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AUTHOR Benson, Robert T.
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ABSTRACT

Addressed to the student, this manual, which includes supplementary diagrams, discusses the following topics and principles: Electromagnetic fields, electromagnets, parts of an electric motor, determining speed of an electric motor, types of electric motors in common use (split-phase, capacitor, repulsion-induction, three-phase), the electric motor nameplate, and electric motor comparisons (in chart form). (TA)

AGRICULTURAL ELECTRICITY

ELECTRIC MOTORS

Student Manual

Prepared by

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This publication was prepared and edited by Robert T. Benson, Vocational Materials Specialist, Vocational Education Media Center. Illustrations were prepared by Ronald D. Mattox, Art Director, Vocational Education Media Center.

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INTRODUCTION

Electric motors are used to assist us in our work and to make our lives easier in general. Just how do electric motors operate? Electric motors operate using electricity and magnetism. Electricity and magnetism are closely associated; however, very little is known about them and what they are, but a great deal is known about how they act.

Magnetism is often defined as the power to attract. Certain materials have the power to attract other similar materials – this force is known as magnetism. Natural magnetism occurs in only a few materials; namely, iron, nickel, cobalt and their alloys. All other materials are considered to be non-magnetic.

The question is often asked why some materials are magnetic and others non-magnetic. The most recent theory is the "Electron Theory of Magnetism." According to this theory, magnetism is caused by the unbalanced movements of the electrons in their orbits within the atoms of magnetic substances. The exact details have not been formulated because of the difficult nature of the investigation. Figure 1 is a drawing of what is believed to be the "Electron Theory of Magnetism." Regardless of the theory, we know what magnetism can do and how we can use it.

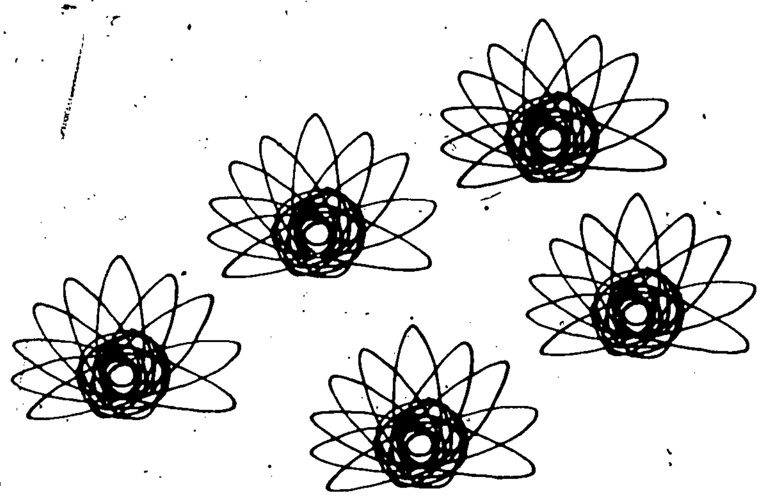

Figure 1. Electron Theory of Magnetism

Magnets are of three types: natural, permanent and electromagnets. The ones of most interest to us are the permanent and electromagnets. All magnets have a north and south pole.

The study of these so-called magnetic materials reveals that the attraction between two materials is limited to a short distance. This indicates that there is a limited area around magnetic materials in which the attractive force is apparent. The area in which the magnet's pulling force is effective is called a "magnetic field." Also known is that the attracting force becomes stronger as the magnets are placed closer together. This indicates that around a magnet there are invisible lines of force (Figure 2) which are close together near the magnet and progressively farther apart away from the magnet. Since the north pole is attracted to the south pole of another magnet (Figure 3), it follows that the unlike poles of one magnet will be attracted to each other and the lines of force around the magnet have a direction from the north to the south pole. As previously stated, unlike poles of a magnet attract each other, therefore, like poles repel when placed near each other. The fundamental law of magnetism can be stated as: "Unlike poles attract and like poles repel each other."

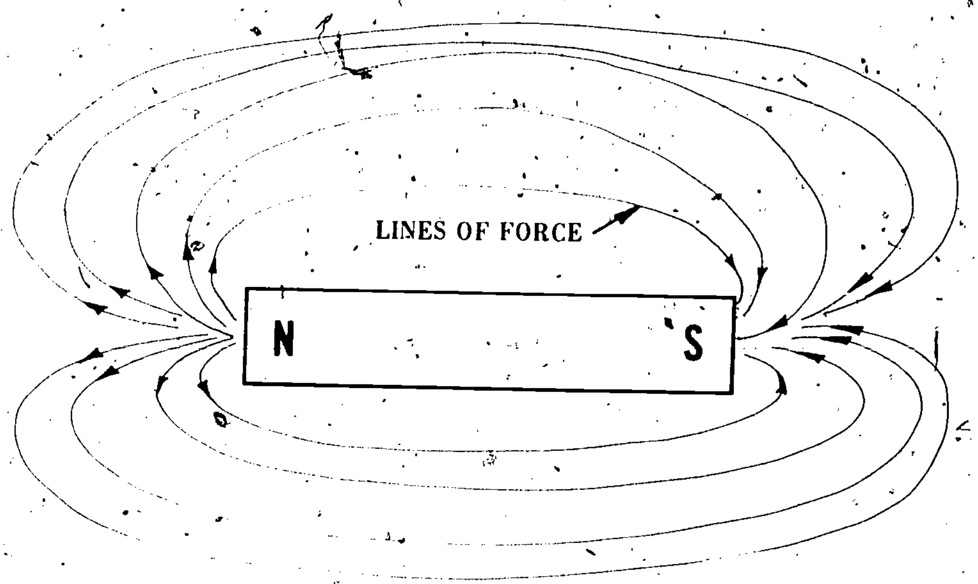

Figure 2. Magnetic Field Around A Magnet

The drawing in Figure 3 illustrates how the magnetic lines of force behave when unlike poles are placed near each other (Illustration A), and how like poles are repelled (Illustration B).

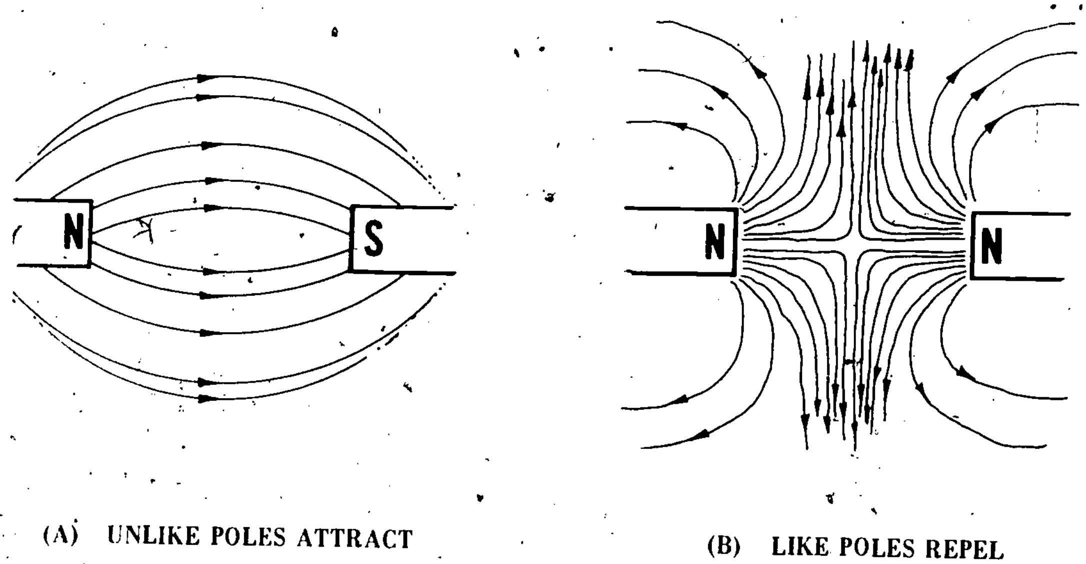

Figure 3. Magnetic Attraction

ELECTROMAGNETIC FIELDS

How can this basic knowledge of magnetism be applied to electric motors? When a compass is placed near a wire through which current is flowing, the compass needle points toward the wire (Figure 4). Since a magnetic force is the only force that will deflect a compass needle, it is apparent that a magnetic field is produced by the current flow in the wire.

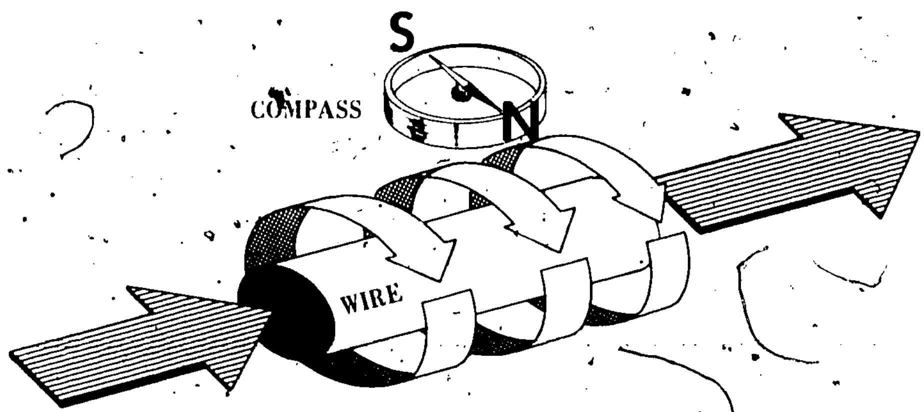

Figure 4. Magnetic Field Around A Conductor

In the case of the straight conductor, the lines of force form concentric circles around the wire. In this respect, the field differs from that of the permanent magnet. There are no magnetic poles in the conductor at which the lines of force can enter or leave. The strength of the magnetic field is increased with an increase in current flow. The increase in the number of lines of force is in direct proportion to the increase in current flow. This field is distributed along the full length of the conductor.

As in the case of the magnetic lines of force set up by the permanent magnet, the lines of force around a wire travel in a definite direction. The direction of these lines of force is dependent upon the direction of current flow in the wire. If the direction of current flow is known, then the direction of the lines of force around the conductor can be determined by what is known as the right hand rule. If the right hand grasps the conductor with the thumb pointing in the direction of current flow, the fingers will point in the direction of lines of force around the conductor. If the direction of current flow is not known, then a compass may be used to determine the direction of the lines of force and by using the right rule, the direction of current flow can be determined.

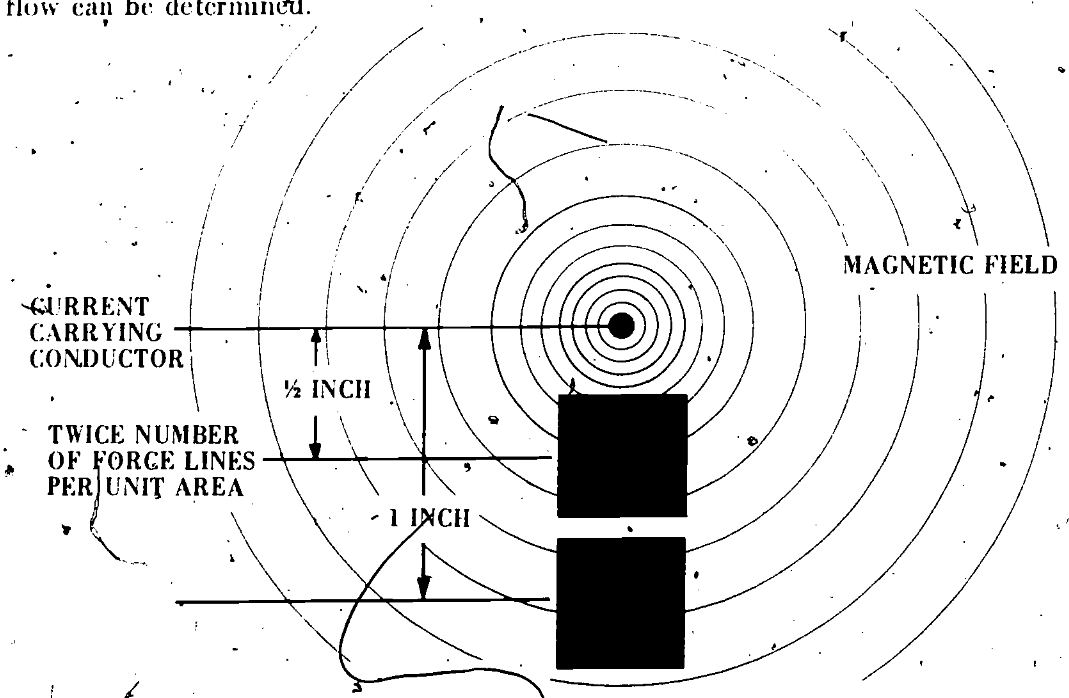

Figure 5. Magnetic Field Strength

The extent of the magnetic field around a conductor is limited in the permanent magnet and is progressively weaker as the distance from the conductor is increased (Figure 5). This is shown graphically as a series of concentric lines around the conductor progressively become farther apart as the distance from the conductor is increased. For example, with a given current traveling in a conductor there will be twice the number of lines of force at a distance of ½ inch from the conductor as there will be at a distance of one inch. The number of lines per unit area is called "density." The density of the field being greatest near the conductor means that the most useful portion of the magnetic field is near the conductor.

If we take a straight current carrying conductor and bend it into a loop, the lines of force are still traveling around the conductor at right angles to it. The lines of force all pass through the inside of the coil. This concentrates the lines inside the coil, and, therefore, materially strengthens the field without increasing the current flow. In addition, the polarity on one side of the loop is opposite to that on the other side. This can be observed by using a magnetic compass. The magnetic field around the loop is very similar to that produced by a permanent magnet (Figure 6).

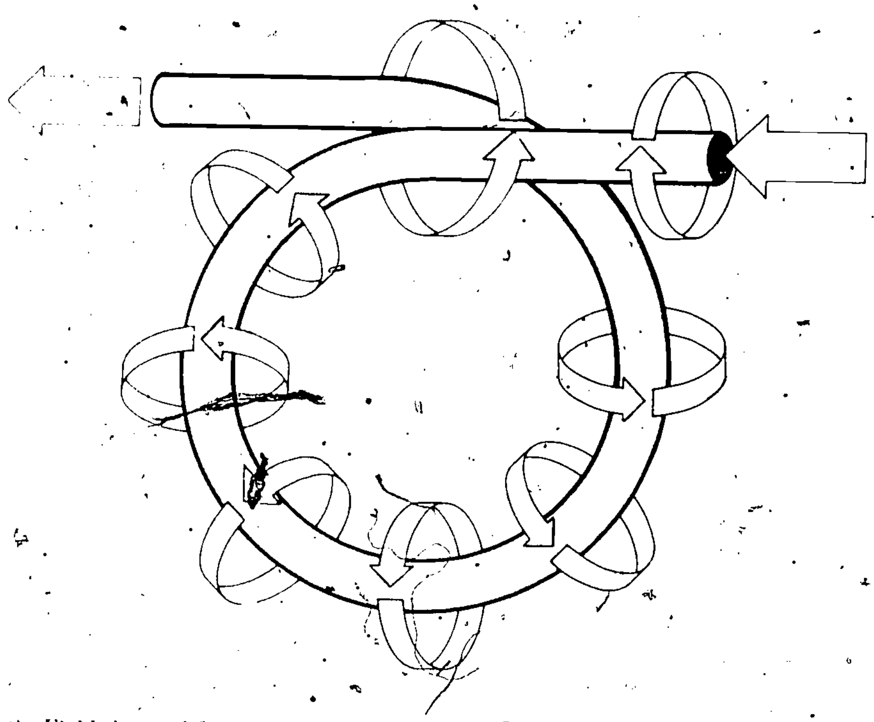

Figure 6: Magnetic Field Around Loop of Current Carrying Conductor

ELECTROMAGNETS

An electromagnet is a single conductor wound around a common core (Figure 7). When current is passed through this simple coil, the current is traveling in the same direction through each loop of the coil and the magnetic lines of force are traveling in the same direction around the wire. When current is traveling in the same direction through several conductors, the lines of force around each conductor join and surround the several conductors. The lines of force join and travel around all the loops of the coil, entering the coil at one end, leaving at the other end and returning outside the coil. Since all lines of force travel down the inside of the coil, the area within the coil becomes a strong magnetic field. We also see that one end of the coil has become a north pole and the other a south pole similar to a permanent magnet

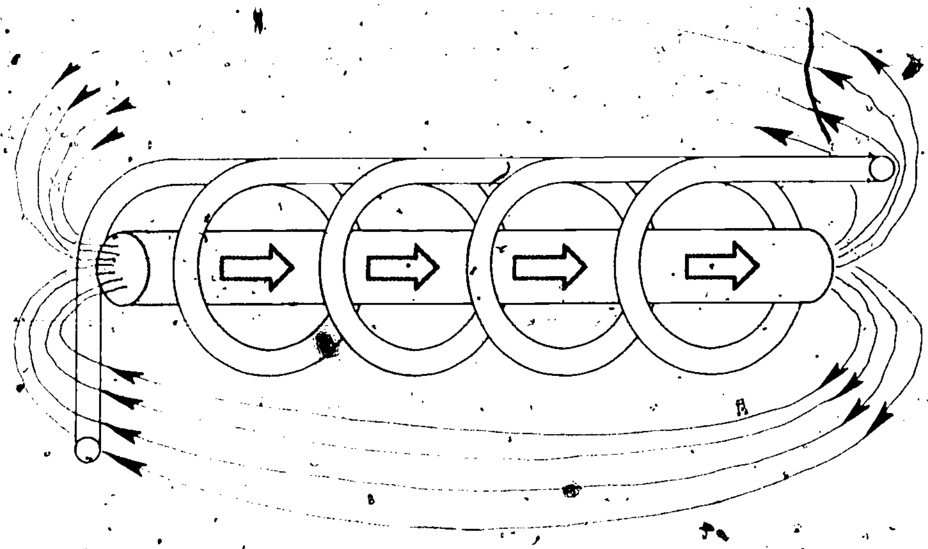

Figure 7. Electromagnet

Air is a poor conductor for lines of force so the coil loses many of the lines of force around the coil to the surrounding air. In order to strengthen the field within the coil, it is necessary to place a soft iron core within the coil replacing the air. This soft iron core is easily magnetized and will materially strengthen the magnetic field. This then becomes a true electromagnet. With a given amount of current passing through a coil, the strength of the electromagnet produced is directly proportional to the number of turns in the coil. The strength of the electromagnet having a given number of turns is also directly proportional to the amount of current passing through the coil. By varying the number of turns in the coil and the amount of current passing through it, virtually any strength of electromagnet may be obtained.

An electromagnet differs in two ways from a permanent magnet. First, it is temporary, only magnetic when current is passing through it; and, second, the poles of an electromagnet change when the direction of current flow is changed. In an ordinary 60 cycle alternating current, this will result in a change of the direction of flow of current 120 times per second which causes the poles of the electromagnet to reverse 120 times per second.

The basic principle of all electric motors can be seen if we examine the following illustration. When current is passed through coil 1, the north pole is established; and through coil 2, the south pole is established (Figure 8). A permanent magnet is mounted between the two coils so that it will rotate, and lined up so that the 2 north and south poles are opposite each other. Since like poles repel, the permanent magnet will be caused to rotate and the force of attraction between the unlike poles will pull the permanent magnet. Now the rotation would normally stop due to the attraction of the unlike poles. However, if we reverse the current flow in the two coils at this time, we can cause the poles on the coils to be reversed and the permanent magnet would be repelled again and would continue to rotate. If the current to the coils is reversed every time the permanent magnet rotated 180 degrees or halfway around, the magnet would continue to rotate. This simple device operates on the same principle as an electric motor. The electric motor is naturally more complex, but it operates on this principle.

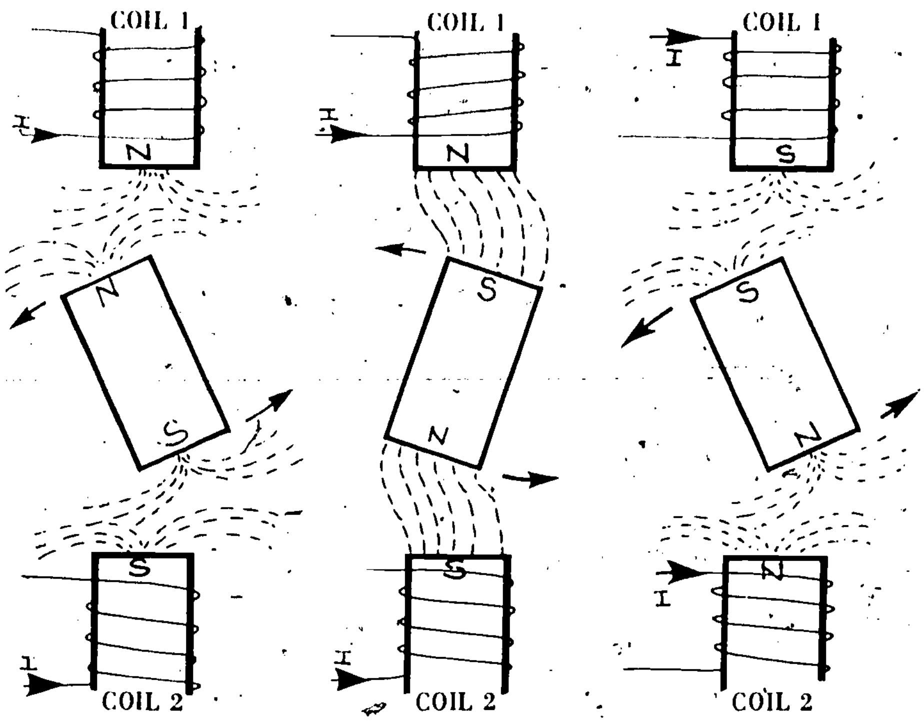

Figure 8. A Simple Electric Motor

PARTS OF AN ELECTRIC MOTOR

Electric motors are basically composed of two parts – (1) the rotor which is the rotating part; and (2) the stator which is the stationary part. These could be compared to our permanent magnet and electromagnetic coils in our discussion of how a motor runs. In addition to the two main parts, the motor also has a frame, end bells, and through bolts.

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DETERMINING SPEED OF AN ELECTRIC MOTOR

The speed of an electric motor is determined by the cycles of the electrical current and the number of pairs of poles in the stator. For example, with regular 60 cycle single phase current, the cycles switch 60 times per second or 3600 times per minute. The poles in the stator change every time the cycles change. Considering the example of how a motor runs, this will cause our permanent magnet to rotate 3600 times per minute or 3600 rpm. The formula to determine speed is:

$$\frac{\text{cycles per minute}}{\text{pairs of poles}} = \text{Speed in RPM}$$

This speed – the speed of the magnetic field within the stator – is called synchronous speed. In actual practice, the speed will be 4 to 5% less due to the fact that the rotor cannot quite keep up with the speed of the pole changes within the stator. In the two-pole (one pair of poles) motor, the actual speed will be 3450 rpm – this difference in speed is known as slip.

The following listing will help show the relationship of number of pairs of poles to synchronous speeds and actual speeds for electric motors operating on 60 cycle single phase current.

Number of Poles	Synchronous Speed	Actual Speed
2	3600	3450
4	1800	1725
6	1200	1140
8	900	850

TYPES OF ELECTRIC MOTORS IN COMMON USE

Basically, there are four types of electric motors which are used in home and farm application. The most commonly used are the split-phase, the capacitor motors, and repulsion-induction motors. In certain applications where large motors are required, three-phase motors are used; these motors are simple in construction and are relatively lower in cost for the larger motors.

The major difference between these motors is the starting capability. After they get up to operating speed, all motors will do the same amount of work. We will briefly consider the four types of motors mentioned above and their construction.

1. Split Phase Motors

Split-phase motors (Figure 9) usually consist of a rotor and two sets of windings in the stator. The windings are the running and the starting windings. The running windings consist of more turns of heavier wire than the starting windings and are usually wound on the stator slots first. There are always the same number of poles in both the running and starting windings with the poles of the starting windings halfway between the poles of the running windings. When starting, the current flows through both sets of windings, and after the motor reaches about 3/4 speed, the starting windings are cut out of the circuit by a centrifugal switch.

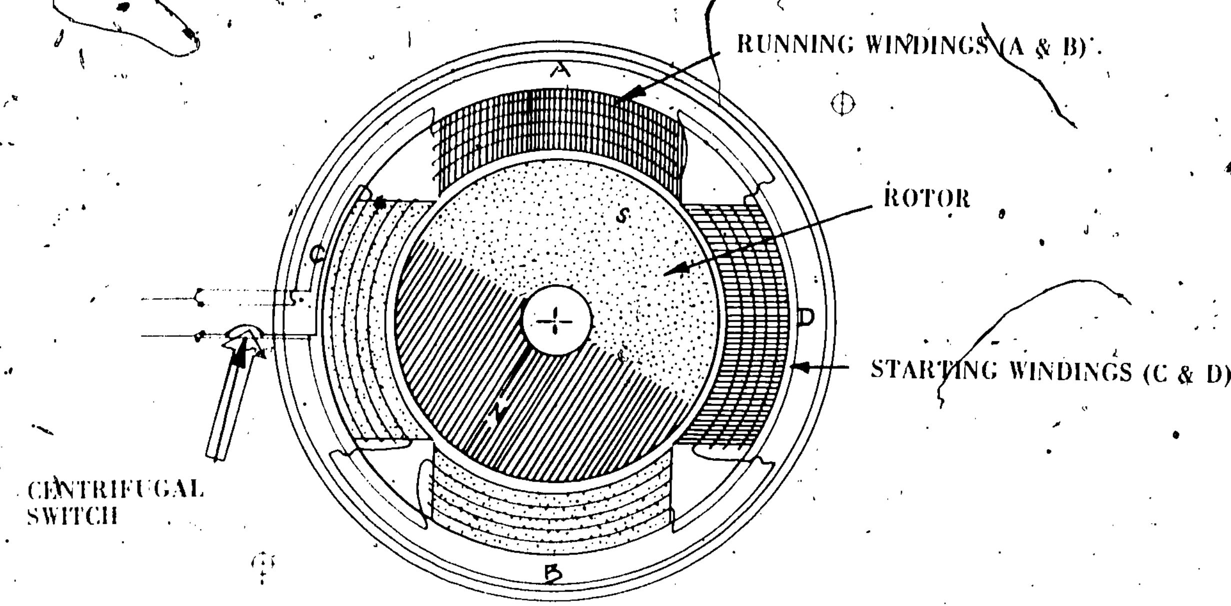

Figure 9. Split Phase Motor

2. Capacitor Motors

The capacitor motors can be of two types — the capacitor-start or the capacitor-start, capacitor-run.

The capacitor-start motor (Figure 10) is similar to the split phase in that both have the rotor and starting and running windings. They differ in that the capacitor-start motor has a capacitor (condenser) in series with the starting winding and has a capability of starting a much heavier load.

The purpose of the capacitor is to act as a reservoir where an electrical charge can be stored and fed back into the circuit. The capacitor has the effect of splitting the phases in the single phase circuit wider, thereby creating a longer time between the current peak and magnetism in the starting winding. This results in a higher starting torque and lower starting current requirement.

A capacitor (Figure 11) is made of two sheets of aluminum foil separated by a layer of an insulating material. They are usually rolled up and encased in a metal tube with the two terminals connected to the aluminum foil sheets.

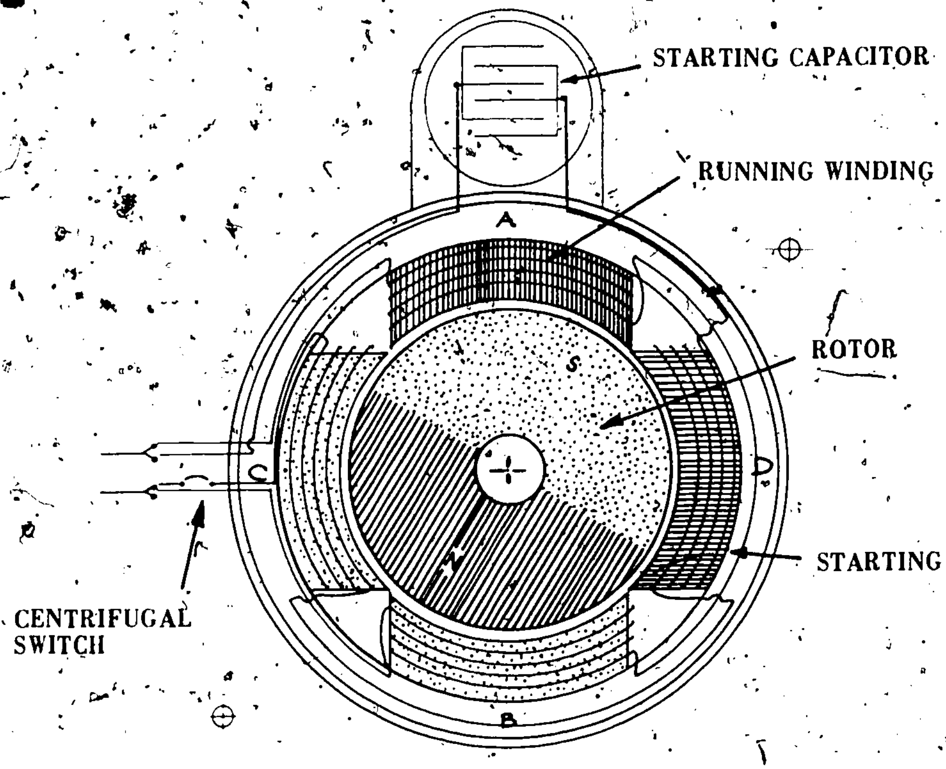

Figure 10. Capacitor Start Motor

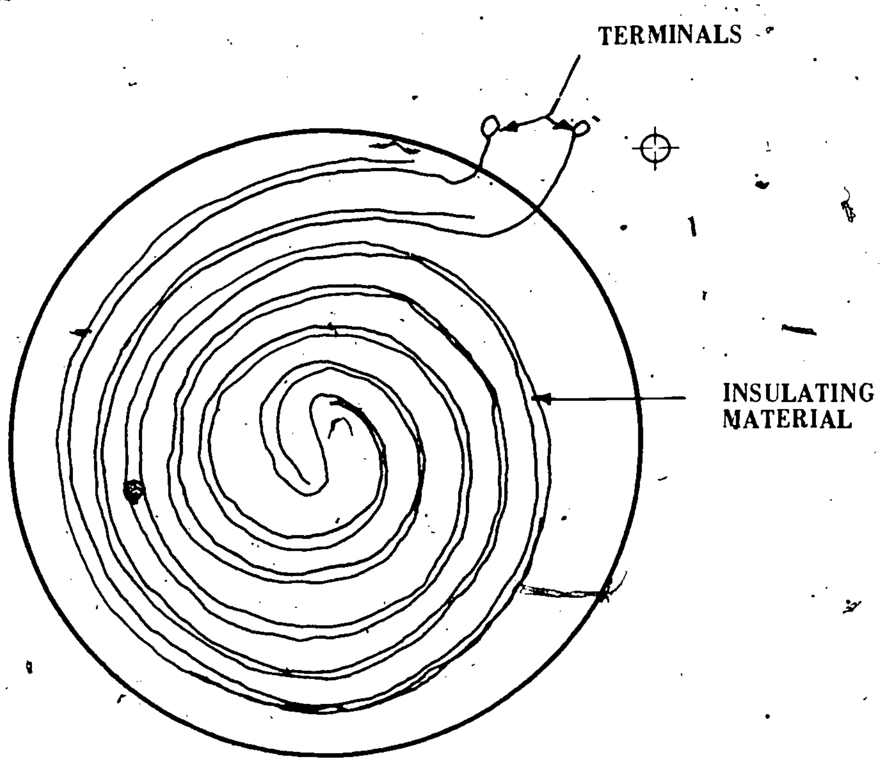

Figure 11. Capacitor

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A capacitor-start, capacitor-run motor (Figure 12) is very similar to the capacitor-start motor; the only difference being an additional capacitor in series with the running winding. In this motor, the centrifugal switch disconnects the starting capacitor leaving the starting winding in the circuit as an extra running winding. In larger motors above 3 horsepower, the running and starting characteristics are improved.

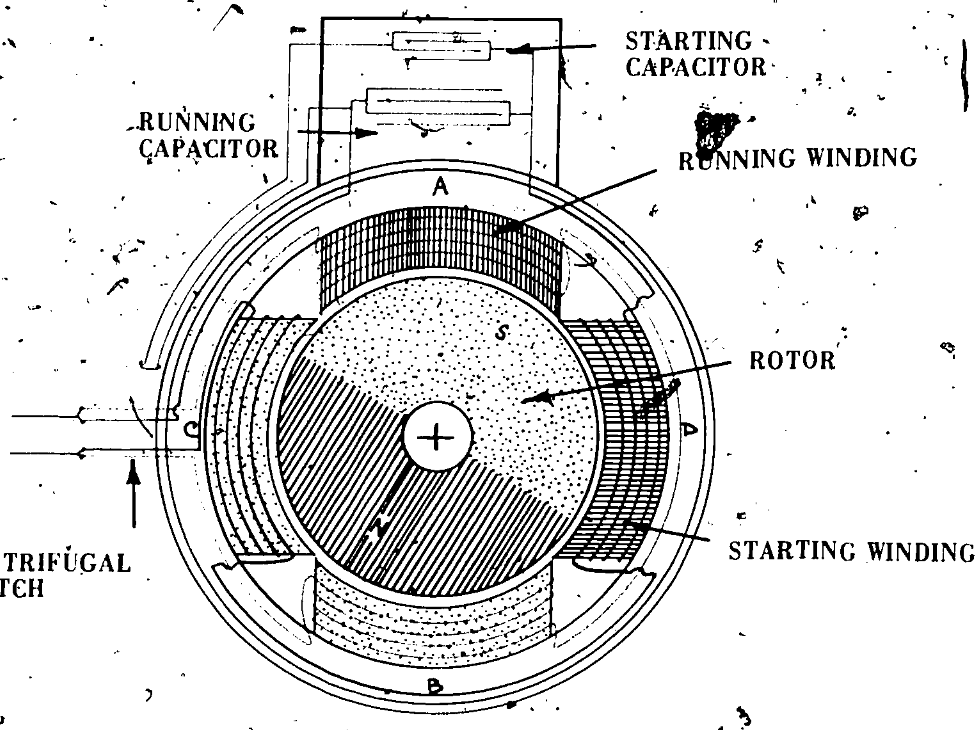

Figure 12. Capacitor Start — Capacitor Run Motor

3. *Repulsion-Induction Motors*

The repulsion-induction motor (Figure 13) is, as its name indicates, a combination motor. The motor starts on one principle and runs on another. It starts on the principle of magnetic repulsion and when almost up to operating speed, it switches over and runs on the induction principle the same as the other motors we have discussed before. Due to its starting principle, repulsion, it has a high starting torque and it can handle large variations in load with a minimum of variation in input current.

The repulsion-induction motor has only one winding in the stator which acts as a running winding. It has a wound rotor instead of the squirrel-cage type and has a commutator and brushes.

There is no direct connection between the line current and the brushes or rotor windings. The brushes serve only to complete the circuit in certain rotor coils. This creates strong magnetic forces within the rotor which react with those of the stator causing the motor to start. When it approaches full running speed (above 75% of running speed), all the commutator bars are short-circuited together by a centrifugal device within the rotor so that the rotor operates at full speed like the squirrel-cage type.

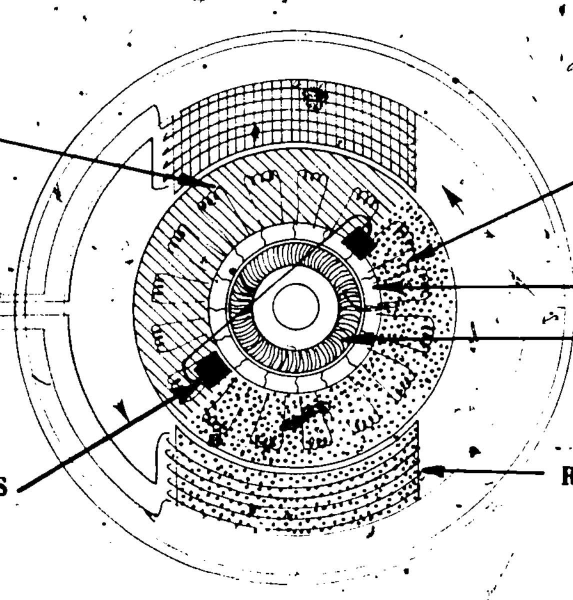

Figure 13. Repulsion – Induction Motor

Both capacitor and repulsion-start induction motors are designed to have the same high-starting torque. For this reason, they can be used interchangeably in farm applications under normal voltage conditions. Because of having greater starting torque per ampere of current, the repulsion-start induction motor is less likely to aggravate a low-voltage condition or be troubled by voltage drop. Both types of motors are ruggedly built and give good service on the farm for steady or intermittent use.

Most repulsion-start induction motors, even in the fractional horsepower sizes, can be operated on either 120- or 240-volt current. The stator winding is usually divided into halves and four leads are brought into the terminal box. These two halves are connected in parallel for 120-volt and, in series, for 240-volt operation.

Direction of rotation is determined by the position of the brushes with respect to the centers of the stator coils. Therefore, reversing is accomplished by shifting the brushes to a different position. Some motors have a brush-shifting lever which extends outside the motor. With others, it may be necessary to remove a plate on the end shield, and move an internal brush shifting device.

4. *Three-Phase Motors*

Three-phase motors (Figure 14) are not presently used to any great degree on farms; however, with the use of more and larger motors, the three-phase motor will become common.

The construction of three-phase motors differs from the other motors we have considered. A three-phase motor has three separate windings, one for each phase, which are equally spaced around the inside of the stator. Three-phase electric motors use a squirrel-cage rotor and will start and run without starting windings. These motors are simple in construction having no centrifugal switch, brushes or short circuiting devices and are, therefore, cheaper and easier to maintain. The currents in these windings alternate progressively and continually so as to produce a uniformly revolving field that drags the rotor around with it.

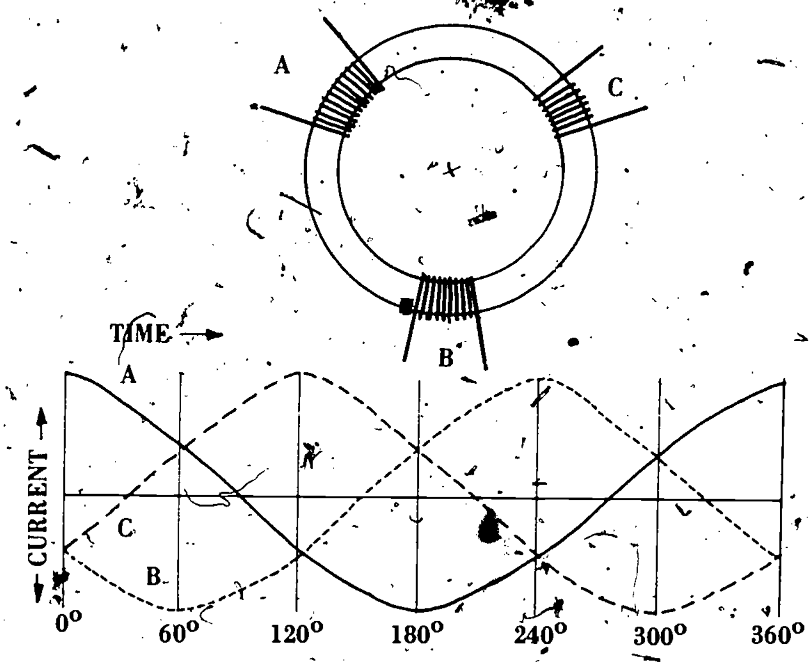

Figure 14. Three–Phase Motor

One major problem with three-phase motors in rural areas is the availability of three-phase current. In some cases a converter for changing single-phase to three-phase current may be used. The advantages of three-phase motors are unlimited horsepower range, simple in construction, rugged and lower cost for motors rated above one horsepower.

THE ELECTRIC MOTOR NAMEPLATE

The electric motor nameplate can provide you with a great amount of information concerning the characteristics of the motor. In motor selection, the nameplate can give you all the needed information about a specific motor and the characteristics and/or conditions under which it will operate.

A sample nameplate is shown in Figure 15. The various numbered items are indicated by arrows and described below:

1. The style number is the manufacturers specifications code. It corresponds to a set of drawings and electrical specifications that were necessary to produce this motor.

2. Frame size as defined by the National Electrical Manufacturers Association. The most common small motor frame sizes are Size 42, Size 48, and Size 56.

3. The type of power the motor has been designed to operate on. Some motors operate on single-phase A-C, others on two-phase and three-phase A-C, and still others on direct current.

4. The number of horsepower (or fractional part) this motor will produce at rated speed.

5. The speed in revolutions per minute the motor will produce at rated horsepower, voltage and frequency.

6. Frequency at which this motor is to be operated (usually 60 cycles, although 50 cycle power will occasionally be encountered).

7. Voltage at which this motor may be operated (generally this will be 115 volts, 230 volts, 115/230 volts or 220/440 volts).

8. Normal current drawn at rated load, rated voltage, and rated frequency.

9. Amount in degrees centigrade by which motor temperature will rise over the ambient or surrounding air temperature when operating at rated load and speed. Forty or fifty degrees centigrade rise are the most common types.

10. Duty rating, the period of time the motor may be operated without overheating (usually continuously).

11. A N.E.M.A. code letter designating the locked rotor kva per horsepower. For example, the letter M allows for 10 to 11.2 kva per horsepower.

12. The current this motor will draw when it is loaded to its full service factor.

13. When the motor is operating at rated voltage and frequency, it may be overloaded up to the horsepower obtained by multiplying the service factor by the nameplate (rated) horsepower. However, when operating at the full service factor, both the current and temperature rise will exceed the values shown on the nameplate.

14. Housing or type of enclosure.

15. Type letter code that each manufacturer uses to indicate something about the construction and the power the motor runs on. Codes will indicate split-phase, capacitor-start, etc.

16. Manufacturers code number appearing on a motor nameplate may be an actual serial number used on only one motor manufactured by that particular company; it may indicate the serial number of a motor built on a particular order for some customer; or it may be coded with letters or numbers to indicate merely the date the motor was manufactured.

17. The type of thermoguard protection installed in this motor.

A – Indicates automatic reset, U. L. approved

D – Indicates automatic reset, time delay, U. L. approved for oil burner service

M – Indicates manual reset, U. L. approved

X – Indicates automatic or manual reset, not U. L. approved

Note: U. L. refers to the Underwriters Laboratory.

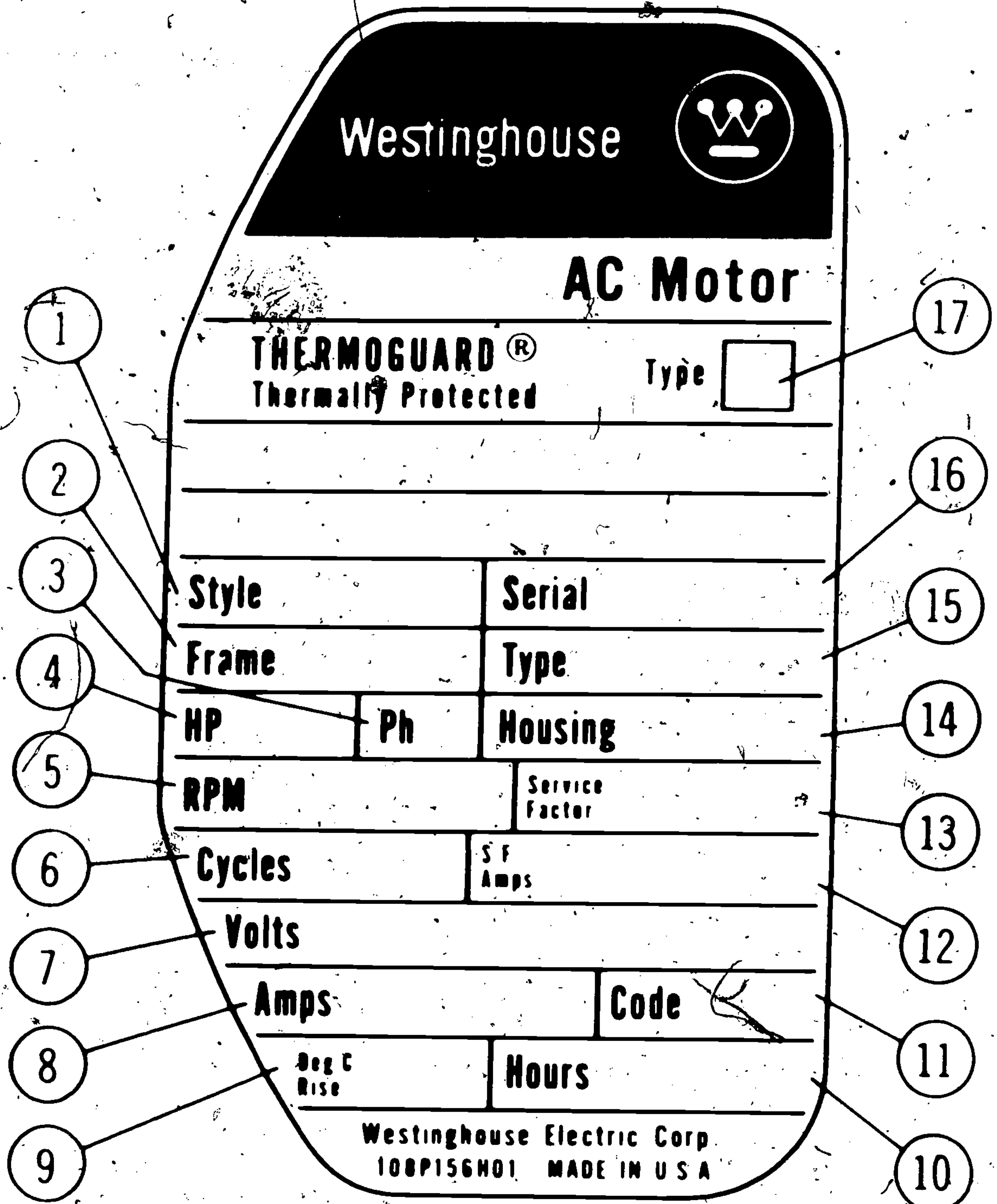

Figure 15. Sample nameplate which explains the basic electrical and mechanical characteristics of the motor.

ELECTRIC MOTOR COMPARISONS

LOAD TYPE	MOTOR TYPE (1)	STARTING ABILITY (TORQUE) (2)	STARTING CURRENT (3)	SIZE HP-RANGE (4)	ELECTRICAL POWER REQUIREMENTS: PHASE (5)	ELECTRICAL POWER REQUIREMENTS: VOLTAGE (6)	SPEED RANGE (7)	REVERSIBLE (8)	RELATIVE COST (9)	OTHER CHARACTERISTICS (10)	TYPICAL USES (11)
EASY STARTING LOADS	(a) Shaded-Pole Induction	Very low. 50% to 100% of its running torque.	Low	1/20-1/4	Single	Usually 120	900 1200 1800 3600	No	Very Low	Light duty; low in efficiency, no radio interference.	Small fans, freezer blowers, arc welder blowers, hair dryers, small tool grinders.
	(b) Split-Phase	Low. 100% to 150% of its running torque.	High. 6 to 8 times running current.	1/20-3/4	Single	Usually 120	900 1200 1800 3600	Yes	Low	Simple construction.	Fans, furnace blowers, lathes, small shop tools, jet pumps.
	(c) Permanent-Split, Capacitor-Induction	Very low. 50% to 100% of its running torque.	Low	1/20 1	Single	Single Voltage 120 or 240	Variable 900-1800	No	Low	Usually custom-designed for special application, not recommended for belt drive.	Air compressors, fans.
	(d) Soft-Start	Very low. 50% to 100% of its running torque.	Low. 2 to 2¼ times running current.	7½-50	Single	240	1800 3600	Yes	High	Used in motor sizes normally served by 3-phase power when 3-phase power is not available.	Centrifugal pumps, crop dryer fans, feed grinder.
DIFFICULT STARTING LOADS	(e) Capacitor-Start, Induction-Run	High. 3 to 4 times running torque.	Medium. 3 to 6 times running current.	1/6-10	Single	120-240	900 1200 1800 3600	Yes	Moderate	Long service, low maintenance, very popular.	Water systems, air compressors, ventilating fans, grinders, blowers.
	(f) Repulsion-Start, Induction-Run	High. 4 times running torque.	Low. 2½ to 3 times running current.	1/6-20	Single	120-240	1200 1800 3600	Yes	Moderate to High	Handles large load variations with little variation in current demand.	Grinders, deep-well pumps, silo unloaders, grain conveyors, barn cleaners.
	(g) Capacitor-Start, Capacitor-Run	High. 3½ to 4½ times running torque.	Medium. 3 to 5 times running current.	½-25	Single	120-240	900 1200 1800 3600	Yes	Moderate.	Good starting ability and full-load efficiency.	Pumps, air compressors, drying fans, large conveyors, feed mills.
	(h) Repulsion-Start, Capacitor-Run	High. 4 times running torque.	Low. 2½ to 3 times running current.	1-15	Single	Usually 240	1200 1800 3600	Yes	Moderate to High	High efficiency, requires more service than most motors.	Conveyors, deep-well pump, feed mill, silo unloader.
	(i) Three-Phase, General-Purpose	Medium. 2 to 3 times running torque.	Low-medium. 3 to 4 times running current.	½-400 or more	Three	120-240 240-480 or higher	900 1200 1800 3600	Yes	Very Low	Very simple construction, dependable, service-free.	Conveyors, dryers, elevators, hoists, irrigation pumps.

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