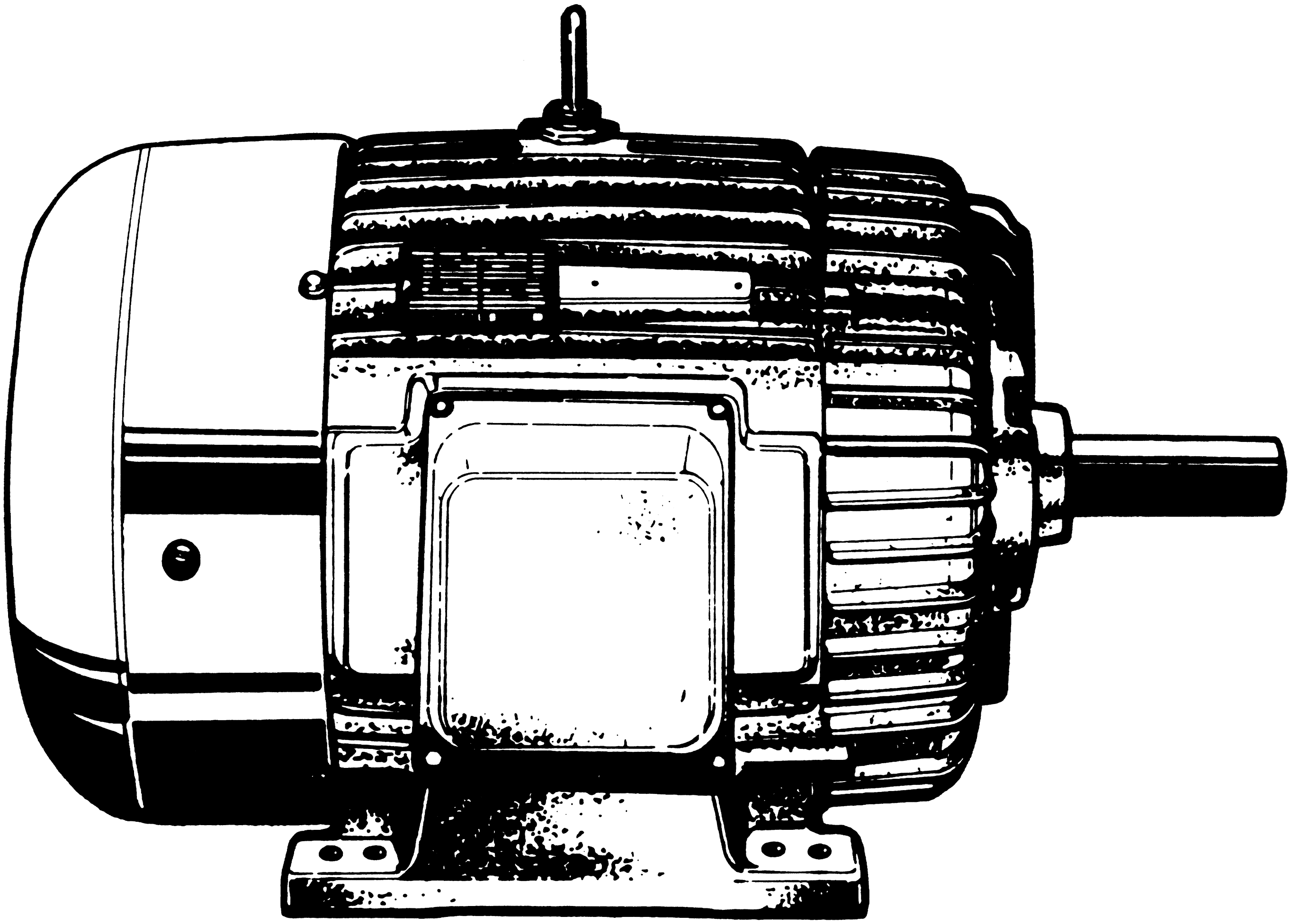
D

FUNDAMENTALS
OF
POLYPHASE ELECTRIC MOTORS



By: LINCOLN® ELECTRIC

MOTOR DIVISION

Manufacturer of fractional and integral horesepower, AC, Squirrel Cage Motors
Totally Enclosed - Drip Proof - Encapsulated

INTRODUCTION

This bulletin provides basic information on the nature and design of polyphase electric motors. The information is simply presented so extensive engineering or electrical knowledge is not necessary for a good understanding. It is divided into four sections:

Squirrel cage motors are covered in detail because they are the most common type motor used in industry. Typical applications include blowers, fans, pumps, compressors, machine tools, conveyors, mixers, crushers, and industrial machinery of all kinds. Basic characteristics are as follows:

MACHINE	Squirrel Cage
TORQUE	Normal or High Starting Torque
SPEED	Constant Speed
USUAL HP RANGE	1/3 to 250

BASIC MOTOR PRINCIPLES

All motors can be classed into two categories, AC and DC. The basic motor principles are alike for both the AC and DC motor.

Magnetism is the basis for all electric motor operation. It produces the forces necessary for the motor to run. There are two basic types of magnets, the permanent magnet and the electromagnet. The electromagnet has the advantage over the permanent magnet in that the magnetic field can be made stronger. Also the polarity of the electromagnet can easily be reversed.

The construction of an electromagnet is simple. When a current is passed through a coil of wire, a magnetic field is produced. This magnetic field can be made stronger by winding the coil of wire on an iron core (Fig. 1). One end of the electromagnet is a north pole, while the other end is a south pole. These poles can be reversed by reversing the direction of current in the coil of wire.

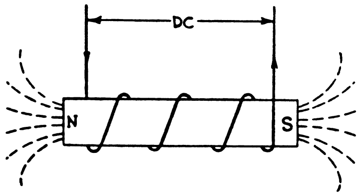


Figure 1

HOW A MOTOR WORKS

The basic principle of all motors can be easily be shown using two electromagnets and a permanent magnet. Current is passed through coil #1 and coil #2 in such a direction that north and south poles are generated next to the permanent magnet, as shown in Figure 2. A permanent magnet with a north and south pole is the moving part of this simple motor. In Figure 2 the north pole of the permanent magnet is adjacent to the north pole of the electromagnet. Similarly, the south poles are adjacent to each other. Like magnetic poles repel each other, causing the movable permanent magnet to begin to turn. After it turns part way around, the force of attraction between the unlike poles becomes strong enough to keep the permanent magnet rotating. The rotating magnet continues to turn until the unlike poles are lined up. At this point the rotor would normally stop because of the attraction between the unlike poles (Fig. 3).

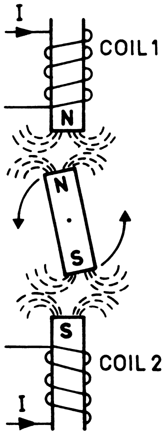


Figure 2

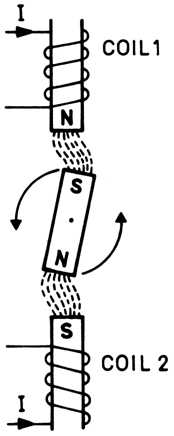


Figure 3

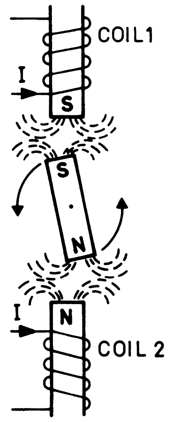


Figure 4

If, however, the direction of currents in the electromagnetic coils was suddenly reversed, thereby reversing the polarity of the two coils, then the poles would again be opposites and repel each other (Fig.4). The movable permanent magnet would then continue to rotate. If the current direction in the electromagnetic coils was changed every time the magnet turned 180° or halfway around, then the magnet would continue to rotate. This device is a motor in its simplest form. An actual motor is more complex than the simple device shown above, but the principle is the same.

THE AC MOTOR

ALTERNATING CURRENT

In order to fully understand the AC motor, we must first examine the fundamentals of alternating current. Alternating current has several advantages over direct current. One of the biggest advantages is economical power transmission. Alternating current, after leaving the generator, can be “stepped up” in voltage by means of a transformer. This reduces the size of the wire needed to transmit the current and, hence, lowers the cost. After the power reaches its destination, it can be “stepped down” again to the required voltage.

Another big advantage of AC over DC is the fact that AC motors are simpler in construction, less expensive than DC motors, and require less maintenance.

SINGLE-PHASE AC

Alternating current alternates or reverses many times each second. The current increases to a maximum in one direction, decreases to zero, and increases to a maximum in the opposite direction. The number of times this process occurs each second is called the frequency. The frequency of most AC power systems is 60 Hertz (cycles per second). Alternating current may be better understood by referring to a hydraulic analogy (Fig. 5).

A belt drives the pulley, causing the crankshaft and piston to move. As the piston moves back and forth in the water-filled cylinder, it causes the water in the pipe to flow first in one direction and then in the other. A flowmeter at G registers the rate of water flow in the pipe as it reaches peak speed, decreases to 0 and reverses direction.

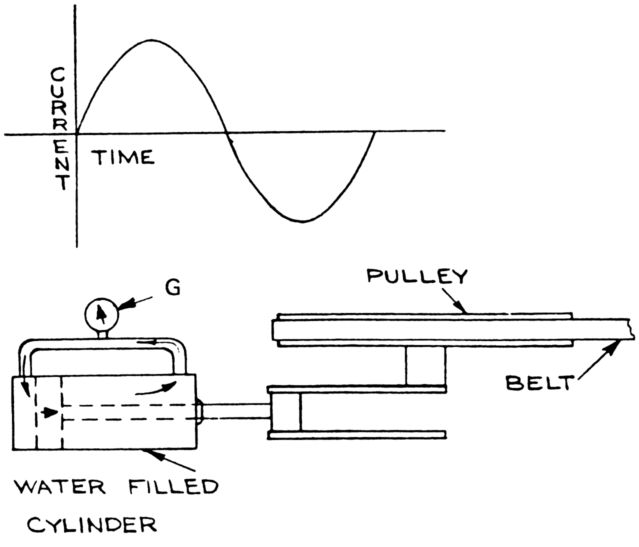


Figure 5

Since the alternating electric current undergoes similar changes, the sine curve will apply equally well to the pump cycle as to the alternating current cycle.

THREE-PHASE AC

Industry uses, in addition to single-phase AC, a power source called polyphase AC (“poly” meaning “many”). The most common form of polyphase AC is three-phase. Three-phase AC consists of three alternating currents of equal frequency and amplitude, but differing in phase from each other by one-third of a period. By adding two more pistons to our hydraulic system, we can illustrate three-phase AC (Fig. 6).

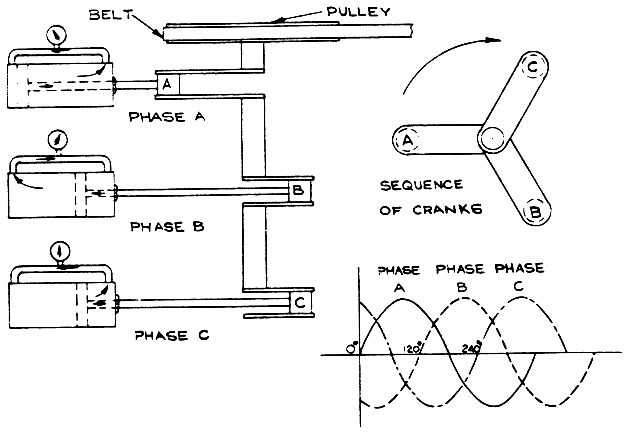


Figure 6

The cranks are placed 120° apart with the result that the current in each cylinder reaches its maximum at a different time. When any one of the currents is at its maximum, the other two are at half their maximum value.

The biggest advantage in using three-phase power is in the machines it supplies. Three-phase motors are much simpler in construction than other types and, hence, require less maintenance. A more powerful machine can be built into a smaller frame and it will operate at a higher efficiency.

All AC motors then can be classified into single-phase and polyphase motors. Because polyphase motors are the most commonly used in industrial applications, we shall examine them in detail.

POLYPHASE AC MOTORS

Polyphase motors make up the largest single type in use today and usually are the first to be considered for the average industrial application. There are several types of polyphase motors. The most common type of motor in this group is the squirrel-cage polyphase induction motor so called because the rotor is constructed like a squirrel-cage (Fig. 7). The squirrel-cage motor is the simplest to manufacture and the easiest to maintain.

SQUIRREL-CAGE INDUCTION MOTOR

The operation of the squirrel-cage motor is simple. The polyphase current produces a rotating magnetic field in the stator. This rotating magnetic field causes a magnetic field to be set up in the rotor also. The attraction and repulsion between these two magnetic fields causes the rotor to turn. Essentially this is all there is to the operation of this type of motor.

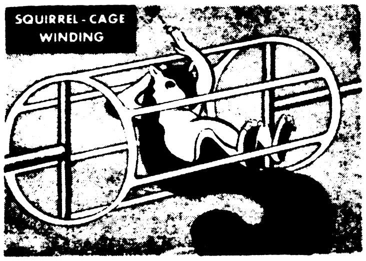


Figure 7

The squirrel-cage motor is a constant speed motor with either a normal or high starting torque. These characteristics fulfill the requirements of the majority of industrial applications, making the squirrel-cage motor ideal for such applications including lathes, presses, blowers, pumps, etc. Because of the importance of the squirrel-cage motor to industry, and because of the fact that the Lincoln motor is of this type, a more complete analysis of this motor begins on page 5.

WOUND ROTOR INDUCTION MOTOR

The wound rotor or slip-ring induction motor differs from the squirrel-cage motor only in the rotor winding. The rotor winding consists of insulated coils, grouped to form definite polar areas of magnetic force having the same number of poles as the stator. The ends of these coils are brought out to slip-rings. By means of brushes, a variable resistance is placed across the rotor winding (Fig. 8). By varying this resistance, the speed and torque of the motor is varied. The wound rotor motor is an excellent motor for use on applications that require an adjustable-varying speed (an adjustable speed that varies with load) and high starting torque.

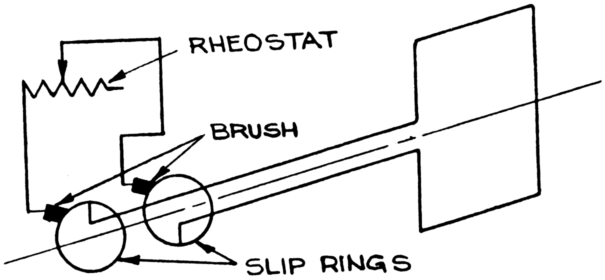


Figure 8

SYNCHRONOUS MOTORS

Synchronous motors comprise the third group in the AC polyphase group. Synchronous motors are motors that always run at the same speed regardless of load. Synchronous motors are somewhat more complex than squirrel-cage and wound rotor motors and, hence, are more expensive. There is *no slip* in a synchronous motor, that is, the rotor always moves at exactly the same speed as the rotating stator field. The speed is thus determined by the design of the motor and frequency of the power supply. The speed will remain constant with wide variations in load. As the load increases, the motor will keep a constant speed until the point is reached where the machine can no longer take the load and maintain a constant speed. At this point, the speed of the synchronous motor drops abruptly.

Synchronous motors are often used without a load for power factor correction. By adding the synchronous motor to the circuit, the power factor can be corrected so that the machine will do the same amount of work as before power factor correction, but will draw less current from the power lines. Fixed condensers (capacitors) are often used in place of synchronous motors for power factor correction (see Lincoln Bulletin ADR-6 for information on power factor).

Synchronous motors are used whenever *exact* speed must be maintained or for power factor correction. Synchronous motors are more expensive than other types for the lower horsepower ratings, but may possibly be more economical for 100 hp and larger ratings.

SQUIRREL-CAGE MOTORS

Squirrel-cage motors are ideal for most industrial applications because of their simple construction and absence of parts requiring frequent maintenance. IT IS THE ONE MOTOR USED MORE THAN ANY OTHER FOR INDUSTRIAL APPLICATIONS. Because the squirrel-cage motor is so widely used, Lincoln Electric Company has concentrated its efforts on this particular motor, thereby producing a motor of the highest quality and performance at low cost.

This section is devoted exclusively to a discussion of squirrel-cage motors. It is divided into two parts:

1. BASIC PRINCIPLES OF THE SQUIRREL-CAGE INDUCTION MOTOR.
2. DESIGN OF SQUIRREL-CAGE MOTORS.

Figure 9

THE BASIC PRINCIPLES OF THE SQUIRREL-CAGE MOTOR

The three-phase current with which the motor is supplied establishes a rotating magnetic field in the stator. This rotating magnetic field cuts the conductors in the rotor inducing voltages and causing currents to flow. These currents set up an opposite polarity field in the rotor. The attraction between these opposite stator and rotor fields produces the torque which causes the rotor to rotate. This simply is how the squirrel-cage motor works.

ROTATING MAGNETIC FIELD

The concept of the rotating magnetic field is explained with the aid of Figure 10. The stator of a squirrel cage induction motor consists of groups of coils wound on a core which is enclosed by a frame. The simple two-pole stator represented has three coils in each pole group. Each coil in a pole group is connected to one phase of a three-phase power source. One characteristic of three-phase power is that the phase currents reach maximum values at different periodic time intervals. Refer to the sine wave representation in Figure 6 and note that maximum values may be + or –.

Assume an instant in time when the current is maximum in the "A" coils. The magnetic fields of these coils will also be maximum. Since at this same instant the currents of phase "B" and "C" are considerably less than "A", the magnetic fields of "B" and "C" coils are likewise less. At a later instant in time the current in the "C" coils reaches a maximum with consequent maximizing of the magnetic field of the "C" coils. At this same instant the fields of the "A" and "B" coils are considerably less. This same process repeats as the magnetic field of the "B" coils becomes maximum while the fields for "A" and "C" are much less. The maximum field thus sequentially repeats at "A", "C" and "B" continuously around the stator and essentially defines a rotating field.

Examination of the coils in Figure 10 will show that the diametrically opposite coils, which carry the same phase current, are connected so their magnetic fields are of opposite polarity. The particular configuration in this example creates a two-pole winding.

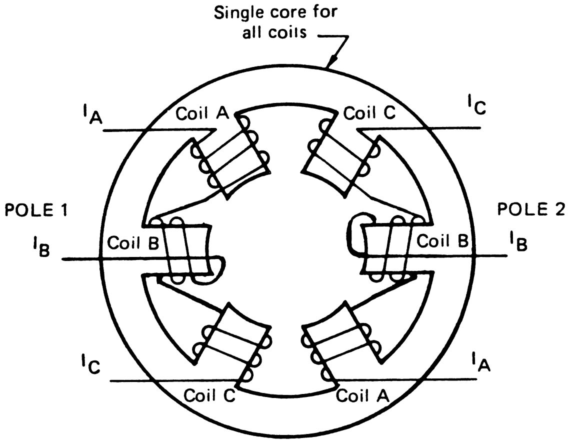


Figure 10 — Basic Two Pole Stator

The rotor is the moving part of the motor. Basically, the rotor consists of copper or aluminum bars, connected together at the ends with heavy rings (Fig. 11).

The revolving field set up by the stator currents cut the squirrel-cage conducting bars of the rotor. This induces voltages in these bars. These voltages cause currents to flow in the bars and these currents set up a magnetic field with north and south poles in the rotor. The attraction and repulsion between these poles and the poles of the revolving field produce a torque which causes the rotor to turn.

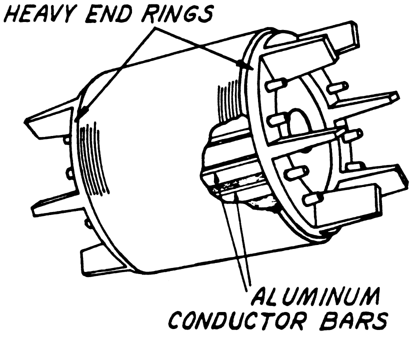


Figure 11 — Rotor for a Squirrel-Cage Motor

EDDY CURRENTS

The rotating magnetic field, in addition to inducing voltages in the rotor bars, induces voltages in the stator and rotor cores. The voltages in these cores cause currernts to flow. These currents, called eddy currents, serve no useful purpose and only result in wasted power. To keep these currents to a minimum, the stator and rotor cores are made of thin steel discs, called laminations. These laminations are coated with insulating varnish and then welded together to form the core. This type of core substantially reduces eddy current losses, but it does not entirely eliminate them.

DESIGN OF SQUIRREL-CAGE MOTORS

By varying the design of the basic squirrel-cage motor, the engineer can develop motors for almost every industrial need. Characteristics such as speed, torque, and voltage are just a few of the features controlled by the designer.

In order to standardize certain motor features, the National Electrical Manufacturers Association (NEMA) has established standards for a number of motor features. The following section contains many of the features that will be particularly helpful in selecting the right motor for a particular application (see Lincoln Bulletin C1T).

SPEED AND SLIP

The speed of a squirrel-cage motor depends on the frequency and the number of poles for which the motor is wound. The *higher* the frequency, the *faster* the motor runs. The *more* poles the motor has, the *slower* it runs. The smallest number of poles ever used in a squirrel-cage motor is two. A two-pole 60 cycle motor will run at approximately 3600 rpm.

To find the *approximate* speed of any squirrel-cage motor we can use the formula for synchronous speed which is the speed of the rotating magnetic field:

Formula (1): **Synchronous speed Ns =** $\frac{60 \times 2f}{p}$

where f = frequency of the power supply

p = number of poles for which the machine is wound.

Squirrel-Cage Induction Motors are wound for the following synchronous speeds:

No. Poles	60 Hertz Sync. Speed	50 Hertz Sync. Speed
2	3600	3000
4	1800	1500
6	1200	1000
8	900	750
10	720	600
12	600	500

Most standard commercial motors (143T thru 445T frame sizes) are wound with a maximum of 8 poles.

The actual speed of the motor is somewhat less than its synchronous speed. This difference between the synchronous and actual speeds is defined as slip. If the squirrel-cage rotor rotated as fast as the stator field, the rotor conductor bars would be standing still with respect to the rotating field; hence no voltage would be induced in the bars and no current would be set up to produce torque. Since no torque is produced, the rotor will slow down until sufficient current is induced to develop enough torque to keep the rotor at a constant speed. Therefore, the rotor rotates slower than the rotating magnetic field of the stator.

With an increased load, the rotor speed decreases and hence the rotating field cuts the rotor bars at a higher rate than before. This has the effect of increasing the current in the bars and hence increasing the pole strength of the rotor. This increased pole strength makes it possible for the motor to carry the larger load. Slip is usually expressed in percent and can easily be computed using:

Formula (2):

$$\textbf{Percent slip=} \frac{\textbf{Synchronous speed – Actual speed}}{\textbf{Synchronous speed}} \textbf{ x 100}$$

Squirrel-cage motors are made with the slip ranging from less than 5% to around 20%. Motors with slip of 5% or higher are used for hard-to-start applications. A motor with a slip of 5% or less is called a *normal slip* motor. A normal slip motor is often referred to as a *constant speed* motor because the speed changes very little with variations in load. The Lincoln motor is of this type. An examination of the performance curves for a typical motor (Fig. 14) shows how the slip varies with load.

In specifying the speed of the motor on the nameplate, most motor manufacturers use the *actual speed* of the motor at rated load which will, of course, be somewhat lower than the synchronous speed.

ROTATION

The direction of rotation of a polyphase squirrel-cage motor depends on the motor connection to the power lines. Rotation can be readily reversed by interchanging any *two input* leads.

TORQUE AND HORSEPOWER

Torque and horsepower are two very important motor characteristics that determine the size of the motor for a particular job. The difference between the two can be explained using a hand grinding wheel.

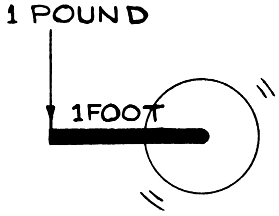


Figure 12

Torque is merely a turning effort. Suppose we have a grinding wheel with a crank one foot long (Fig. 12). It takes a force of one pound to turn the wheel at a steady rate. We say *the torque is one pound x one foot or one pound-foot*. Now let us turn the crank twice as fast. The torque remains the same. Regardless of how fast we turn the crank, as long as we turn it at a steady rate, the torque is unchanged.

Horsepower, on the other hand, takes into account "how fast" we turn the crank. Turning the crank rapidly takes more horsepower than turning it slowly. *Horsepower is a rate of doing work.* By definition, *one horsepower equals 33,000 foot-pounds/min.* In other words, to lift a 33,000 pound weight one foot in one minute would take one horsepower.

Let's find out how fast we would have to turn the crank to produce one horsepower. In one revolution the one pound force moves a distance of 2 x π x 1 foot or 2π feet. The work done in one revolution is 2π feet times 1 pound or 2π foot pounds. Thus, to produce one horsepower we would have to turn the crank at a rate of:

$$\frac{\text{one horsepower x 33,000 foot-pounds/minute/horsepower}}{2\pi \text{ foot pounds/revolution}}$$

or

5252 revolutions per minute

From the example above we can derive a formula for determining the horsepower from the speed and torque.

Formula (3): $$\mathbf{HP} = \frac{\textbf{Speed in RPM x } 2\pi \textbf{ x torque}}{\mathbf{33{,}000}}$$

or

$$\mathbf{HP} = \frac{\textbf{RPM x torque}}{\mathbf{5252}}$$

By transposition:

$$\textbf{Torque} = \frac{\textbf{HP x 5252 lb.-ft.}}{\textbf{RPM}}$$

This steady constant torque at rated load is called the Rated Load Torque.

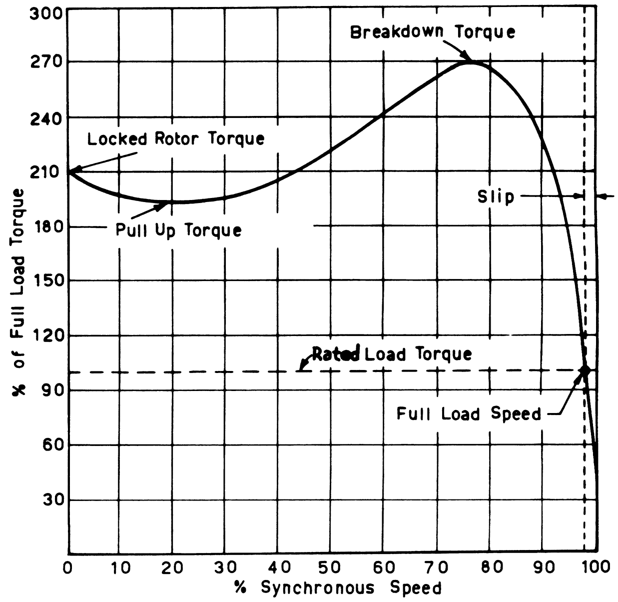


Figure 13 – Representative Speed-Torque Curve for NEMA Design B Motors. It does not apply to any particular motor.

LOCKED ROTOR TORQUE

So far, we have been speaking of the torque at a steady speed. But what happens at other times? When starting the grinder from a dead stop, it takes more effort to get it started than to keep it running. The same thing is true with a car. Low or first gear is used when starting to give the extra torque needed to overcome the inertia of starting. Once the grinder or car is moving, it doesn't take as much torque to *keep it* moving.

An induction motor is built to supply this extra torque needed to start the load. The speed torque curve for a typical motor (Fig. 13) shows the starting torque to be 210% of the rated-load torque.

BREAKDOWN TORQUE

Occasionally a sudden overload will be placed on a motor. To keep the motor from stalling every time an overload occurs, these motors have what is called a breakdown torque. The breakdown torque is much higher than the rated-load torque so that it takes quite an overload to stall the motor. The speed torque curve shows the breakdown torque for a typical motor to be about 270% of the rated-load torque. Operating a motor overloaded for an extended period of time will cause an excessive heat buildup in the motor and may eventually burn up the motor windings.

The NEMA definitions for an induction motor's characteristic torques are given on the next page.

Locked Rotor Torque — (Static or Starting Torque)

The locked rotor 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.

Pull-Up Torque

The pull-up torque of an alternating-current motor is the minimum 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.

Breakdown Torque

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

Rated-Load Torque

The rated-load torque of a motor is the torque necessary to produce its rated horsepower at rated-load speed. In pounds at a 1-foot radius, it is equal to the horsepower times 5252 divided by the rated-load speed.

These torques are all very important and motors can be designed with emphasis on one or more torque characteristics to produce motors for various applications. An improvement in one of these characteristic torques may adversely affect some other motor characteristic.

Because of the variety of torque requirements, NEMA has established different *Designs* to cover almost every application. These *Designs* take into consideration starting current and slip, as well as torque. These *Designs* should not be confused with the various *Classes* of insulation which are also designated by letter.

EFFICIENCY

The efficiency of a motor is simply the ratio of the power "out" to the power "in" expressed in percentage.

Formula (4): $$\textbf{Efficiency} = \frac{\textbf{power out}}{\textbf{power in}} \times 100$$

Figure 14 illustrates how efficiency may vary with percent load. Generally, motor efficiency is relatively flat from rated load to 50% of rated load. Some motors exhibit peak efficiency near 75% of rated load. See Lincoln Bulletins ADR-6 and D11T for more information on efficiency.

POWER FACTOR

Power factor is the ratio of real power to apparent power, or $\frac{KW}{KVA}$, where KW or kilowatts are measured with a wattmeter and KVA or kilo volt-amperes are measured with a voltmeter and ammeter. A power factor of one or unity is ideal. Figure 14 shows that power factor is highest near rated load. Power factor at 50% load is considerably less and continues an even sharper drop to idle.

CURRENT DRAW

Current draw in amperes is proportional to the actual load on the motor in the area of rated load. *It departs from this linearity at other loads* (See Fig.14). Other factors, such as voltage, affect current as indicated in Lincoln Bulletin B2T.

NEMA TORQUE DESIGNS FOR POLYPHASE MOTORS

NEMA Design	Starting Current	Locked Rotor	Breakdown Torque	% Slip	Applications
B	Medium	Medium Torque	High	Max. 5%	Normal Starting Torque for fans, blowers, rotary pumps, unloaded compressors, some conveyors, metal cutting machine tools, misc. machinery. Constant load speed.
C	Medium	High Torque	Medium	Max. 5%	High inertia starts such as large centrifugal blowers, fly wheels, and crusher drums. Loaded starts such as piston pumps, compressors and conveyors. Constant load speed.
D	Medium	Extra High Torque	Low	Very high inertia and loaded starts. Also, considerable variation in load speed.	
				5% or more	Punch presses, shears and forming machine tools. Cranes, Hoists, Elevators, and Oil well pumping jacks.

NEMA Design A is a variation of Design B having higher locked rotor current.

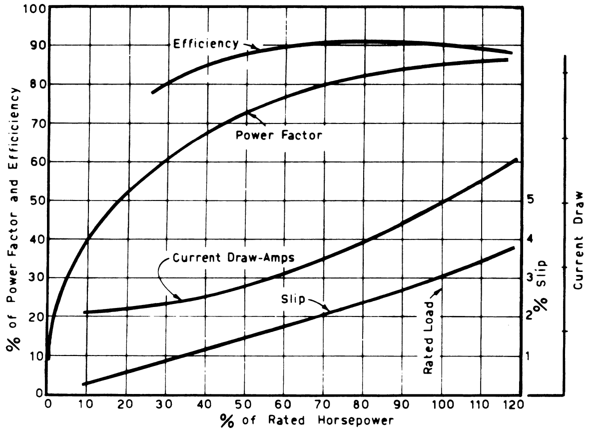


Figure 14 — Representative Performance Curves for Typical NEMA Design B Motors. Values shown do not apply to a particular motor.

LOCKED ROTOR KVA/HP

Another rating specified on motor nameplates and determined by the motor design is locked rotor kva per horsepower. A letter appears on the nameplate corresponding to various kva/hp ratings.

Code Letter	kva/hp[1]	Code Letter	kva/hp[1]
A	0 – 3.15	L	9.0 – 10.0
B	3.15 – 3.55	M	10.0 – 11.2
C	3.55 – 4.0	N	11.2 – 12.5
D	4.0 – 4.5	P	12.5 – 14.0
E	4.5 – 5.0	R	14.0 – 16.0
F	5.0 – 5.6	S	16.0 – 18.0
G	5.6 – 6.3	T	18.0 – 20.0
H	6.3 – 7.1	U	20.0 – 22.4
J	7.1 – 8.0	V	22.4 and up
K	8.0 – 9.0		

(1)Locked rotor kva/hp range includes the lower figure up to, but not including, the higher figure.

These nameplate code ratings give a good indication of the starting current the motor will draw. A code letter at the beginning of the alphabet indicates a low starting current and a letter at the end of the alphabet indicates a high starting current for the particular horsepower rating of the motor. Computation of the starting current can be accomplished using the formula:

Formula (5):

$$\textbf{Locked Rotor Amps (Starting Current)} = \frac{1000 \times hp \times kva/hp}{1.73 \times Volts}$$

Example: What is the approximate starting current of a 7-1/2 hp 220 volt motor with a nameplate code letter of "G"?

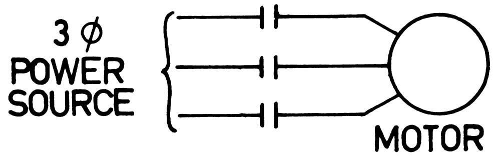
Solution: From the above table the kva/hp for a code letter of "G" is 5.6 to 6.3. Taking a number approximately halfway in between and substituting in the formula we get:

$$\textbf{Locked Rotor Amps} = \frac{1000 \times 7.5 \times 6}{1.73 \times 220} = 118 \text{ amps}$$

Thus, the starting current is approximately 118 amperes. The starting current is important to the motor buyer because he must know what kind of protection to provide. In other words, he must install power lines big enough to carry the required currents and put in fuses of the proper size.

ACROSS THE LINE STARTING

Squirrel-cage motors are usually designed for across the line starting which means that they can be connected directly to the power source by means of a suitable contactor.



REDUCED VOLTAGE STARTING

In large squirrel-cage motors and in some other types of motors the starting currents are very high. Usually the motor is built to stand these high currents, but since these currents are almost six times rated load current, there may be a large voltage drop in the power system. Some method of reducing the starting current must thus be employed to limit the voltage drop to a tolerable value. See Lincoln Bulletin D2T.

Reducing the starting current may be accomplished by any one of the following starting methods:

Primary Resistor or Reactance – Employs series reactance or resistance to reduce the current on the first step and after a preset time interval the motor is connected directly across the line. Can be used with any standard motor.

Auto Transformer – Employs auto transformers to directly reduce voltage and the current on the first step and after a preset time interval the motor is connected directly across the line. Can be used with any standard motor.

Wye-Delta – Impresses the voltage across the Y-connection to reduce the current on the first step and after a preset time interval the motor is connected in delta permitting full current. Must have a winding capable of Wye-Delta connection.

COMPARATIVE SPEED – TORQUE CURVES AND CHARACTERISTICS

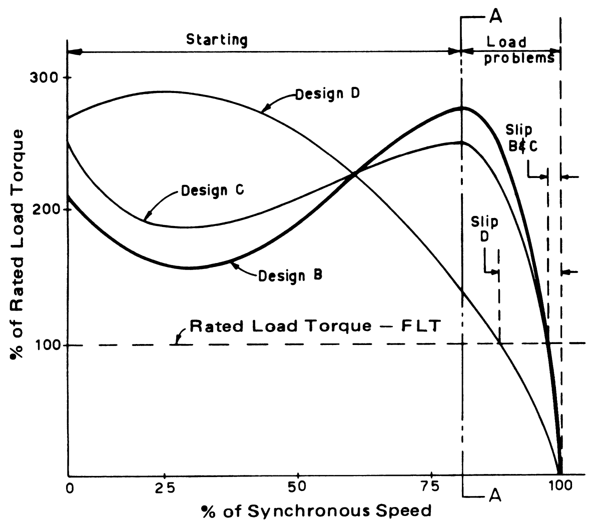


Figure 15

Note that:

1) Slip of B & C Design are the same – Maximum 5%. Therefore, a C Design is no more suitable for a high slip load than a B Design.
2) Slip of Design D is 5% or higher.
3) On B Design Motors:
   PUT occurs at approximately 1/4 to 1/3 Rated Load Speed.
   BDT occurs at approximately 2/3 to 3/4 Rated Load Speed.
4) High Locked Rotor Torque of a C Design motor can usually be attained by the next size larger B Design motor.

STARTING CHARACTERISTICS in the area to the left of Line A-A in Figure 15 are affected by the following factors. When appropriate, the Lincoln bulletin containing more information on the subject is listed.

Power Supply, Starters and Protection

1. Low Line Voltage and Voltage Drop – B2T
2. KVA Capacity of Power Supply
3. Starter Size – D1T
4. Fusing and Heater Links – D3T, ADR-7
5. Reduced Starting Torque Due to PWS or Other Reduced Voltage Starting Methods – D2T

Torque Requirements and Conditions of Starting

6. High Inertia Start – D3T, D6T
7. Loaded Start – D3T, D6T
8. Rate of Load Build Up – D3T, D6T
9. Starting Torque Requirement vs Motor Torque Characteristics – D3T, D6T
10. Starting Current – Time Limitation of Motor – D6T
11. Jogging Starts – D3T, D6T, D7T
12. Frequency of Starts – D3T, D6T

Abuse and Its Consequences

13. Abuse and Poor Preventive Maintenance
14. Single Phase Burn Outs – D3T, ADR-7
15. Overload Burn Outs – D3T

LOAD CHARACTERISTICS in the area to the right of Line A-A in Figure 15 are affected by the following factors. When appropriate, the Lincoln bulletin containing more information on the subject is listed.

Power Supply, Starters and Protection

1. Low Line Voltage – Excessive Current Draw –B2T
2. Excessively High Voltage – Excessive Current Draw – B2T
3. Unbalanced Voltage – Unbalanced Current – D3T, ADR-7
4. KVA Capacity of Power Supply
5. Starter Size – D1T
6. Fusing And Heater Links – D3T, ADR-7
7. Thermal Protection – D9T

Load Requirements, Variations and Cycling

8. Load Peaks Above Rated or Service Factor HP – D3T
9. Motor Undersized for Average Load Condition – D3T
10. Load Slip Greater Than Rated Motor Slip Capability – Forcing High Current Overloads.
11. Load Levels, Cycling and Reversals Beyond the Heat Dissipation Capacity of the Motor – D3T, D7T

Abuse and Its Consequences

12. Restricted Ventilation and/or Excessively High Ambient Temperatures
13. Operating Abuse and Poor Preventive Maintenance
14. Excessive Load – Short Life – D3T
15. Overload Burn Outs – D3T
16. Single Phase Burn Outs – D3T, ADR-7

Part-Winding — Employs a motor with two separate winding circuits. Upon starting only one winding circuit is engaged and current is reduced. After a preset time interval the full winding of the motor is put directly across the line. Must have motor with two separate winding circuits. To avoid possible overheating and subsequent damage to the winding, the time between the connection of the first and second windings is limited to 4-second maximum.

All of these starting methods are commonly referred to as Reduced Voltage Starting. They all require special starters designed for the particular method and are controlled between the start and run functions by an adjustable timer.

Reduced voltage starting significantly reduces the load acceleration characteristic of any motor. It is therefore, necessary to have the motor unloaded or nearly so at the start (See Lincoln Bulletin D6T).

INSULATION SYSTEMS

An insulation system is an assembly of insulating materials in association with conductors and the supporting structural parts of a motor. Insulation systems are divided into classes according to the thermal endurance of the system for temperature rating purposes. Four classes of insulation systems are used in motor; namely, classes A, B, F, and H. Do not confuse these insulation classes with motor designs (page 8) which are also designated by letter.

Class A — A Class A insulation system is one which by experience or accepted test can be shown to have suitable thermal endurance when operated at the limiting Class A temperature of 105°C. Typical materials used include cotton, paper, cellulous acetate films, enamel-coated wire, and similar organic materials impregnated with suitable substances.

Class B — A Class B insulation system is one which by experience or accepted tests can be shown to have suitable thermal endurance when operated at the limiting Class B temperature of 130°C. Typical materials include mica, glass fiber, asbestos and other materials, not necessarily inorganic, with compatible bonding substances having suitable thermal stability.

Class F — A Class F insulation system is one which by experience or accepted test can be shown to have suitable thermal endurance when operating at the limiting Class F temperature of 155°C. Typical materials include mica, glass fiber, asbestos and other materials, not necessarily inorganic, with compatible bonding substances having suitable thermal stability.

Class H — A Class H insulation system is one which by experience or accepted test can be shown to have suitable thermal endurance when operated at the limiting Class H temperature of 180°C. Typical materials used include mica, glass fiber, asbestos, silicone elastomer, and other materials, not necessarily inorganic, with compatible bonding substances, such as silicone resins, having suitable thermal stability.

USUAL SERVICE CONDITIONS

When operated within the limits of the following NEMA specified "Usual Service Conditions," standard motors will perform in accordance with their ratings. For service conditions other than usual, the precautions listed must be considered.

1. *Ambient or room temperature not over 40°C.*

   If the ambient temperature is over 40°C (104°F) the motor service factor must be reduced or a higher horsepower motor used. The larger motor will be loaded below full capacity so the temperature rise will be less and overheating reduced.

2. *Altitude does not exceed 3300 feet (1000 meters).*

   Motors having Class A or B insulation systems and temperature rises according to NEMA will operate satisfactorily at altitudes above 3300 feet in these locations where the decrease in ambient temperature compensates for the increase in temperature rises as follows:

Ambient Temperature – °C	Maximum Altitude – Feet
40	3300
30	6600
20	9900

   Motors having a service factor of 1.15 or higher will operate satisfactorily at unity service factor and an ambient temperature of 40°C at altitudes above 3300 feet up to 9000 feet.

3. *A voltage variation of not more than plus or minus 10% of nameplate voltage:* Operation outside these limits or on unbalanced voltage conditions can result in overheating or loss of torque and may require using a larger hp motor.

4. *A frequency variation of not more than plus or minus 5% of nameplate frequency:* Operation outside of these limits results in a substantial speed variation and causes overheating and reduced torque.

5. *A combination of 10% variation in voltage and frequency provided the frequency variation does not exceed 5%.*

6. *The mounting surface must be rigid and the drive must be in accordance with NEMA specifications.*

7. *Location of supplementary enclosures must not seriously interfere with the ventilation of the motor.*

UNUSUAL SERVICE CONDITIONS

Motors are often exposed to damaging atmospheres such as excessive moisture, steam, salt air, abrasive or conducting dust, lint, chemical fumes and combustible or explosive dust or gases. To protect such motors a certain enclosure or encapsulated windings and special bearing protection may be required.

Motors exposed to damaging mechanical or electrical loading such as unbalanced voltage conditions, abnormal shock or vibration, torsional impact loads, or excessive thrust or overhang loads may require special mountings or protection designed by the user for the installation (see Lincoln Bulletin ADR-2).

ENCLOSURES

The enclosure category includes many types of enclosures. Only a few of the most common types are listed here.

It is strongly recommended that all concerned personnel be familiar with and adhere to the contents of NEMA MG2, “Safety Standard for Construction and Guide for Selection, Installation and Use of Electric Motors and Generators.”

The Open Motor — is one having ventilating openings which permit passage of external cooling air over and around the windings.

The Drip-Proof Motor — is an open motor in which ventilating openings are so constructed that drops of liquid or solids falling on the machine at any angle not greater than 15 degrees from the vertical cannot enter the machine. The Lincoln Lincguard® and Signature Series ODP motors fit this classification.

A Guarded Motor — is an open motor in which all ventilating openings are limited to specified size and shape to prevent insertion of fingers or rods to avoid accidental contact with rotating or electrical parts.

A Splash-Proof Motor — is an open motor in which ventilating openings are so constructed that drops of liquid or solid particles falling on the machine or coming toward the machine in a straight line at any angle not greater than 100 degrees from the vertical cannot enter the machine.

A Totally-Enclosed Motor — is a motor so enclosed as to prevent the free exchange of air between the inside and outside of the case, but not airtight.

A Totally-Enclosed Nonventilated (TENV) Motor — is a totally-enclosed motor which is not equipped for cooling by means external to the enclosing parts.

A Totally-Enclosed Fan-Cooled (TEFC) Motor — is a totally-enclosed motor with a shaft-mounted fan to blow cooling air across the external frame. It is a popular motor for use in dusty, dirty, and corrosive atmospheres.

A Totally-Enclosed Blower-Cooled (TEBC) Motor — is a totally-enclosed motor which is equipped with an independently powered fan to blow cooling air across the external frame. A TEBC motor is commonly used in constant torque, variable speed applications.

Encapsulated Motor — is an open motor in which the windings are covered with a heavy coating of material to protect them from moisture, dirt, abrasion, etc. Some encapsulated motors have only the coil noses coated. In others, like the Lincoln MULTIGUARD® with pressure embedded windings, the encapsulation material impregnates the windings even in the coil slots. With this complete protection, the motors can often be used in applications which demand totally-enclosed motors.

An Explosion-Proof Motor — is a totally-enclosed motor designed and built to withstand an explosion of gas or vapor within it, and to prevent ignition of gas or vapor surrounding the machine by sparks, flashes or explosions which may occur within the machine casing.

SUMMARY OF FORMULAS

MECHANICAL FORMULAS

$$\text{Torque in Lb.-Ft.} = \frac{\text{HP x 5252}}{\text{RPM}} \; ; \quad \text{HP} = \frac{\text{Torque x RPM}}{5252}$$

$$\text{Sync. RPM} = \frac{\text{120 x Frequency}}{\text{No. of Poles}}$$

RULES OF THUMB(1)

At 1800 RPM, a motor develops 3 lb.-ft. per HP
At 1200 RPM, a motor develops 4.5 lb.-ft. per HP
At 575 volts, a 3-phase motor draws 1 amp per HP
At 460 volts, a 3-phase motor draws 1.25 amp per HP
At 230 volts, a 3-phase motor draws 2.5 amp per HP

(1)Departs on Lower HP and RPM Motors.

TEMPERATURE CONVERSION

Deg C = (Deg F – 32) x 5/9
Deg F = (Deg C x 9/5) + 32

ELECTRICAL FORMULAS

To Find	Alternating Current – Three-Phase
Amperes when horsepower is known	$\frac{\text{HP x 746}}{\text{1.73 x E x Eff x pf}}$
Amperes when kilowatts are known	$\frac{\text{Kw x 1000}}{\text{1.73 x E x pf}}$
Amperes when Kva are known	$\frac{\text{Kva x 1000}}{\text{1.73 x E}}$
Kilowatts	$\frac{\text{1.73 x I x E x pf}}{1000}$
Horsepower = (Output)	$\frac{\text{1.73 x I x E x Eff x pf}}{746}$

I = Amperes
E = Volts
Eff = Efficiency

pf = Power Factor
Kva = Kilovolt-Amperes
Kw = Kilowatts

LINCOLN® ELECTRIC
MOTOR DIVISION

THE LINCOLN ELECTRIC COMPANY
CLEVELAND, OHIO 44117-2525 U.S.A.

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