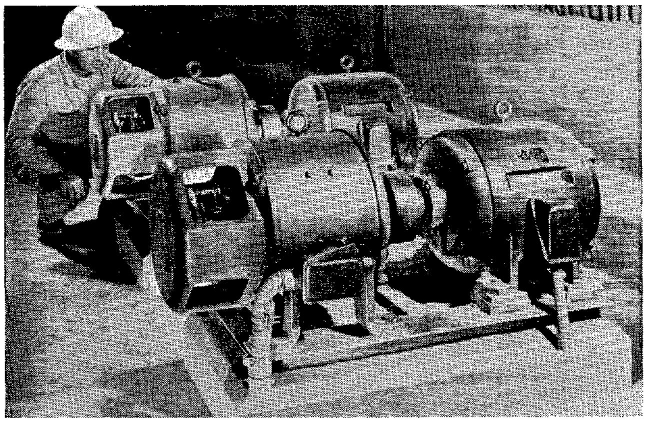


Fig. H-87. Two 15-kw induction m-g sets used for excitation of cement-plant synchronous motors.

TABLE 31

NEMA KILOWATT AND SYNCHRONOUS SPEED RATINGS FOR 60 CYCLE 2 AND 3-PHASE SQUIRREL-CAGE INDUCTION MOTOR-DRIVEN SETS

Generators: 125 or 250 V Shunt or Compound-Wound
Motors: 110, 220, 440, 550 and 2300 V

Generator Rating Kw	Motor Rating Hp	Motor Voltage 110	208-220-440-550			2300, Three-Phase
		Synchronous Speed—Rpm				
1	2	1800	1800	....	....	....
1½	3	1800	1800	....	....	....
2	3	1800	1800	....	....	....
3	5	1800	1800	....	....	....
5	7½	....	1800	....	....	....
7½	15	....	1800	....	....	....
10	15	....	1800	....	....	....
15	25	....	1800	....	....	....
20	30	....	1800	....	....	....
25	40	....	1800	....	....	1200
30	50	....	1800	....	1800	1200
40	60	....	1800	1200	1800	1200
50	75	....	1800	1200	1800	1200
60	100	....	1800	1200	1800	1200
75	125	....	1800	1200	1800	1200
100	150	....	1800	1200	1800	1200
125	200	....	1800	1200	1800	1200
150	250	....	1800	1200	1800*	1200

*250-volt generators only.

TABLE 32

NEMA KILOWATT AND SYNCHRONOUS SPEED RATINGS FOR 60 CYCLE SINGLE-PHASE MOTOR-DRIVEN SETS

Generators: 125 or 250 V Shunt or Compound-Wound
Motors: 110 or 220 V

Generator Rating Kw	Motor Rating Hp	Synchronous Speed Rpm
1	2	1800
1½	3	1800
2	3	1800
3	5	1800
*5	7½	1800

*230-volt motor only.

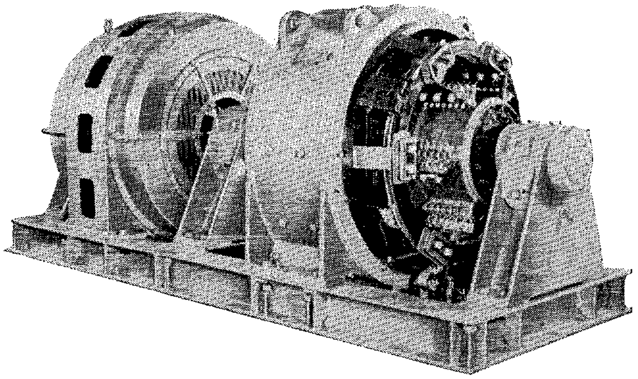


Fig. H-88. Synchronous m-g set rated 500 kw, 900 rpm built to support rubber-mill calender drive.

increase or decrease the speed of the motors from the six fundamental speeds, thus providing a wide range of easy control.

As has already been noted in the discussion of dc generators, a two-unit balancer can be used to change a single-voltage, two-wire dc system into a three-wire system.

Alternating Current to Alternating Current

Frequency-changer sets normally consist of a synchronous motor driving a synchronous generator, but occasionally an induction motor is used to drive the synchronous generator.

Since there is a fixed relationship between speed and frequency, the number of poles for the motor and generator must be chosen so that the two frequencies desired will be obtained at the same speed. For example, in changing from 60 to 25 cycles a 300-rpm set can be used; in this case the motor would have 24 poles and the generator 10 poles.

Frequency changers are used (a) to interchange power between two systems of different frequencies, or (b) to supply power at either a higher or lower frequency than that of the available supply.

Another means of changing frequencies is the *induction frequency converter set,* consisting of a wound-rotor induction machine driven by a suitable motor.

The primary circuits of the wound-rotor machine are connected to a fixed-frequency source of electric power. The secondary circuits deliver power at a frequency proportional to the relative speeds of the primary magnetic field and the secondary (rotating) member. If a frequency higher than that of the power lines is desired, the rotor of the frequency converter is driven in the direction opposite to that in which it would run as a motor.

By using a multi-speed or varying-speed driving motor, the converter can deliver a secondary frequency that varies to suit the requirements. It should be noted that the secondary voltage of the wound-rotor machine varies directly as the secondary frequency.

Tables 31, 32, 33 and 34 give the standard NEMA ratings for motor-generator sets.

TABLE 33

NEMA KILOWATT AND SYNCHRONOUS SPEED RATINGS FOR 60 CYCLE 2 AND 3-PHASE SYNCHRONOUS MOTOR-DRIVEN SETS, 0.8 POWER FACTOR LEADING AT FULL LOAD

Generators: 125 or 250 V Shunt or Compound-Wound
Motors: 220, 440, 550 or 2300 V

Generator Rating Kw	Motor Rating Hp	Synchronous Speed Rpm
50	75	1200
60	100	1200
75	125	1200
100	150	1200
125	200	1200
[illegible]	250	[illegible]

TABLE 34

NEMA STANDARD KILOWATT AND SPEED RATINGS FOR SYNCHRONOUS MOTOR-GENERATOR SETS 200 KW AND LARGER

Rating Kw	Speed Rpm	Type of Set
	125 Volts—60 Cycles	
200	1200	Two-Unit
250	1200	Two-Unit
300	1200	Three-Unit
300	900	Two-Unit
400	1200	Three-Unit
400	720	Two-Unit
500	1200	Three-Unit
500	720	Two-Unit
600	900	Three-Unit
800	720	Three-Unit
1000	720	Three-Unit
	250 Volts—60 Cycles	
200	1200	Two-Unit
250	1200	Two-Unit
300	1200	Two-Unit
400	1200	Two-Unit
500	1200	Two-Unit
600	900	Two-Unit
750	900	Two-Unit
1000	720	Two-Unit
1250	720	Two-Unit
1500	514	Two-Unit
2000	360	Two-Unit
2000	720	Three-Unit
2500	720	Three-Unit
3000	514	Three-Unit
4000	360	Three-Unit
	600 Volts—60 Cycles	
300	1200	Two-Unit
500	1200	Two-Unit
600	900	Two-Unit
750	900	Two-Unit
1000	720	Two-Unit
1250	720	Two-Unit
1500	514	Two-Unit
1750	514	Two-Unit
2000	514	Two-Unit
2000	720	Three-Unit
2500	514	Three-Unit
2500	720	Three-Unit
3000	360	Three-Unit
3000	514	Three-Unit
3500	514	Three-Unit
4000	514	Three-Unit
5000	514	Three-Unit
6000	360	Three-Unit

Standard rating for two-unit motor-generator sets above 2000 kw, 514 rpm, will be in steps of 500 kw.

Standard rating for three-unit motor-generator sets above 4000 kw, 514 rpm, will be in steps of 1000 kw.

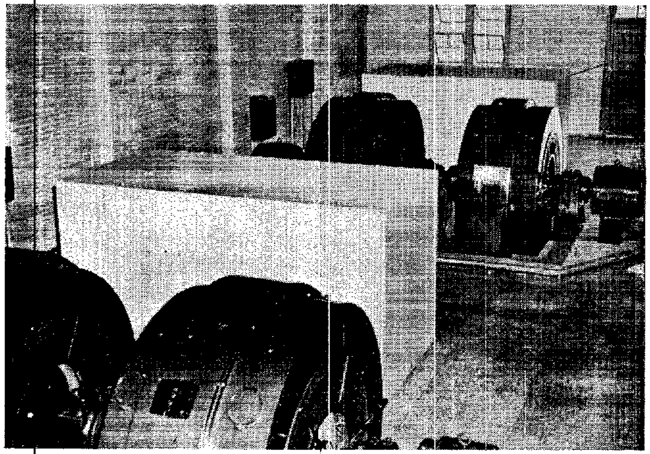


Fig. H-89. Two 2500-kva, 600-rpm, 40/60-cycle frequency-changer sets. Generator in background has [illegible] device.

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STEAM TURBINES . . . for all power plant applications . . . ship propulsion.

GAS TURBINES . . . for use with axial blowers in process work . . . power generation . . . locomotives.

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GENERATORS . . . synchronous, induction, direct current . . . vertical and horizontal . . . all sizes.

GENERATOR VOLTAGE REGULATORS . . . for providing constant output voltage on generators of all sizes.

SYNCHRO-OPERATORS . . . for full automatic synchronizing of ac generators.

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SWITCHBOARDS to suit application.

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CIRCUIT BREAKERS . . . oil, magnetic and air blast types . . . outdoor and indoor . . . manual and automatic.

MOTOR CONTROL . . . standard and special for motors of all sizes above ½ hp.

UNIT SUBSTATIONS . . . single circuit, multi-circuit and load center types.

POWER CONVERSION

RECTIFIERS . . . mercury arc power, with metal tanks, single and multiple anode . . . also permanently evacuated type.

MOTOR-GENERATOR SETS . . . all sizes, with synchronous or induction motor drive . . . frequency changers . . . converters.

SYNCHRONOUS CONDENSERS . . . for power factor correction and improvement of system stability.

GENERAL INDUSTRIAL PRODUCTS

ELECTRIC MOTORS . . . all types, synchronous, induction, direct current, 1 hp up to largest . . . motor control.

TEXROPE DRIVES, multiple v-belt . . . cast iron and pressed steel sheaves . . . variable speed . . . speed changers.

CENTRIFUGAL PUMPS . . . single and multi-stage . . . 10 to 300,000 gpm.

COMPRESSORS . . . rotary sliding-vane.

BLOWERS . . . single and multi-stage centrifugal . . . axial.

DIELECTRIC HEATERS . . . for heating, dehydrating, bonding, non-conducting materials.

INDUCTION HEATERS . . . for heating, brazing, melting, metals.

METAL DETECTORS . . . electronic device that safeguards quality . . . prevents damage to machinery.

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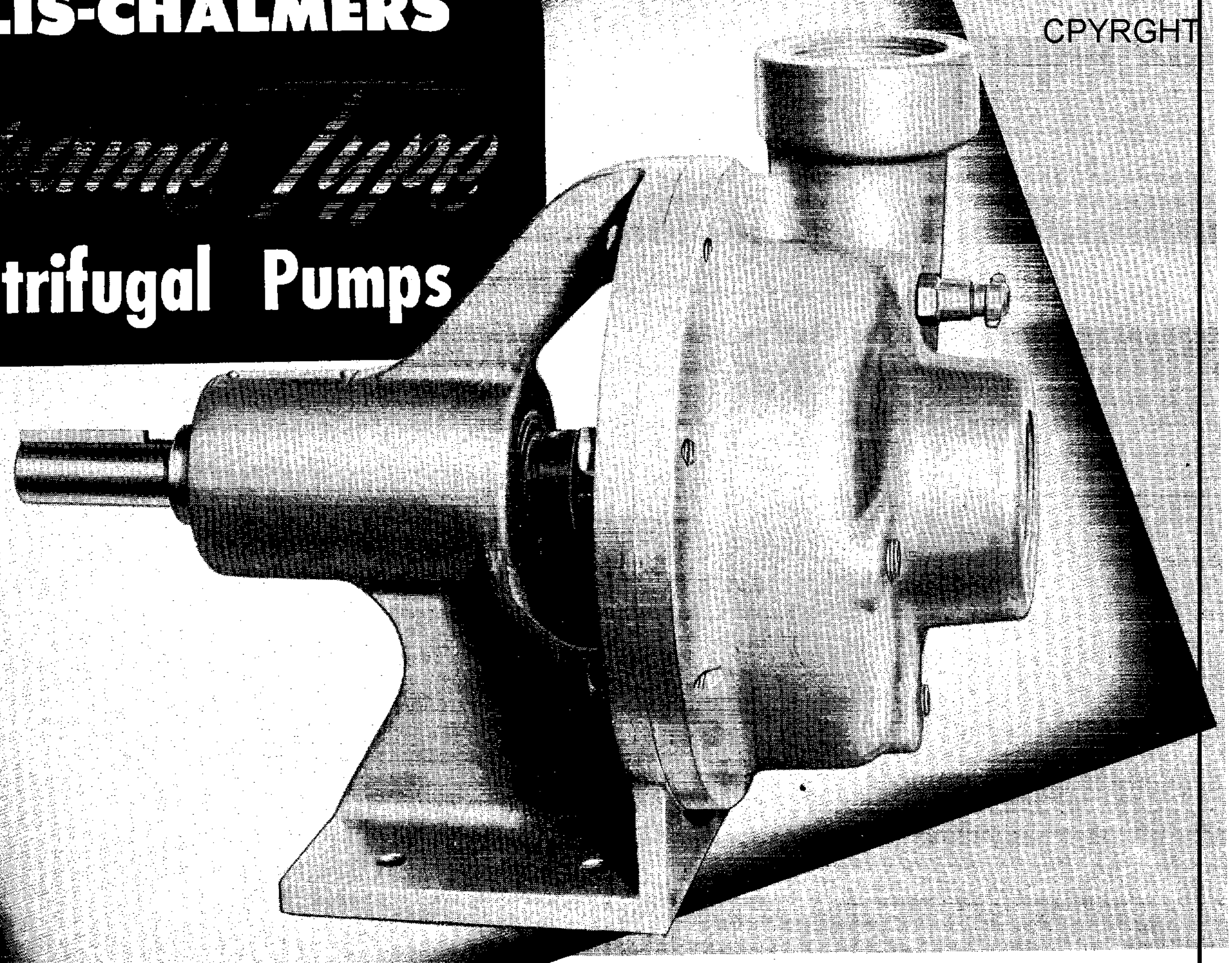
MOTORS AND GENERATORS

ALLIS-CHALMERS

Frame Type

Centrifugal Pumps



Efficient • Versatile • Low-Cost

Here's a pump specially designed for quick, easy application to hundreds of everyday pumping jobs. It offers you top value for your pumping dollar because it has all the quality features that you need to keep your pumping costs low, yet its price is exceptionally low.

Quality Features. You get high grade construction, such as ball bearings, mechanical shaft seal, and generous metal sections. Built to the same top quality precision standards as all Allis-Chalmers pumps.

Easy Installation. The Allis-Chalmers frame type pump is built for V-belt drive. It can be mounted in a variety of positions and connected to any type of prime mover without difficult alignment problems.

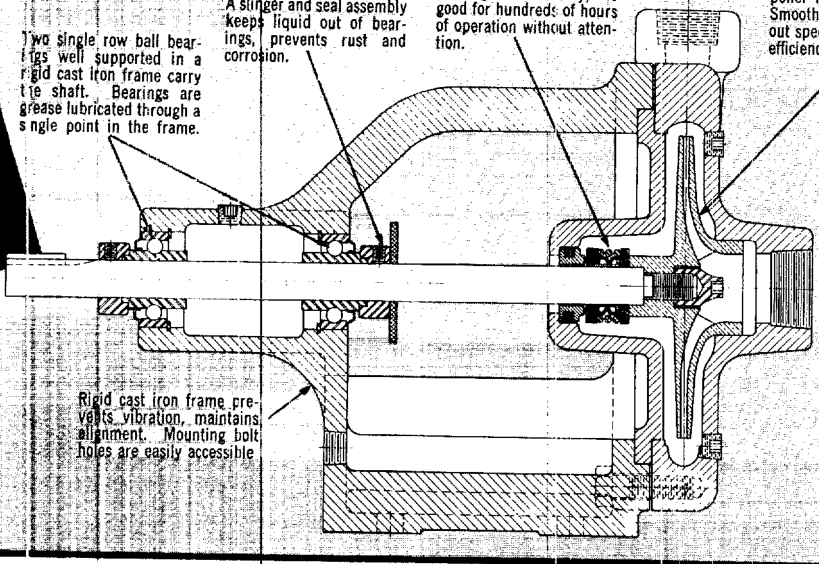
Wide Range. These pumps will handle most ordinary pumping jobs requiring capacities up to 500 gpm and heads as high as 135 feet. Head and capacity can be changed by simply changing sheave size on the V-belt drive. One pump can serve you many places with only this simple change.

Low Maintenance. Rigid base holds alignment, keeps bearing wear down. Mechanical seal requires no attention in normal service. Wearing rings on larger pumps mean efficiency can be maintained easily through years of service.

If you have been looking for a quality pump at a competitive price, you'll find it among these Allis-Chalmers frame type pumps.

ALLIS-CHALMERS

Enclosed impeller
Capacities to 85 gpm
Heads to 100 feet



Two single row ball bearings well supported in a rigid cast iron frame carry the shaft. Bearings are grease lubricated through a single point in the frame.

A slinger and seal assembly keeps liquid out of bearings, prevents rust and corrosion.

Mechanical seal makes packing unnecessary, is good for hundreds of hours of operation without attention.

Precision cast bronze impeller is of enclosed type. Smooth surfaces inside and out speed water flow, keep efficiency high.

Rigid cast iron frame prevents vibration, maintains alignment. Mounting bolt holes are easily accessible

TYPE BHB

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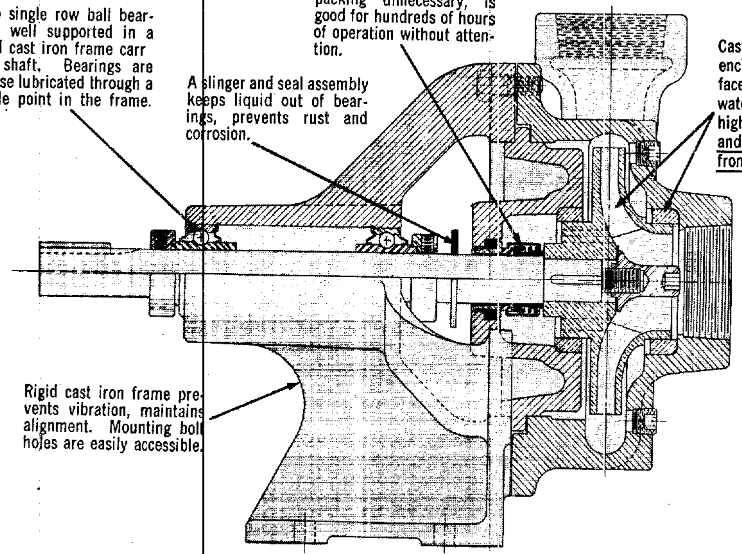


Two single row ball bearings well supported in a rigid cast iron frame carr the shaft. Bearings are grease lubricated through a single point in the frame.

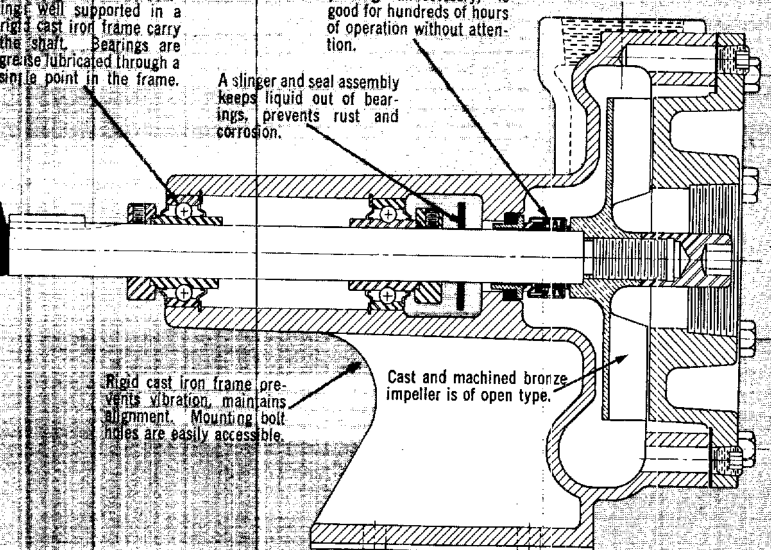
A slinger and seal assembly keeps liquid out of bearings, prevents rust and corrosion.

Mechanical seal makes packing unnecessary, is good for hundreds of hours of operation without attention.

Cast bronze impeller is of enclosed type. Smooth surfaces inside and out speed water flow, keep efficiency high. Wearing rings front and rear on larger sizes, front only on smaller sizes.

Rigid cast iron frame prevents vibration, maintains alignment. Mounting bolt holes are easily accessible.

Open impeller
Capacities to 200 gpm
Heads to 70 feet



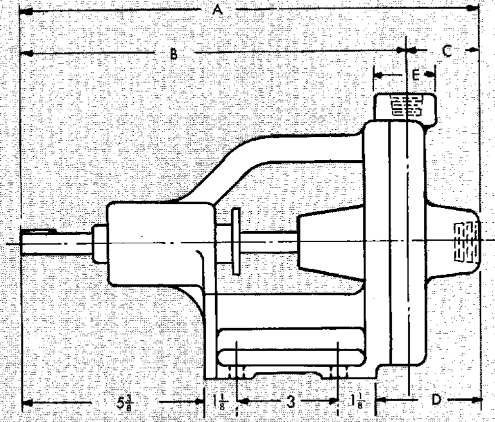
Two single row ball bearings well supported in a rigid cast iron frame carry the shaft. Bearings are grease lubricated through a single point in the frame.

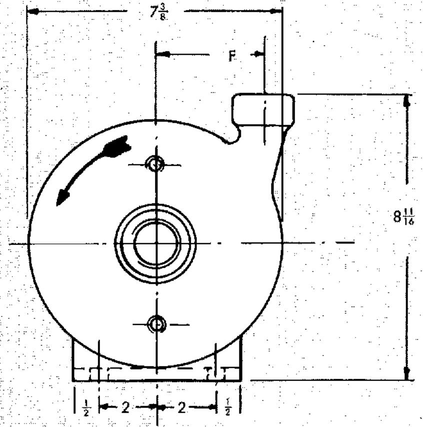
A slinger and seal assembly keeps liquid out of bearings, prevents rust and corrosion.

Mechanical seal makes packing unnecessary, is good for hundreds of hours of operation without attention.

Cast and machined bronze impeller is of open type.

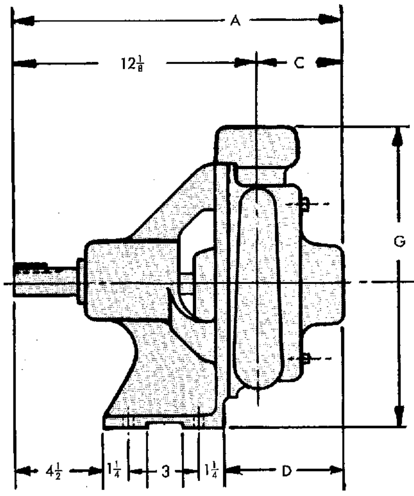
Rigid cast iron frame prevents vibration, maintains alignment. Mounting bolt holes are easily accessible.

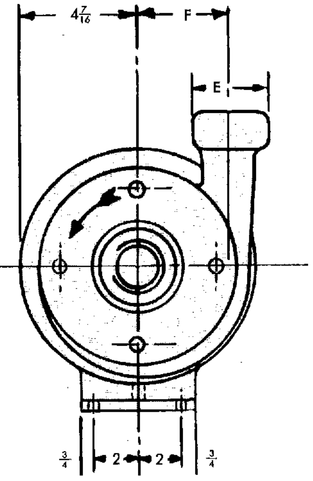




DIMENSIONS IN INCHES

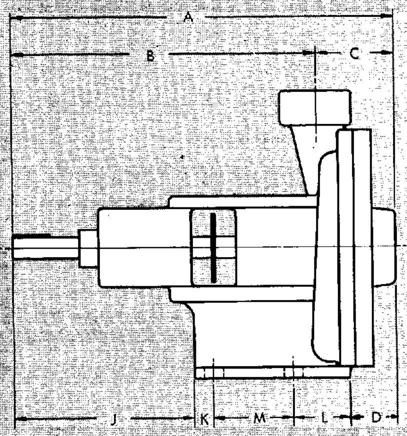
Size....	1 x ¾	1¼ x 1
A	13½	14 1/16
B	11⅜	12 7/16
C	2⅛	1⅝
D	2⅞	3 7/16
E	1¾	2
F	3 3/16	2 15/16

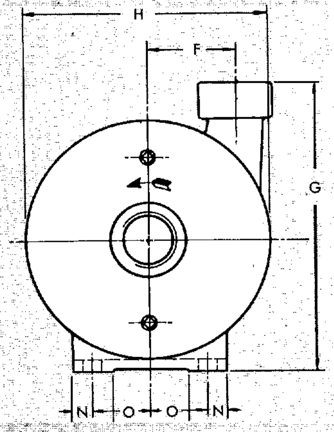




DIMENSIONS IN INCHES

Size..	1½x1½	2x2	2½x2½	3x3
A	14⅝	14¾	14⅞	15
C	2½	2⅝	2¾	2⅞
D	4⅝	4¾	4⅞	5
E	2¾	3¼	3⅞	4½
F	3⅛	3¼	3 7/16	3¾
G	11⅜	11	11¾	11½

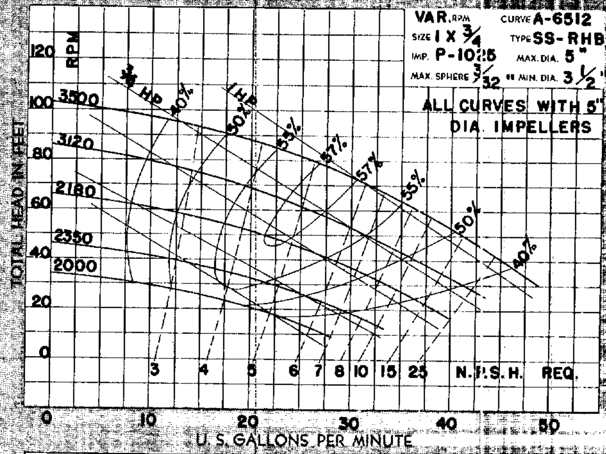


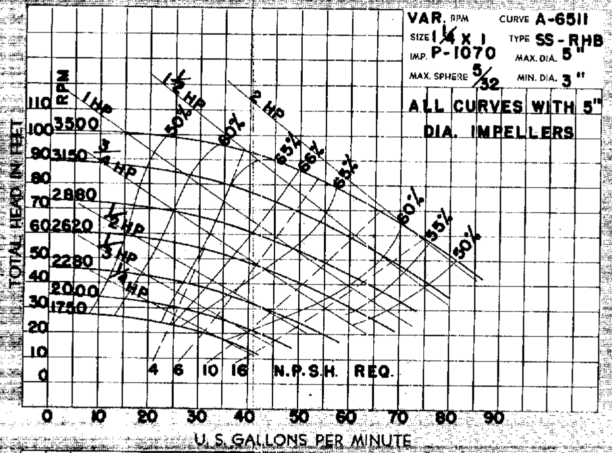


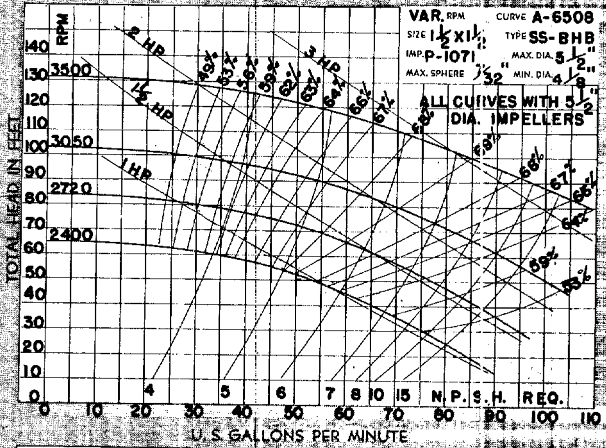
DIMENSIONS IN INCHES

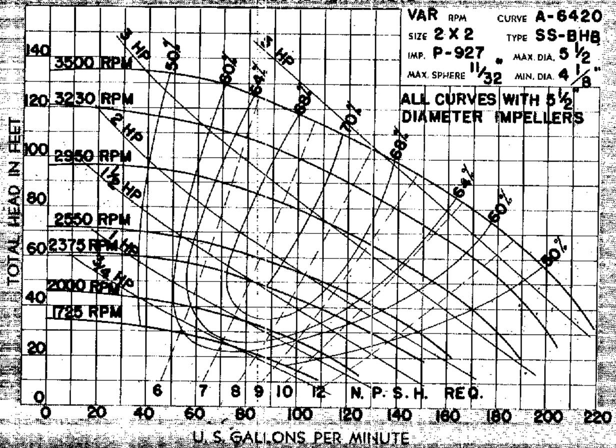
Size....	1 x 1	2½ x 2
A	10	14¼
B	7⅞	11⅜
C	2⅛	2⅞
D	1¼	2¾
F	2 5/16	4⅛
G	7¾	10
H	6⅜	8½
J	4¾	6
K	½	1¼
L	1½	1¼
M	2½	3
N	¼	¾
O	1½	2

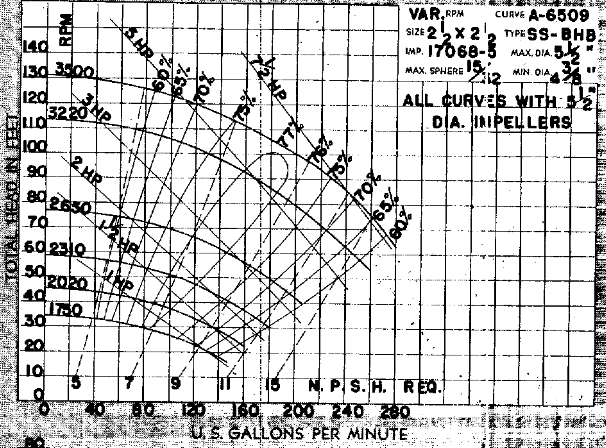
PERFORMANCE CURVES

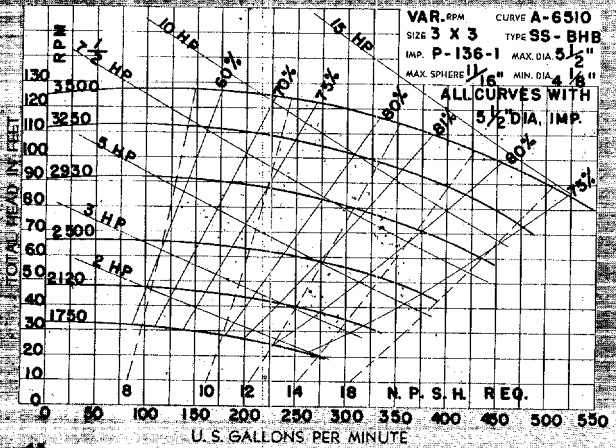


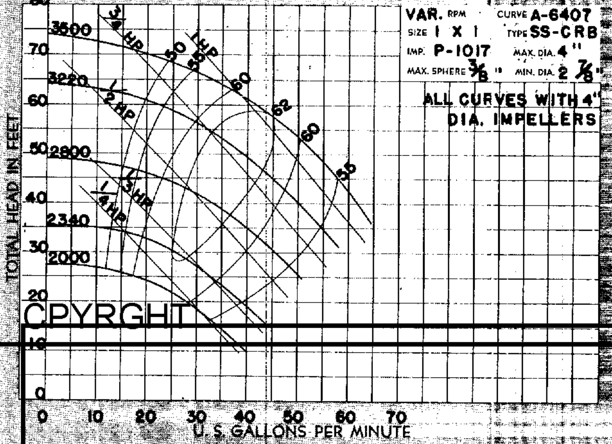


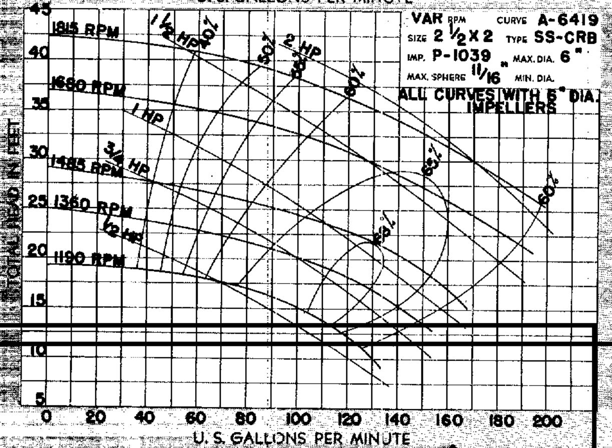












ALLIS-CHALMERS

HEAVY-DUTY SCREENS

for the MINING INDUSTRY

- High Capacity Scalping
- Wet and Dry Screening
- Screening Sticky Ores
- Heavy Media Separation

ALLIS-CHALMERS

MILWAUKEE 1, WISCONSIN

Here is Allis-Chalmers complete line of vibrating screens for the mining industry . . .

ROM SCREENS for Primary Scalping, Maximum Size 3 ft.

Heavy duty screens designed to scalp ahead of primary crushers . . . to handle feed direct from mine in lumps up to 3 ft. diameter. Capacity 1000 tph. These screens are furnished with a variety of decks to suit each application, such as the step deck with grizzly bars (page 3, top photo), or plate deck with skid bars for openings 4 to 10 inches.

A complete line of extra heavy duty two-beam Style C vibrating screens are also built by Allis-Chalmers for this service.

SCALPING SCREENS for Sticky Ores, Maximum Size 16 in.

Two types of decks are available for handling sticky ores, approximately 16 in. maximum feed size. These are the step deck with double tapered grizzly bars shown at the bottom of page 3, and the free discharge rod deck shown at bottom of page 4. The grizzly bar deck has openings 4 to 10 inches; the rod deck has openings 1 to 3 inches, using ⅝ to 1 in. diameter rods.

Both screen decks have a step construction which results in free discharge of the material through the bars or rods and assists in turning the lumps over on the screen to prevent fines from riding on top of the lumps.

SECONDARY SCALPING SCREENS

Used for scalping ahead of secondary or tertiary crushers . . or for preparing grinding mill feed. Rods are mounted in rubber on a step design deck. Maximum size is approximately 6 in. Rod deck screens are furnished in various sizes with openings 3/16 to ¾ in., using ⅜ or ½ in. diameter rods.

CONVENTIONAL SCREENS for Wet or Dry Sizing

A wide range of sizes of *Low-Head* and *Ripl-Flo* vibrating screens are available for essentially all wet and dry screening applications. These Allis-Chalmers screens are well known throughout all industry for their excellent performance and stamina despite heavy-going demands.

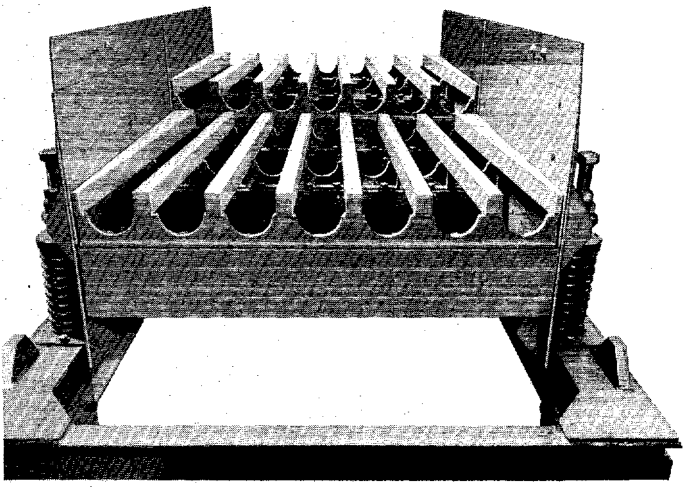
HEAVY MEDIA SEPARATION

The success of the heavy media process is due in large measure to the successful operation of the *Low-Head* vibrating screens used as primary screens ahead of the heavy media separator and as media recovery wash and drain screens following the separator.

Allis-Chalmers pioneered in the development of screens for this important process. In heavy media plants, *Low-Head* screens are by far the most widely used screens. Allis-Chalmers builds *Low-Head* screens in sizes for every capacity needed in this process.

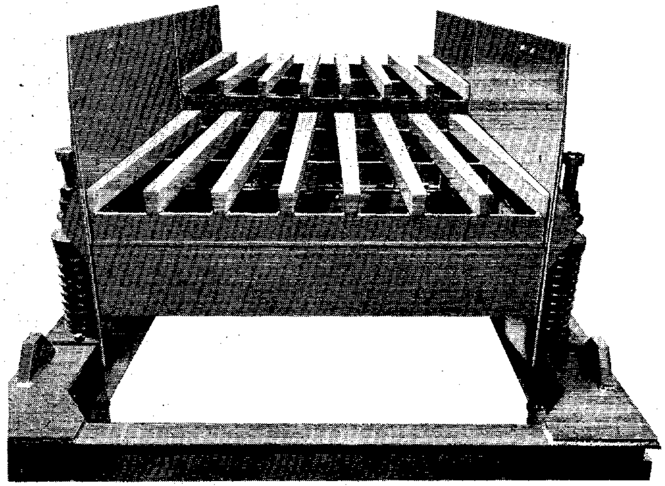
HEAVY DUTY SCALPING SCREENS for ROM ores

. . . WITH STRAIGHT GRIZZLY BARS

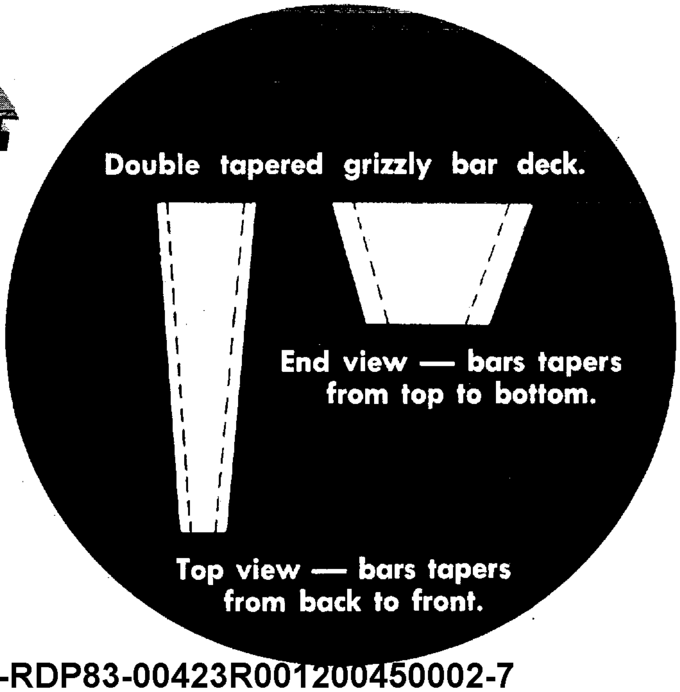


1. No wedging — straight grizzly bars set to provide flared openings.
2. Easy to replace screen — grizzly bar assembly made in panels for bolting to screen body.
3. Openings 4 to 10 in.

. . . WITH DOUBLE TAPERED GRIZZLY BARS



1. No wedging! Grizzly bars set to provide flared openings, tapered from back to front and from top to bottom.
2. Easy to replace screen surfaces. Grizzly bar assembly made in panels for bolting to screen body.
3. Openings 4 to 10 inches.
4. Capacity 1000 tph or more.



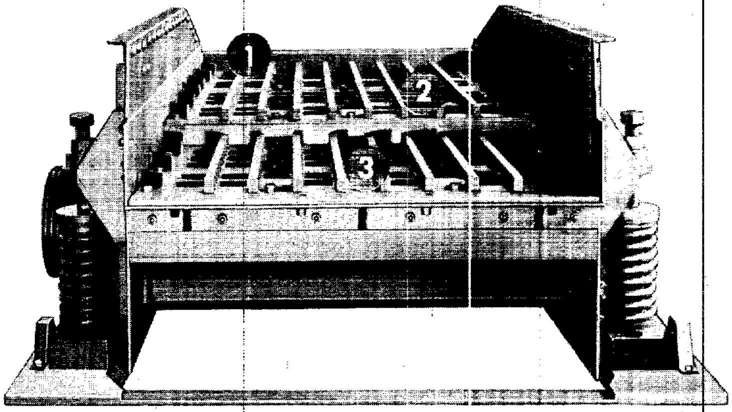
Double tapered grizzly bar deck.

End view — bars tapers from top to bottom.

Top view — bars tapers from back to front.

HEAVY DUTY SCALPING SCREENS for ROM ores

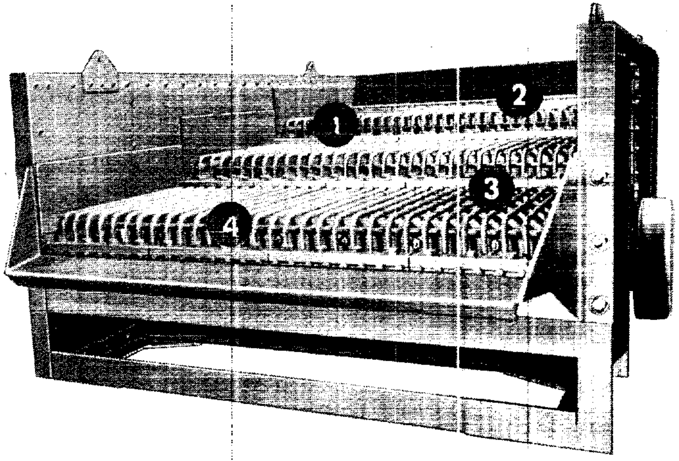
. . . WITH STEEL PLATE DECK



Steel plate deck with 4 in. square openings and rectangular skid bars.

1. Steel plate deck with skid bars.
2. Square openings 3 to 10 inches.
3. Plate deck bolted to screen body.

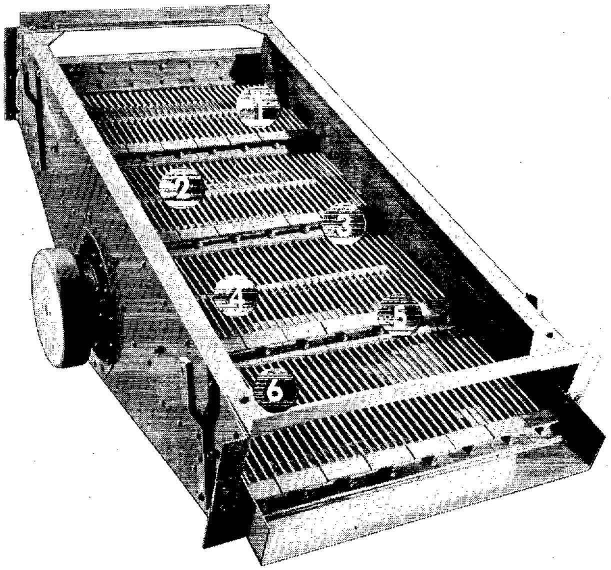
HEAVY DUTY SCREENS for scalping sticky ores



Free discharge rod deck.

1. Step deck for openings 1 to 3 in. using free discharge rods.
2. Rod diameters 5/8 to 1 inch.
3. Maximum size feed 16 in. when using 2 in. opening and 1 in. diameter rods.
4. Low replacement cost. Only worn rods need be replaced. Rods are grouped in small panels . . . spaced with metal spacers.

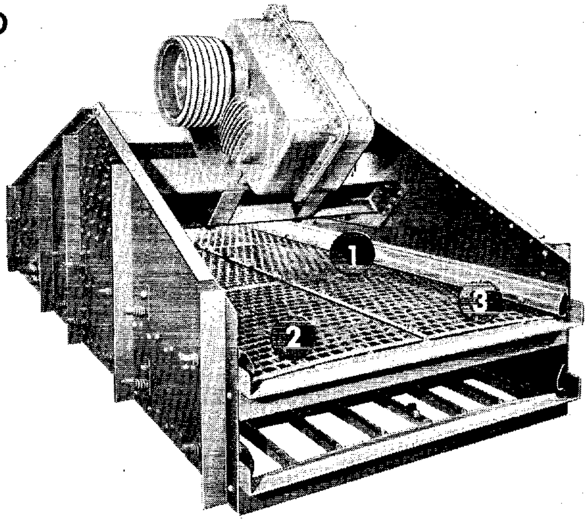
SCREENS for scalping ahead of secondary or tertiary crusher



1. Screen with rod deck for handling maximum size feed of 6 inches.
2. Openings 3/16 to 3/4 inch.
3. Rod diameters: 3/8 or 1/2 inch diameters.
4. Screens have about double the capacity of square mesh screens.
5. Deck construction makes it easy to replace individual rods.
6. Rods grouped in small panels.

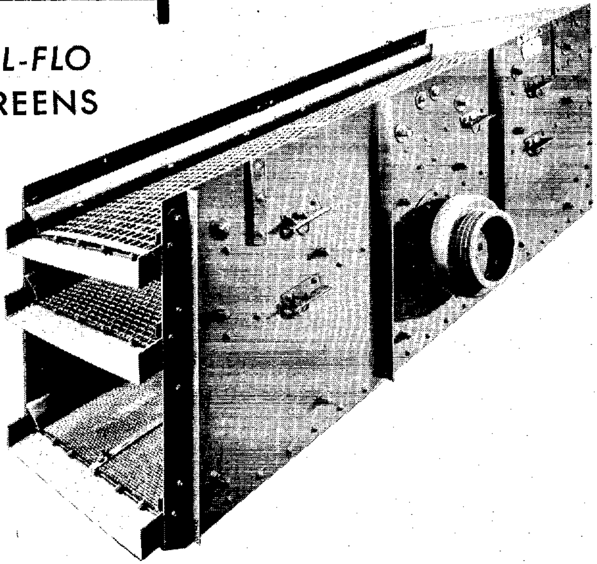
CONVENTIONAL SCREENS for heavy-duty sizing

LOW-HEAD SCREENS



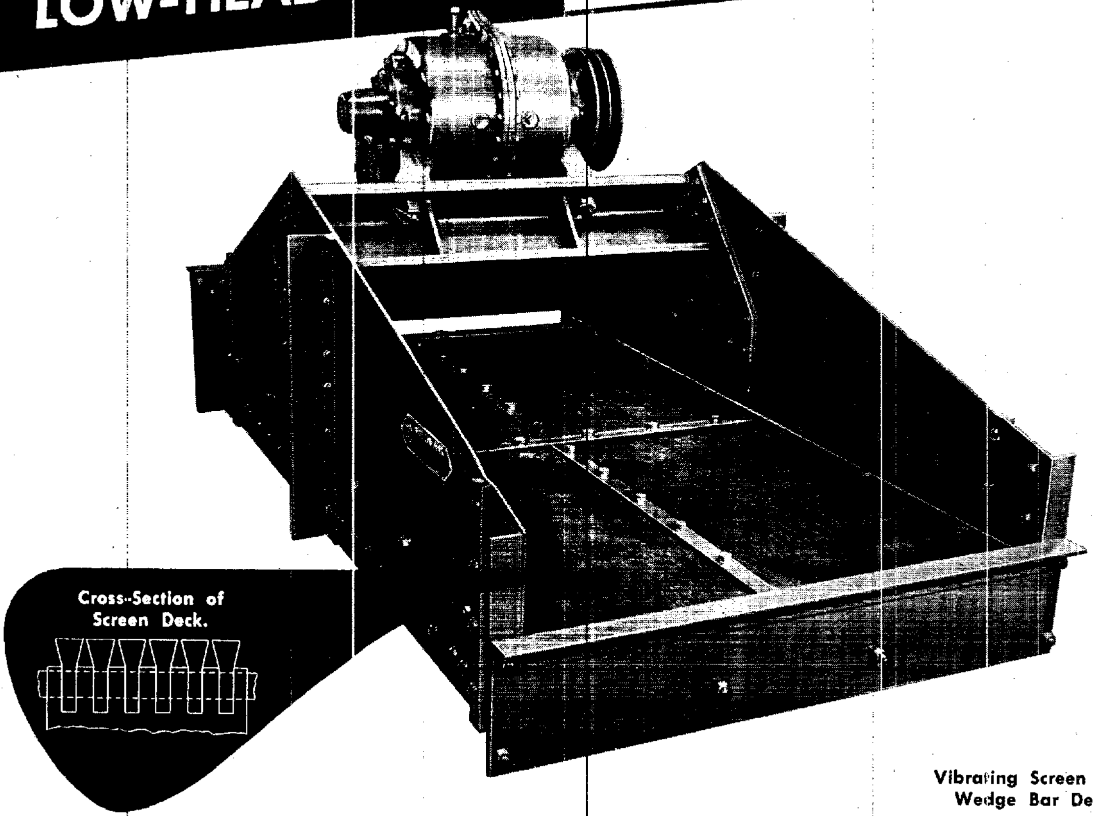
A horizontal screen with straight-line vibratory motion at 45° to the horizontal. Screen openings ¼ to 3 inches. Available with plate or wire screen surfaces . . . or with crowned decks to prevent whipping of screen surface. Sizes 3x6 to 6x16 ft.

RIPL-FLO SCREENS

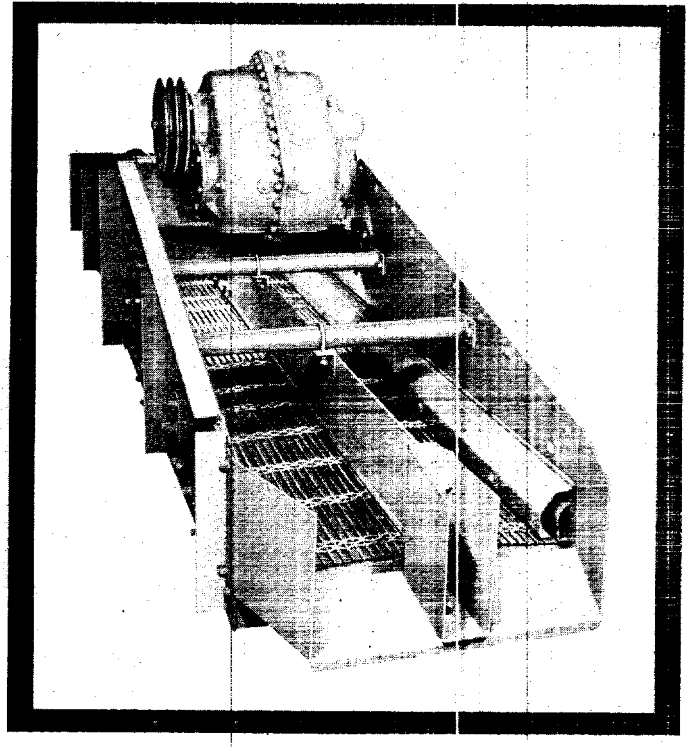


A two-bearing inclined screen for moderate to heavy-duty sizing. Vibrating mechanism is located between decks. Floor mounted or suspended. Available in extra heavy duty type for wet or dry scalping or coarse sizing. Sizes 3x6 to 6x16 ft.

LOW-HEAD MEDIA RECOVERY SCREENS

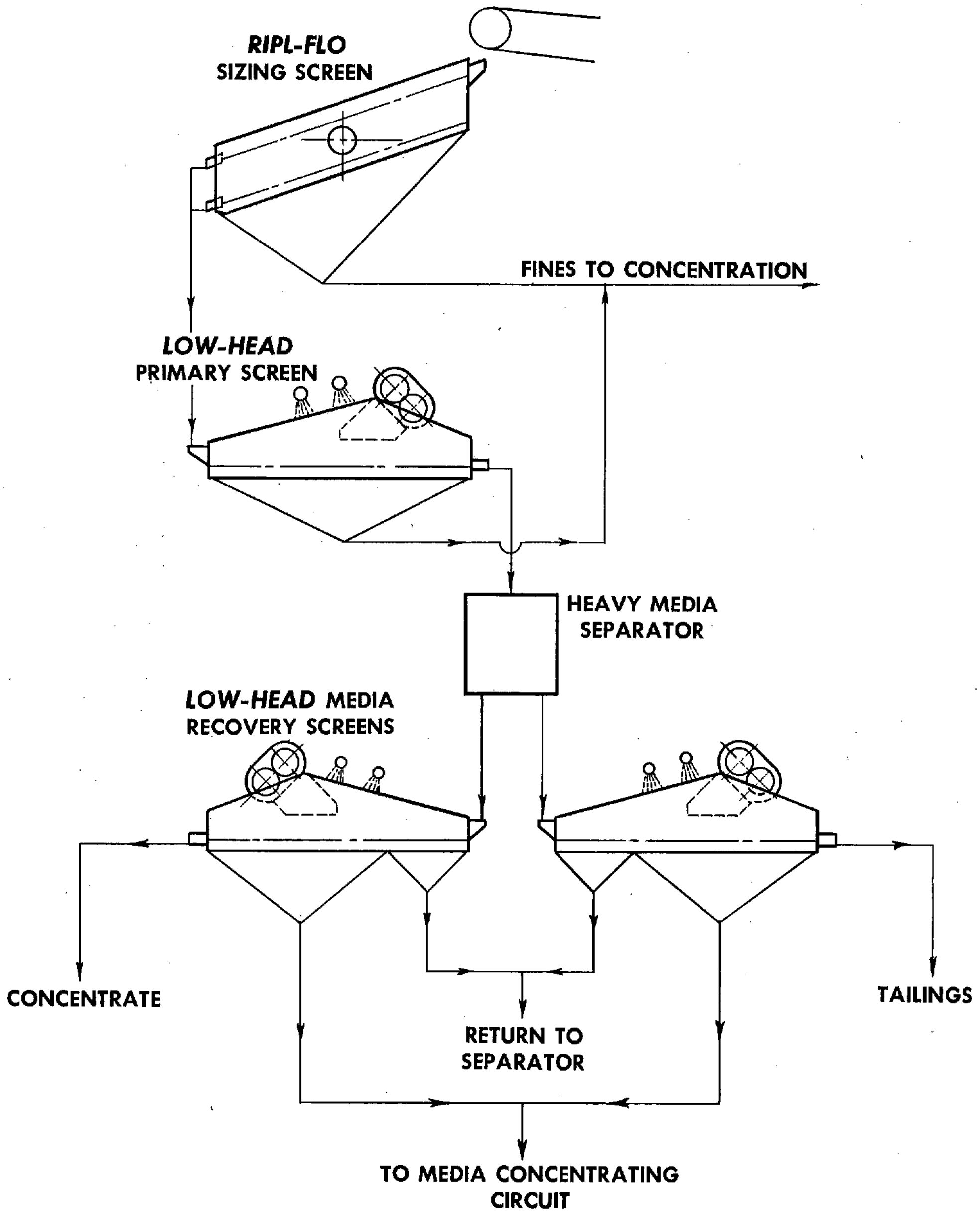


Vibrating Screen with Wedge Bar Deck.



Partition permits handling of sink and float products. Two partitions permit handling sink, float and middlings.

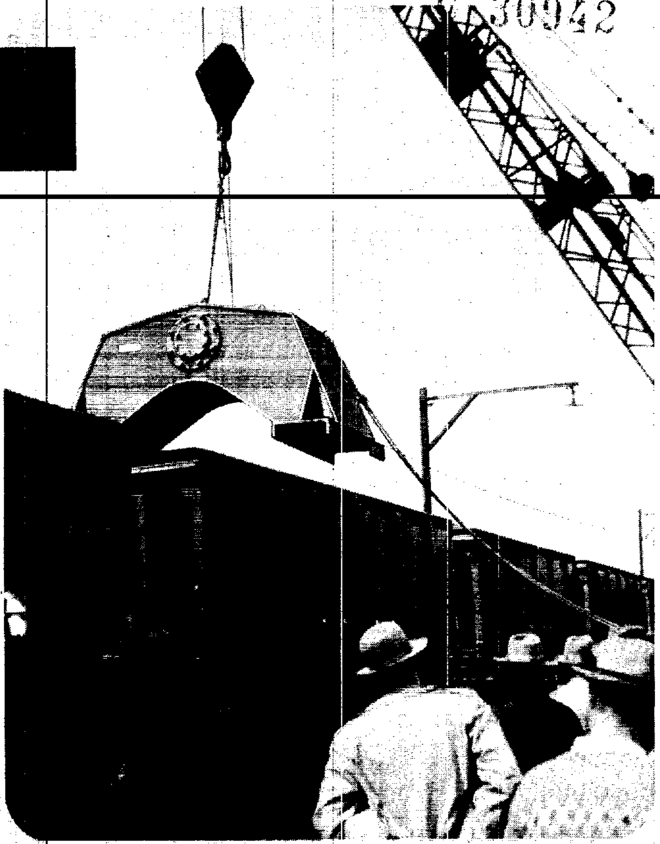
ALLIS-CHALMERS SCREENS in sink-float process



Typical flow-sheet, showing how horizontally operated *Low-Head* screens are used in the sink and float process. These Allis-Chalmers vibrating screens are used as primary screens ahead of the heavy media separator and as drain and wash screens for media recovery following the separator.

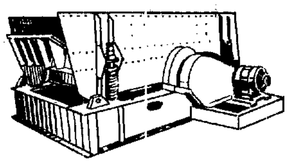
ORE CAR SHAKER

Install a car shaker to reduce unloading time and eliminate dangerous manual operation. Allis-Chalmers builds an ore car shaker with increased clearance above the top of the cars for high loads. Tests indicate that ore cars can be unloaded in an average time of two minutes and at a saving of approximately $3.00 per car.



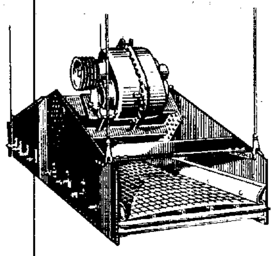
Ore car shaker for unloading underground iron ore.

ALLIS-CHALMERS BUILDS VIBRATING SCREENS FOR *Any* APPLICATION!



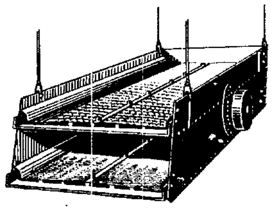
STYLE C SCREENS

For extra heavy duty scalping. Can handle ROM pieces 3x4 ft. in size, weighing 3000 pounds.



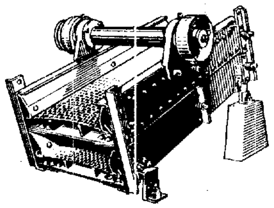
LOW-HEAD SCREENS

A horizontally operated screen for wet or dry screening, rinsing, dewatering. 2½ to 10 mesh.



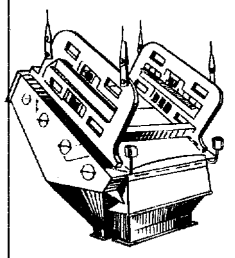
RIPL-FLO SCREENS

Two-bearing inclined screen for coarse to fine, wet or dry sizing, or for rinsing or scalping.



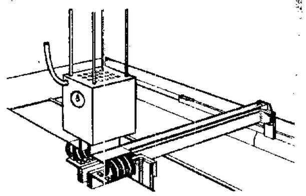
AERO-VIBE SCREENS

For medium to fine materials up to 3-in. size. Makes separations 1½ in. square to 35 mesh.



UTAH ELECTRIC SCREENS

For screening fine materials — 10 to 35 mesh (dry) or 10 to 46 mesh (wet). Easy to regulate.



THERMO-DECK HEATING UNIT

Screens fine, moist materials without binding. Heated screen cloth remains open continuously.

The Allis-Chalmers representative in your area is a trained application engineer. Without obligation, he'll come into your plant, look over your equipment, and make recommendations that will make your screening operations more profitable.

Low-Head, Ripl-Flo, Aero-Vibe, Utah, Thermo-Deck are Allis-Chalmers trademarks.