DC MOTORS

HOME STUDY COURSE

U.S. Electrical Motors Division
Emerson Electric Co.

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INTRODUCTION

The reasons for using direct current machines rather than the simpler and less expensive alternating current machines is the precision, ease and flexibility of control, particularly with respect to speed. The purpose of the first section of this home study guide is to help familiarize you with the basic construction, operation, and terminology associated with DC motors. The Application Considerations section will provide you with an overview of the most common application concerns pertaining to the selection of D.C. Motors. And the last section describes the D.C. product offering available today from U.S. Motors.

This course has been written in a user-friendly format and is designed to provide you with simple, straightforward answers to your D.C. questions. A thorough understanding of this material will enhance your ability to select and price the right D.C. motor for your customer's application.

You will find a brief quiz at the end of each section - please take a few minutes to answer the questions before moving to the next section.

ELECTROMAGNETISM

In 1819 Hans Christian Oersted observed that when he placed a freely pivoted magnetic needle near a wire that conducted current from a battery, the needle moved until it was at right angles to the wire. His extensive research led to the following conclusions:

1) A wire carrying an electrical current produced a magnetic field.
2) The magnetic field created by an electric current could interact with the field of a magnet to produce motion.

Michael Faraday used Oersted's discovery that electricity could be used to produce motion in conjunction with a battery as a power source to build the world's first DC motor. Since its inception, the DC motor has proven itself as a workhorse. Its performance is unmatched in demanding applications such as paper mills and printing presses.

What is a motor? "A motor is a device that converts electrical energy into mechanical energy. And how is this accomplished? It is accomplished through the use of electromagnets. To understand electromagnets, let's first discuss the magnet.

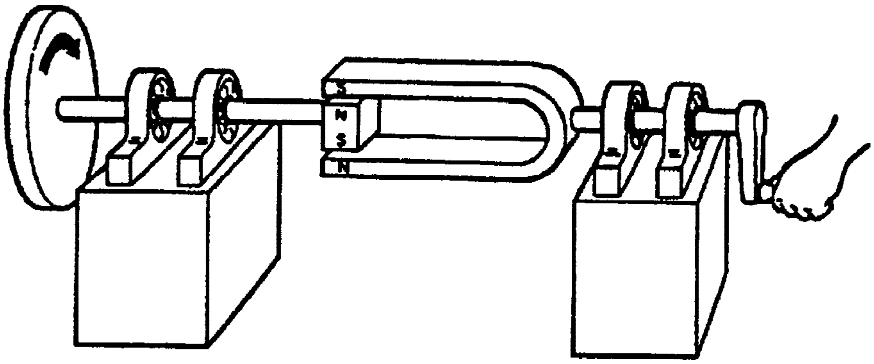
About three thousand years ago, an unusual mineral was discovered in Asia Minor. The mineral had the ability to attract iron objects. It was the first known magnetic material. Man-made magnets were put to practical use in about the twelfth century. At that time, it was established that a magnet which was free to rotate would swing until it came to rest in a north-south direction. Thus, the magnet came into regular use as a compass which early explorers used in navigation.

A substance is called a magnet if it has the property of attracting materials such as iron. Magnets are comprised of two poles: a north pole and a south pole. These poles represent the points of maximum attraction. In the case of a bar shaped magnet, the strongest magnetic effect is produced at each end.

The most basic law of magnetic force is that unlike poles attract each other, and like poles repel. Two important considerations apply to magnetism:

1) Every magnetic object creates a magnetic field that can affect other magnetic objects.
2) Every magnetic object can be acted upon by the magnetic field of another object.

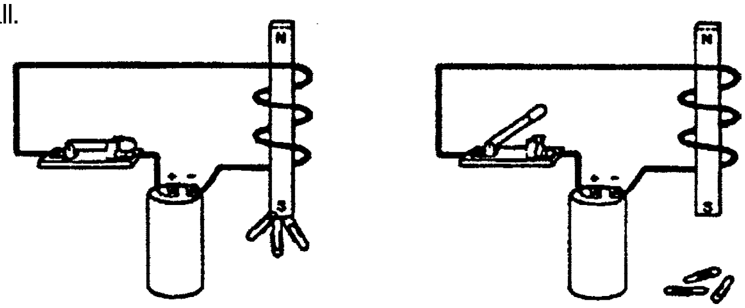
The following diagram shows a device that demonstrates how magnetic fields can transmit mechanical torque without making contact. A change in cranking speed would produce a change in output speed.



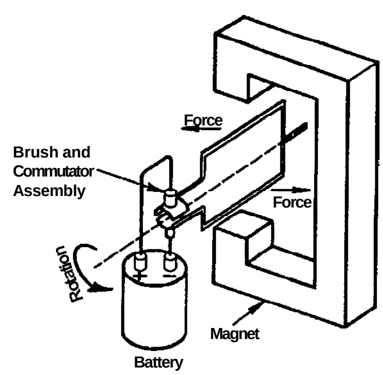
Magnetic fields are important because of the relationship between magnetism and electricity. A moving charge produces a magnetic field and a magnetic field exerts force on a moving charge. These two parts of the relationship between magnetism and electricity have great practical value. They form the basis for understanding motors, generators, and many other electrical devices.

Every moving electrical charge produces a magnetic field. The charge may be moving along a conductor, or it may be moving through a vacuum. The strength of the magnetic field depends on the speed and the strength of the charge.

One of the most important magnetic devices using electricity is the electromagnet. A electromagnet consists of a coil of wire that carries an electric current. Electromagnets are the same as permanent magnets, except they only have magnetic properties when electrical power is applied to the coil. As the example below shows, the paper clips will cling to the bar of metal when electrical power is applied. When electrical power is removed, the bar of metal no longer has magnetic properties, and the paper clips fall.



A motor basically consists of a stationary framework in which a rotating member, called an armature, is mounted. Magnets comprising part of both the framework and armature exert forces of attraction and repulsion upon one another in such a way as to cause rotation of the armature and a resulting mechanical energy output.



DC MOTOR COMPONENTS

In order to understand how this phenomena of electromagnetism is applied to a DC motor, let's first examine the basic components that make up the motor. The DC motor consists of the following components:

1) Motor frame (stator) tubular or laminated steel construction

2) End bells (brackets)

3) Armature: - Commutator
   Laminations
   Shaft and bearings

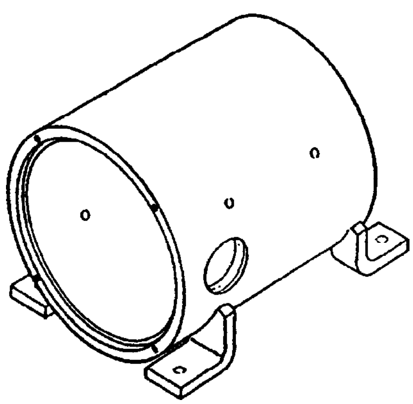
4) Field coil and pole assemblies

5) Interpole coil and pole assemblies

6) Brush rigging: - Brushes
   Brush holders and springs
   Rocker ring

FRAME

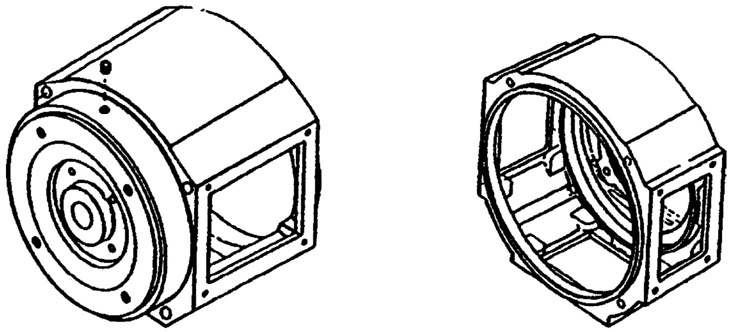
The motor frame on the DC motor is a rolled steel ring structure. The motor frame is lathe turned so that the inside diameter is a true cylinder. The end surfaces of the ring are machined to provide a mounting surface for the end brackets. The field poles are bolted to the inside of the frame, and the feet are welded onto the base of the cylinder.



BRACKETS

The end brackets enclose the ends of the frame. Armature bearings are supported in precision machined cavities which support and center the armature in the magnetic field structure of the frame.

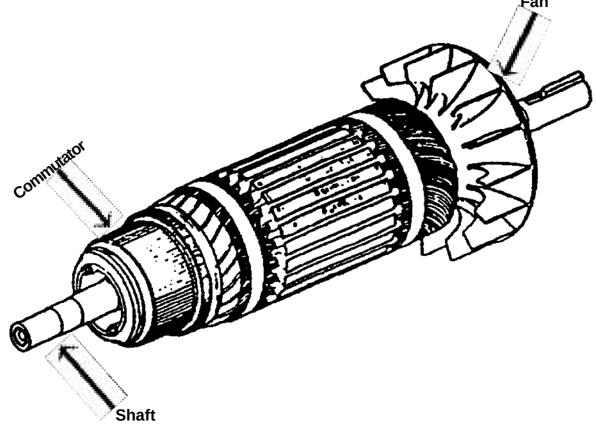
The commutator end bracket supports and locates the brush rigging assembly and also provides the external mounting surface for tachs, brakes, or other shaft driven accessories. All U.S. Motors end brackets are made of cast iron.



ARMATURE

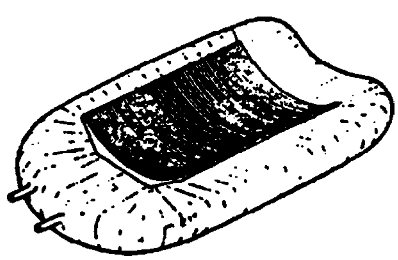
The armature consists of a stack of laminated discs made of a magnetic steel alloy pressed onto a steel shaft. Laminations are notched on the outer periphery to accommodate and support the armature coils.

The commutator consists of wedge shaped segments of hard drawn copper which are insulated from each other by mica segments. It is pressed onto the armature shaft, the armature coils are placed into "risers" (slots) where they are soldered or tig welded into place. Coils are insulated and secured mechanically against centrifugal forces that are applied during rotation. The armature is dipped in electrical insulating varnish and baked to assure a solid mass. A low inertia cast aluminum fan is mounted to the shaft to draw cooling air over the windings.



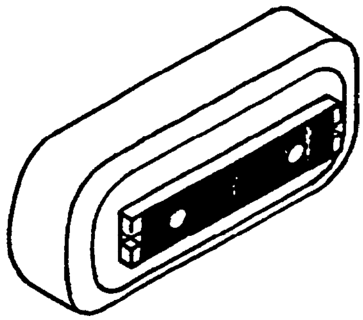
FIELDS

The field coil and pole assembly consists of a stack of laminations which are held together as a unit by appropriately placed rivets. Laminated structures allow magnetic flux to pass along the length of the lamination, but do not allow electrical eddy currents to pass across the structure from one lamination to another. The coils are random or perfect layer wound copper wire with a heat activated bondable insulation coating. Each coil is wrapped with an epoxy tape, shaped, and epoxy bonded to the pole piece.



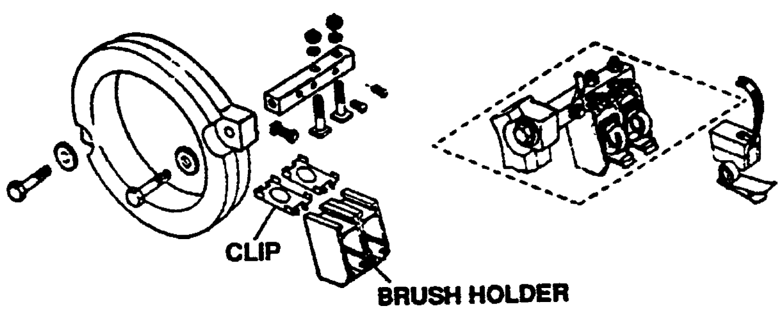
INTERPOLES

On smaller frames the Interpole coil and pole assembly are constructed similarly to the field coils. Large frames utilize coils that consist of a flat copper ribbon insulated with NOMEX between the turns, wound on a laminated pole piece. The coils are dipped in electrical insulating varnish and baked to assure a solid mass.

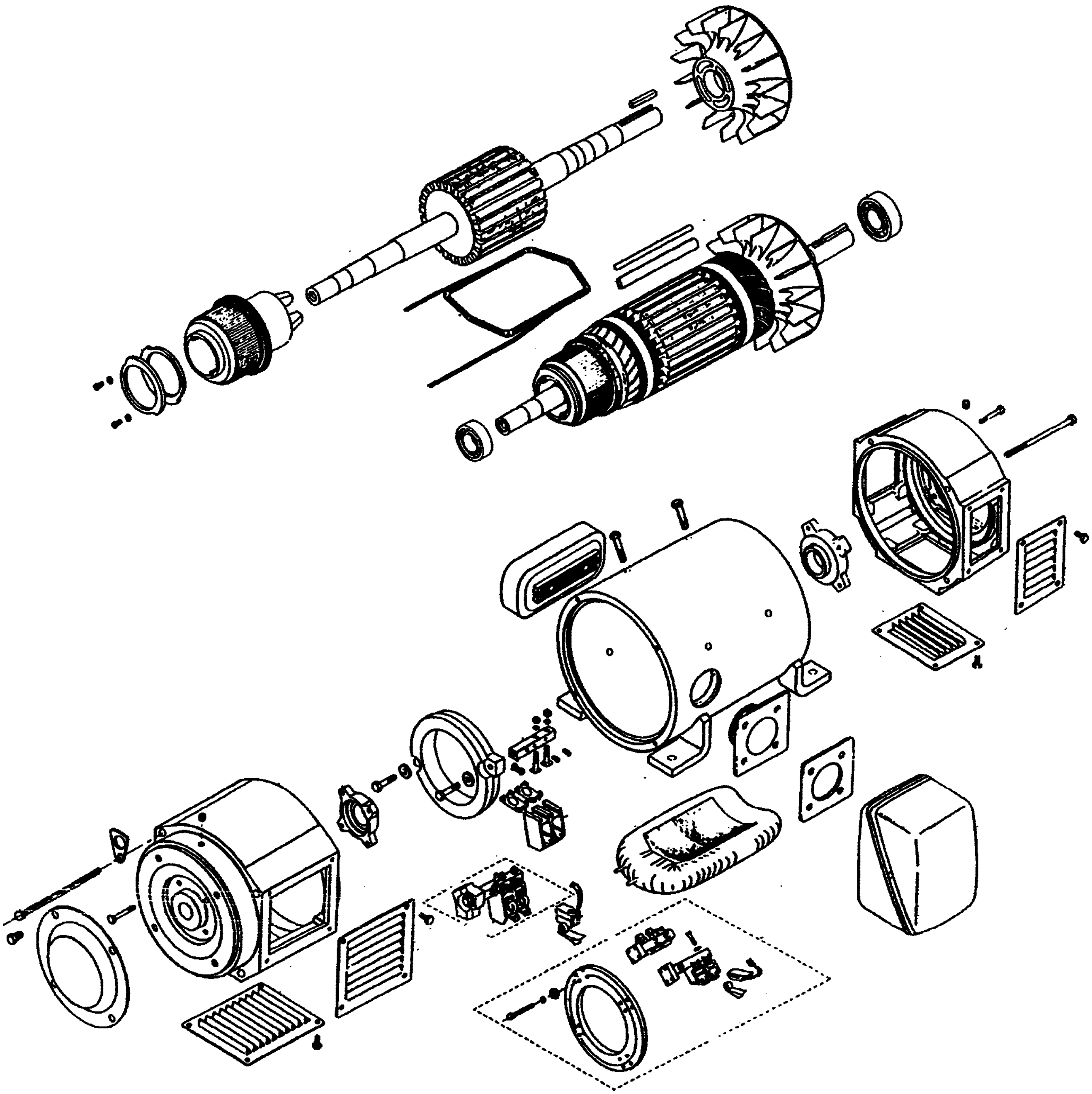


BRUSH RIGGING

The electrical switching function is shared by the commutator and brushes. Brushes are composed of carbon, carbon graphite, or a carbon filled graphite mixture. The rocker ring is a phenolic plastic ring which supports and locates steel studs which in turn support and locate die cast bronze brush holders. Brushes slip-fit into precision broached cavities and a constant pressure spring provides the proper force to hold the brush on the commutator surface.



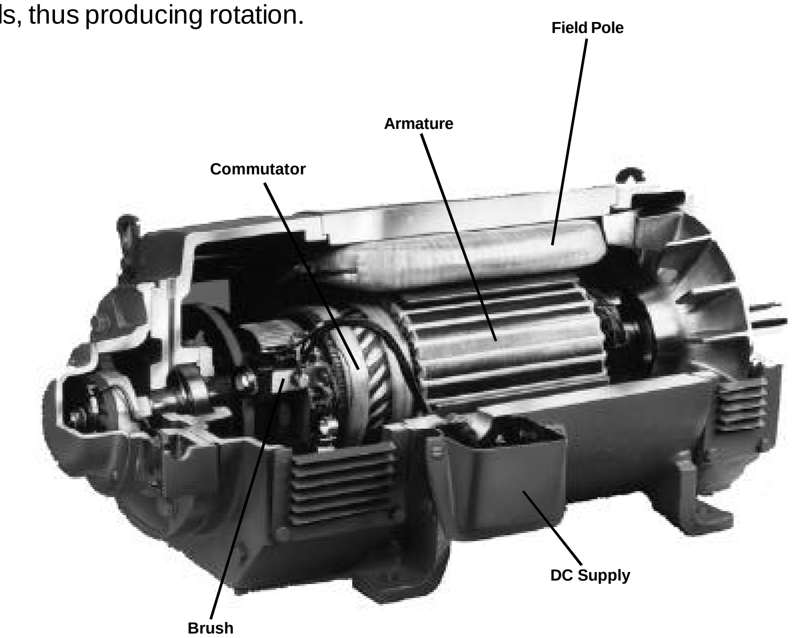
EXPLODED VIEW



PRINCIPLE OF OPERATION

Studying the cutaway picture of the DC motor below, you will note that the armature coil rotates between the poles of the field magnet. It terminates at a segmented ring called a commutator. Each end of the coil is electrically connected to a separate segment of the commutator ring. Small carbon blocks called brushes rub against the commutator ring as the armature rotates. The brushes provide an electrical connection to the armature coil from the DC electrical supply. Current flow in the armature coil sets up magnetic lines of flux around the armature conductors, resulting in a composite magnetic field with its north and south poles.

The field coils are wound on the field pole pieces so as to establish field polarity (north and south). After the armature has been forced through one-half rotation, it is necessary to reverse the magnetic polarity of the armature electromagnet so that it will be attracted to the magnetic orientation of each field pole. This is done by the commutator, which switches the current flow every time the commutator bar passes through a brush and hence reverses the magnetic polarity of the armature. Magnetic polarity changes produced by this switching action cause the armature to “chase” the fixed magnetic north-south field coils, thus producing rotation.



ADVANTAGES OF DC MOTORS

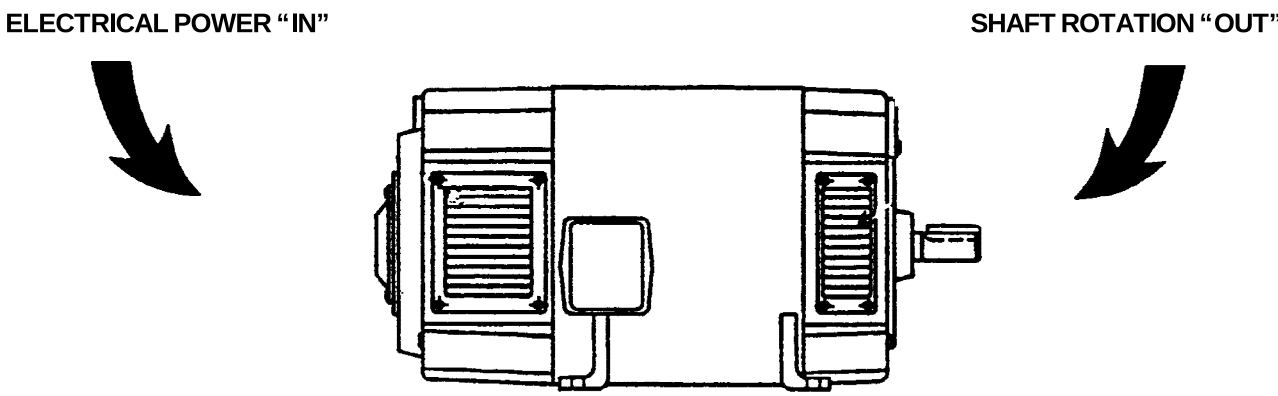
There are two primary advantages to DC motors: speed variation and torque.

SPEED VARIATION

Speed variation is accomplished by changing either the armature voltage or field voltage, or a combination of both. For example, a motor with a base speed of 1750 RPM and armature voltage of 500 VDC will run at 875 RPM with a 50% reduction in armature voltage (to 250 VDC).

TORQUE

Our basic definition of an electric motor is a device that converts electrical energy into mechanical energy. In reality, a motor could be better defined as a "torque generator". Torque can be defined as a turning force that tends to produce rotation on a shaft.



The primary advantage of the DC motor is that it can develop constant torque over a wide speed application.

DC MOTORS FUNDAMENTALS - QUIZ

1. What is a motor?

2. Explain the difference between a magnet and an electromagnet.

3. Name the six components of the DC motor.

4. Why are armature laminations notched on the outer periphery?

5. What material are brushes made of?

6. What component of the DC motor reverses the magnetic polarity of the armature electromagnet?

7. Define torque.

8. What are the two primary advantages of DC motors?

POWER SUPPLY

DC motors can be supplied by five basic types of power sources: batteries, generators, six-step SCR, three-step SCR, and single phase SCR. These various types of supplies are broken down into four categories, or codes, based on the quality of the output power as shown below.

COMMON POWER SUPPLIES

CODE	DESCRIPTION	COST	POWER	USE	COMMENTS
A	Batteries, Generators	High	Excellent	Limited	Limited HP range
C,D	3 PH./6-Step SCR (Solid State)	Medium	Excellent	High	–
E	3 PH./3-Step SCR (Solid State)	Low	Poor	Limited	Inefficient
K	1 PH. SCR (Solid State)	Low	Poor	Limited	Low HP only

COMMON VOLTAGE SUPPLIES

INPUT VOLTAGE	ARMATURE VOLTAGE	FIELD VOLTAGE
115 V	90v VDC	100 VDC
230 V	180 VDC	200 VDC
230 V	240 VDC	150 VDC
460 V	500 VDC	300 VDC

Power supply is an important consideration in the application of DC motors. The most common way to provide DC voltage to a motor from an AC line is through the use of an electronic drive. Depending on the construction, the drive will provide a pulse wave form similar to the perfect voltage from a battery. These pulses are characterized by a form factor which is defined by NEMA (National Electrical Manufacturers' Association) as a power supply code. Codes are based on the quality of the power output. Application concerns include drive cost, operational cost (efficiency), reliability, and output power quality.

NEMA POWER CODE A

This power supply is a pure DC power supply such as a battery or a generator. High frequency PWM power supplies will approach NEMA power code A. All NEMA rated DC motors may be operated off this type of power supply without the use of external reactors.

NEMA POWER CODE C

This power supply is close to being pure and consists of six silicon controlled rectifiers (SCRS) connected in a three phase, full-wave bridge configuration. All NEMA rated DC motors may be operated off this type of power supply with the use of external reactors.

NEMA POWER CODE D

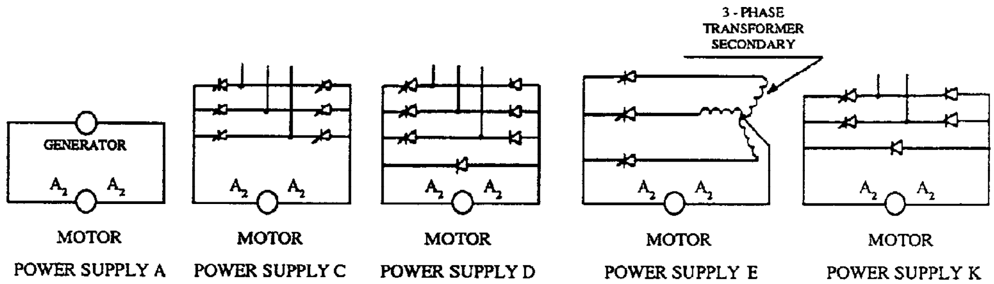
Power code D contains slightly more distortions than code C and consists of six SCRS and three diode style rectifiers connected in a three phase, full-wave bridge configuration. A freewheeling rectifier is used across the armature terminals. Motors rated 250 HP or less may be operated on this type of supply without the use of external reactors. Motors rated 300 HP or greater may require the use of external reactors when operated on this type of power supply.

NEMA POWER CODE E

This power supply has average quality and consists of three controlled rectifiers (SCRS) connected in a three phase, half-wave bridge configuration. Most DC motors will require some derating or the use of an external reactor when used on this type of power supply. Consult the factory when this type of power supply is used.

NEMA POWER CODE K

This power supply has limited applications and consists of two controlled rectifiers (SCRs) and two diode style rectifiers connected in a single phase full-wave bridge configuration. A freewheeling rectifier may be used across the motor armature terminals. This type of power supply is normally used for motors rated up to 7-1/2 HP.



SUMMARY:

- A DC Generator, Battery or 12-pulse/cycle, 6OHz, full control.
- C 6-Pulse/Cycle, 3 phase full control, 230/46OV, 60 Hz input to rectifier.
- D 3-Pulse/Cycle, 3 phase semi-bridge, 230/46OV, 6OHz input to rectifier.
- E 3-Pulse/Cycle, 3 phase 1/2 wave, 46OV, 6OHz input to rectifier.
- K 2-Pulse/Cycle, 1 phase full control, 115/23OV, 6OHz input to rectifier.

THREE PHASE POWER SUPPLY CONSIDERATIONS

NEMA rated DC motors are designed to operate on code A, C, or D power supplies. Derating considerations must be applied for use on code E systems.

The following formulas can be used to determine losses (heat measured in watts) of a standard motor utilized or a code E power supply.

$$I^2R = \text{losses (watts)}$$

I (amps) = Irms

The RMS value is the standard method of averaging AC current.

Irms = (I avg.) x (F.F.)

I avg. = Full load motor current

F.F. = Form Factor

The form factor of a hormonic signal is the ratio of its RMS value to its average value in one-half wave. In DC motors form factor defines the ratio of power absorbed from the line to the power delivered to the motor.

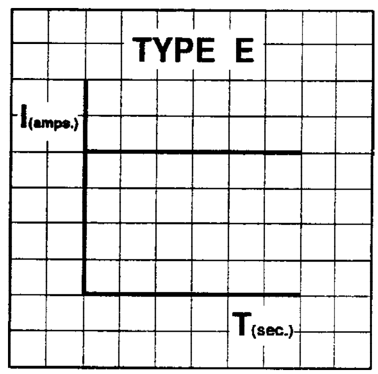
STANDARD FORM FACTORS
CODE A = 1.0
CODE C = 1.04
CODE D = 1.13
CODE E = 1.35
CODE K = 1.20

R(OHMs) = armature resistance - provided by manufacturer

Step 3) Evaluate type E power supply (3 pulse / cycle, 3 phase, 1/2 wave, 460V, 60 Hz input to rectifier) with 1.35 form factor.

Irms = (100) X (1.35)
= 135 AMPS.

LOSSES (WATTS) = $(135)^2$ X (0.1) = 1822W



SUMMARY	LOSSES	FORM FACTOR
CODE A	100 WATTS	1.0
CODE C	1082 WATTS	1.04
CODE E	1822 WATTS	1.35

Because of the high losses produced by a code E power supply, the motor must be measured in accordance with the lowest form factor that it is designed to operate on continuously. All USEM DC motors are designed to operate on codes A, C and D power supplies for three phase service. Therefore, the following relationship should be applied.

$$\frac{\text{CODE C}}{\text{CODE E}} = \frac{1.04}{1.35} = .77$$

In other words, the motor selected is suitable to deliver 77% of full load torque. Therefore, the motor must be oversized in accordance with this output.

SINGLE PHASE POWER SUPPLY CONSIDERATIONS

This type of power supply is limited to motors fractional through 7-1/2HP. Drive application is limited due to simplicity of power supply.

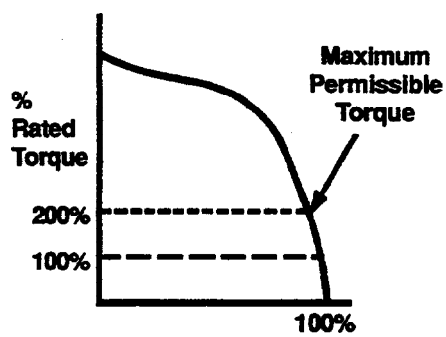
TYPES OF DC MOTORS

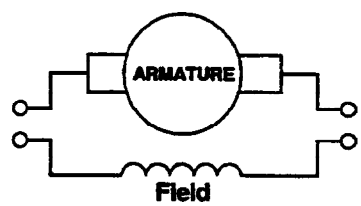
There are four kinds of DC motors commonly used in industrial applications: shunt, series, compound wound or stabilized shunt, and permanent magnet. When selecting a DC motor for a given application, two factors must be taken into consideration:

1) The allowed variation in speed for a given change in load.
2) The allowed variation in torque for a given change in load.

SHUNT MOTORS

A shunt motor has its armature and field in parallel or it may have separate field and armature supplies. In either case, this type of motor has good speed regulation (5% to 10%) and is capable of delivering 300 percent of its full load torque for a very short period of time.



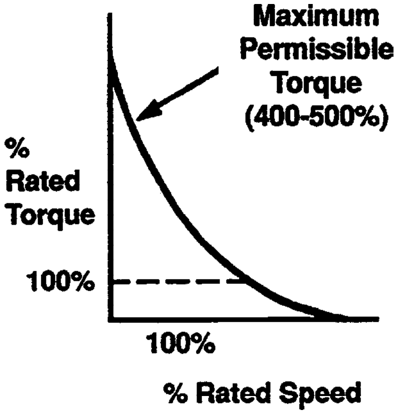


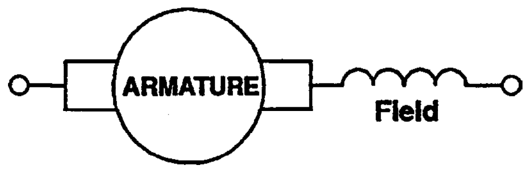
SERIES MOTOR

As its name implies, the series DC motor has its armature and field connected in a series circuit. This type of motor is used where the load requires a high breakaway torque such as locomotive, crane, or oil drilling rig applications.

The starting torque developed by a series motor can be as high as 500 percent of its full load torque rating. The series motor is able to deliver this high starting torque due to the fact that its field is operated below saturation. Therefore, an increase in load will result in an increase in both armature and field current. As a result the armature flux and field flux increase together. Since the torque developed in a DC motor is dependent upon the interaction of armature and field fluxes, torque increases by the square of the value of current increase. Therefore, a series motor will yield a greater torque increase than a shunt motor for a given increase in current.

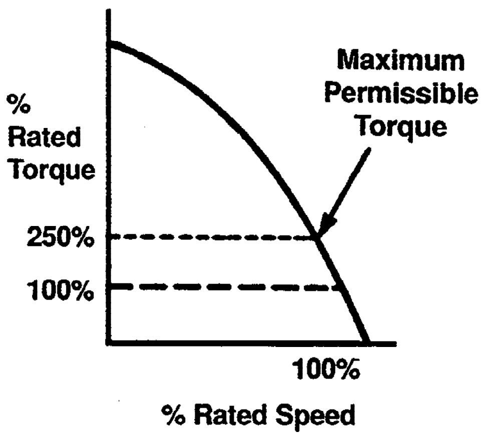
The speed regulation of a series motor is inherently poorer than that of a shunt motor. If the load on the motor is reduced the current flowing in both the armature and the field circuits is reduced causing a reduction in their flux densities. This results in a greater increase in speed than would be realized in a shunt motor. If the mechanical load were to be removed from the motor entirely the speed would increase without limit until the centrifugal forces generated by the armature would destroy the motor. For this reason, series DC motors should always be connected to a load.

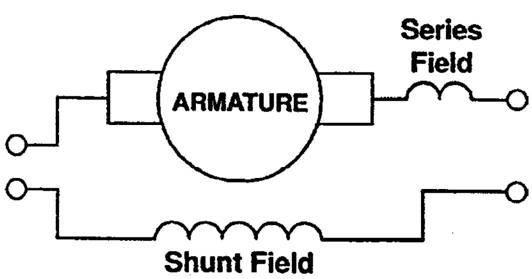




COMPOUND WOUND MOTORS

These motors are used whenever it is necessary to obtain a speed regulation characteristic not obtainable with either a series or a shunt motor. This type of motor offers a fairly high starting torque and delivers constant speed under load. This characteristic is achieved by placing part of the field circuit in series with the armature circuit. This configuration is not to be confused with interpoles which contain only a few turns of wire for the purpose of neutralizing armature reaction. When a load is applied, the increasing current through the series winding increases the field flux, thus increasing the torque output of the motor. As a result, this increase in field flux will yield a greater reduction in speed, for a given load change, than a shunt motor.

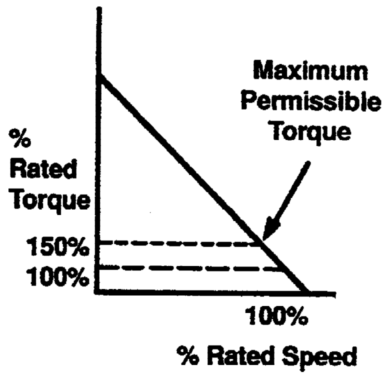


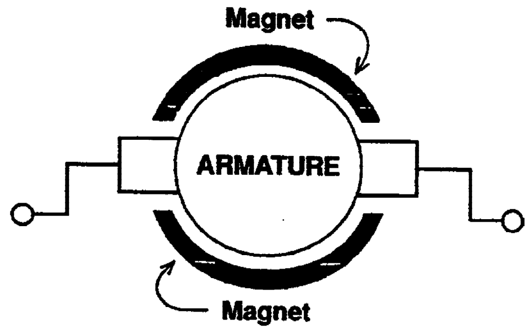


PERMANENT MAGNET MOTORS

Permanent magnet motors are generally used where response time is a factor. Their speed characteristic is similar to the shunt wound motor. They are built with a conventional type of armature, but have permanent magnets in the field section rather than windings.

Permanent magnet motors are considered less expensive to operate as they require no field supply. They can, however, lose their magnetism with age and as a result produce less than rated torque. Some permanent magnet motors have windings built into the field magnets for re-magnetizing purposes.





SPEED VARIATION

Methods of controlling the speed of a direct current motor are armature voltage control, shunt field control and a combination of armature voltage control and shunt field control.

ARMATURE VOLTAGE CONTROL

For this type of speed control the armature voltage is varied while maintaining constant shunt field excitation.

Output torque of a DC motor is proportional to the product of the main pole flux, armature current, and a machine constant which is a function of armature windings. Therefore, with armature voltage speed control and constant shunt field excitation, the torque is dependent upon the armature current only. In other words, at rated armature current the torque is constant.

A DC motor, operated with armature voltage control and fixed field excitation, will develop rated torque at rated armature current independent of the speed. This is commonly called constant torque operation.

SHUNT FIELD CONTROL

With speed control by field weakening, the voltage applied to the shunt field is adjusted by a variable resistance rheostat in series with the shunt field circuit or by varying the voltage of the shunt field power supply.

Reducing the shunt field voltage decreases the field current, which in turn reduces the field flux allowing the speed of the motor to increase. Increasing the field voltage to obtain a speed below base speed cannot be used as the field will overheat at higher than rated current. DC motors operated at constant armature voltage and with field weakening have a constant horsepower capacity over their speed range. Field control speed values range from 1:1 to 6:1.

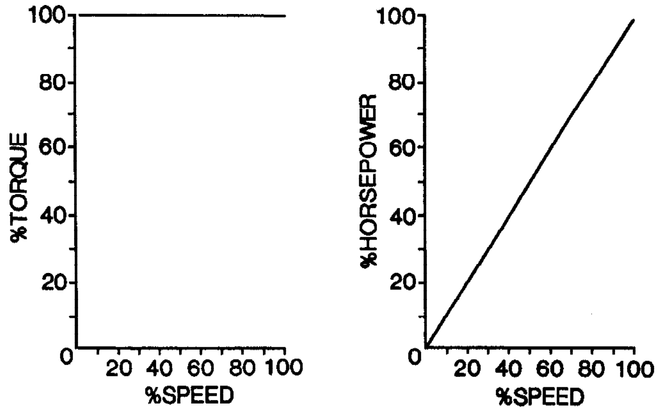
COMBINATION OF ARMATURE VOLTAGE AND SHUNT FIELD CONTROL

Utilizing both methods of speed control will give wide speed ranges. Armature voltage control is used for speeds below base speed, resulting in a constant torque capacity. Shunt field control is used to obtain speeds above base speeds resulting in a constant horsepower capacity.

LOAD CONSIDERATIONS

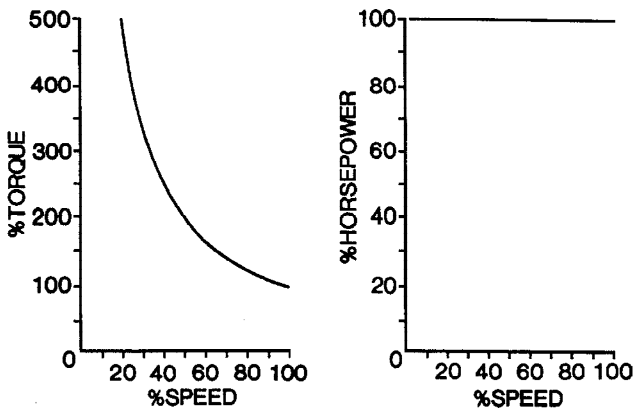
CONSTANT TORQUE

Many industrial applications such as conveyors, mixers, squeeze rolls, continuous processing machinery, etc., require nearly constant torque over their operating speed range. Direct current motors operated with fixed shunt field excitation and adjustable armature voltage have an approximately constant torque capacity over their speed range as shown below.



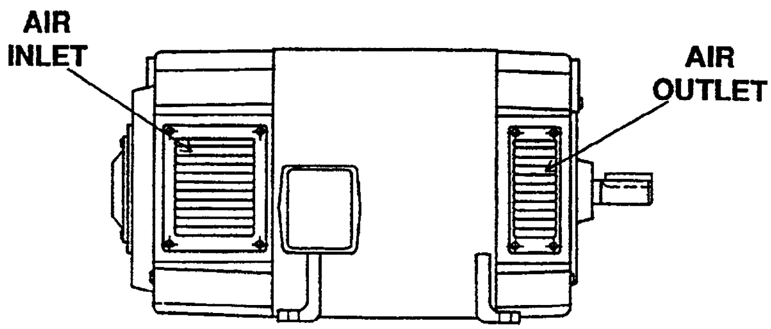
CONSTANT HORSEPOWER

DC motors operated by field control and constant armature voltage have a constant horsepower capacity over the speed range as shown here.



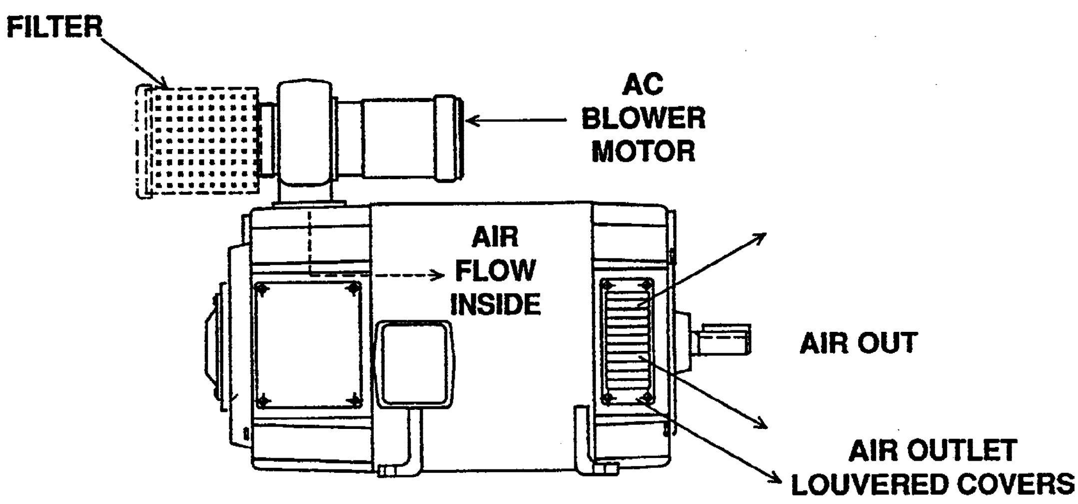
ENCLOSURES

Dripproof Fully Guarded Self Ventilated (DPFG)



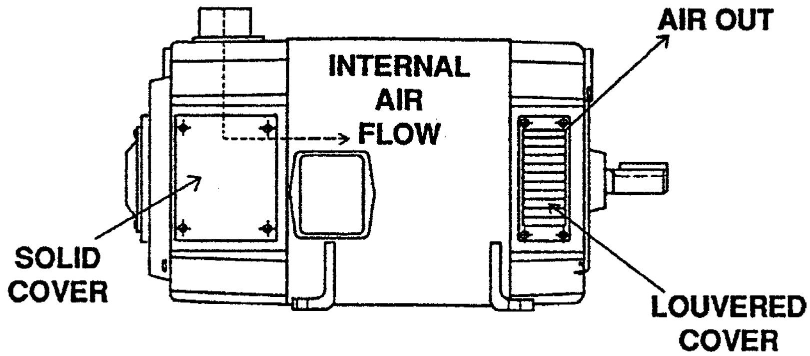
The DPFG motor is self ventilated, with no external cooling. Open dripproof motors are modifiable to separately vented enclosures. They are suitable to deliver 100% rated torque down to 60% of base speed.

Dripproof Fully Guarded Blower Ventilated (DPBV)



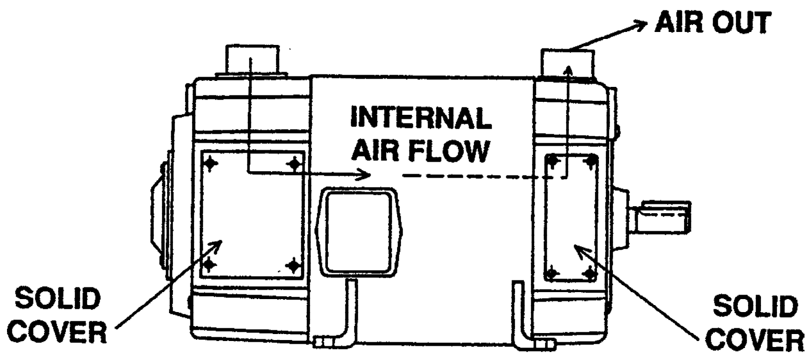
This type of enclosure has a blower, with or without filter, as a standard option. The blower is mounted on the commutator end of the motor to provide constant air flow CFM (ft.1/min.) for cooling. DC motors with blower ventilation deliver 100% of rated torque down to 5% of the motor's base speed. As an example, a 15HP motor @ 1750RPM, 257AT frame with blower delivers 100% torque (45 ft. lb.) @ 87.5RPM (5%).

Dripproof Separately Ventilated (DPPV or DPSV)



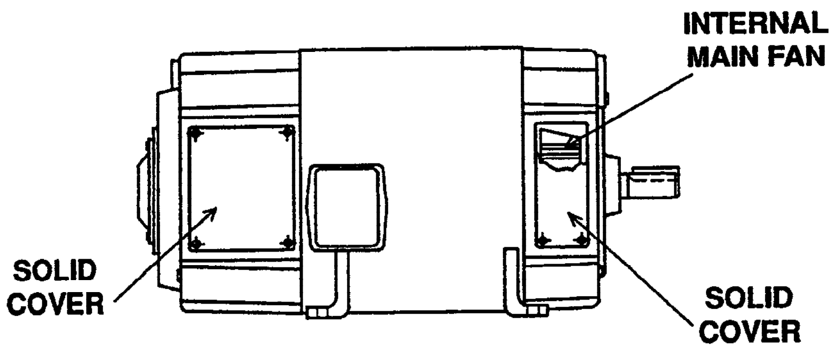
The dripproof, separately ventilated DC motor uses ducted in air, which must provide the proper CFM in order to cool the motor. This type of machine is capable of delivering 100% of rated torque down to 5% of its base speed. It has the same performance as the dripproof blower ventilated type, and is used in hazardous or contaminated environments.

Totally Enclosed Separately Ventilated (TEPV or TESV)



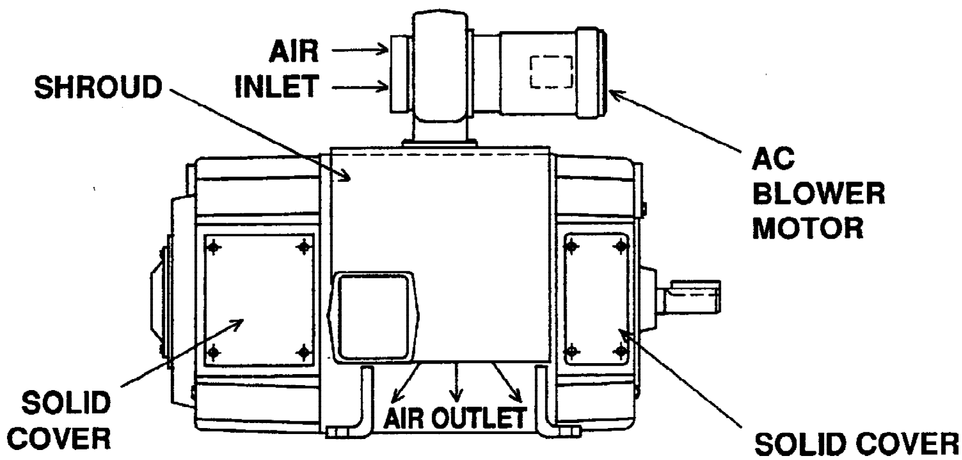
The totally enclosed separately ventilated motor has air flow ducted in and ducted out. This air flow must provide the proper CFM to cool the motor. It is capable of delivering 100% of its rated torque down to 5% of base speed. This type of enclosure is also used in hazardous or contaminated environments.

Totally Enclosed Non-Ventilated (TENV)



The TENV machine has no external cooling, but uses an internal fan to move air within the motor. These enclosures are designed to deliver 100% of rated torque down to 5% of its base speed. They are not practical, however, for large horsepower ratings. As an example, a 100 HP open dripproof motor is equal in size to a 30 HP TENV motor.

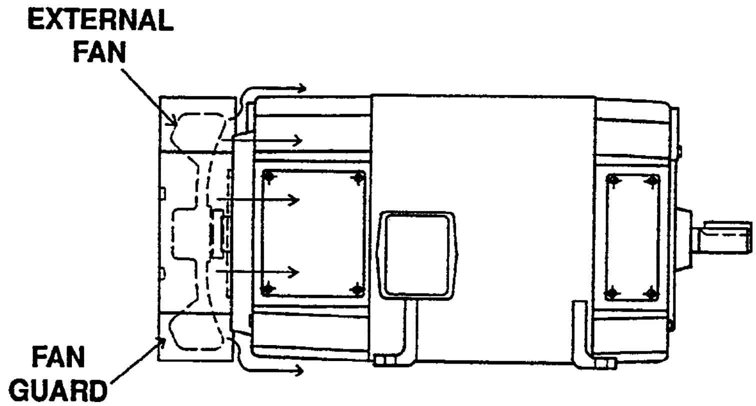
Totally Enclosed Air Over (TEAO)



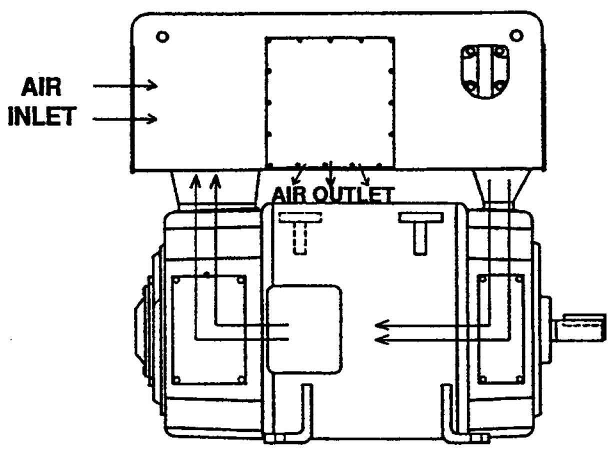
The totally enclosed air over motor has a blower mounted piggyback on top of the motor frame. This allows for constant air flow on the motor frame's external surface. DC motors in totally enclosed air over enclosures deliver 100% rated torque down to 10% of base speed.

Totally Enclosed Fan Cooled (TEFC)

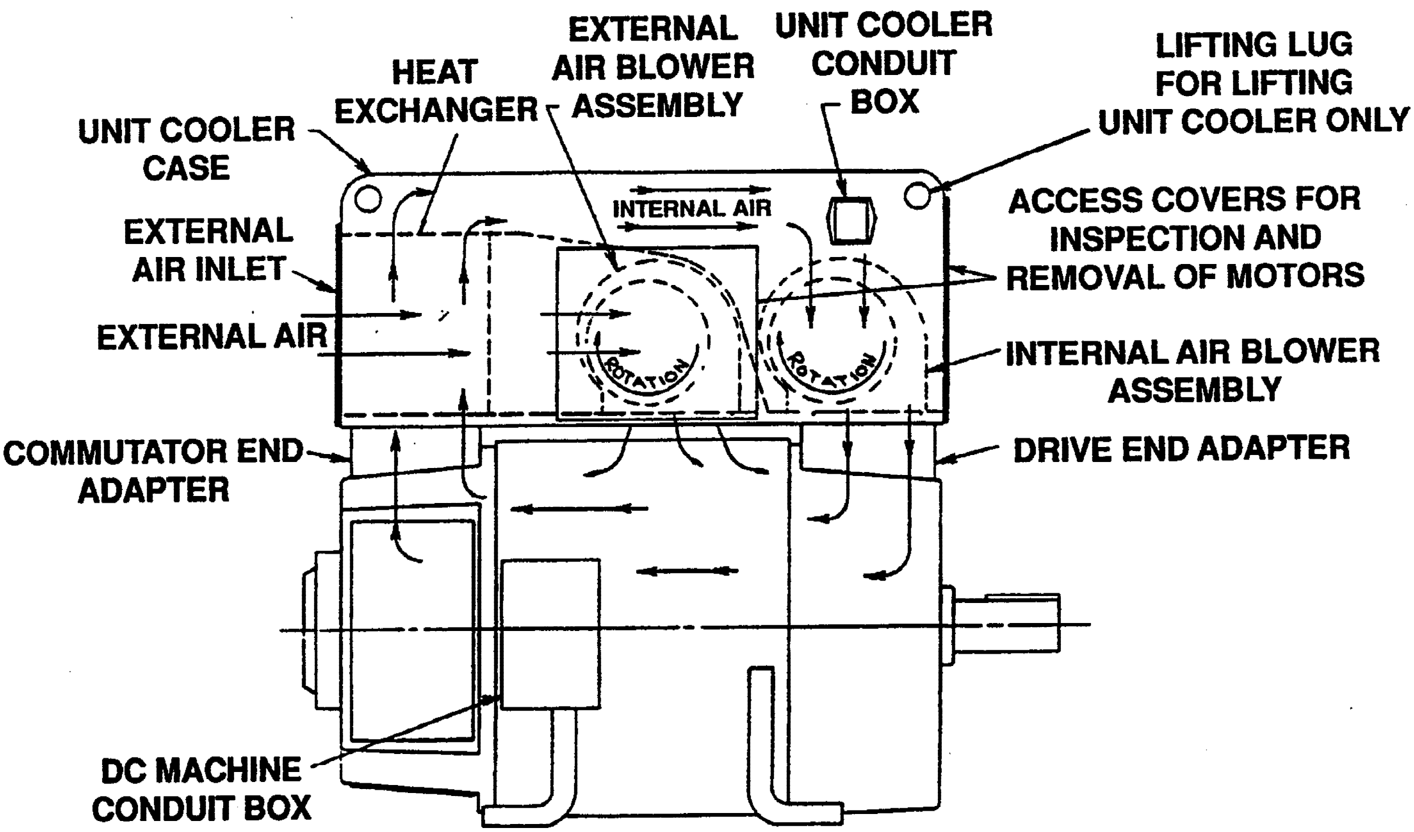
The TEFC machine has an external fan mounted on the commutator end shaft. Air flow varies with the speed of the motor, and is therefore not suited for low RPM applications. These motors are capable of delivering 100% of their rated torque down to 60% of their base speed. As an example, a 15HP, 1750RPM TEFC, 288AT frame, will deliver 45 ft. lb. of torque (100%) at 1050 RPM (60% of base speed.).



Totally Enclosed Unit Cooled (TEUC) Air-to-Air Heat Exchanger



These units consist of an air-to-air heat exchanger that is cooled by an external air blower assembly. The external air blower assembly draws air though the air inlet. An internal air blower assembly circulates the internal cooled air through the motor. The external blower and the internal blower are in two separated chambers so as to restrict the mixing of outside and inside air. TEUC motors are good for 20:1 constant torque applications. An outline of this motor is shown on the following page.



UNIT COOLER OUTLINE

ENVIRONMENTAL CONDITIONS

The exposed un-insulated components of DC motors (commutator, brush rigging, bolted connections) are vulnerable to early electrical failure when enclosure is inadequate; regardless of insulation system. A great many contaminants, wet or dry, are excellent conductors such as carbon, metal dust, and acid salts. Anything wet similarly conducts current quite well even at low voltages across distances of several inches. Normal oily vapors present in most atmospheres gradually deposit on all surfaces. These sticky surfaces then accumulate contaminants which begin to trickle, shorting or grounding currents. Such small leakage current may continue for years without developing actual machine failure. When particular conditions are right, the leakage becomes excessive and machine failure can occur almost immediately.

Because so many conditions contribute toward short service life, it is impractical to set forth all possibilities, but some discussion will help point out the need for application analysis where trouble is experienced.

OVER-TEMPERATURE

Overload is only one cause of over-temperature problems. High ambient temperatures or improper cleaning of filters on the machine itself contribute to short service life by increasing operating temperatures. This in turn causes abnormally high differential expansion stress resulting in cracks in the insulation which usually propagate through to the bare conductor, opening the circuit to contamination failure. In addition, the commonly known effect is the more rapid degradation of the insulation materials which shrink and harden, then gradually lose both strength and insulating characteristics.

Ambient temperatures greater than 40°C are also detrimental to grease, cables, brushes, and commutation.

CONTAMINATION

Nonconducting contaminants such as factory dust and sand gradually promote over-temperature by restricting cooling air circulation. In addition, these may erode the insulation and the varnish, gradually reducing their effectiveness.

Conducting contaminants such as metal dust, carborundum, carbon, and salt, in addition to promoting over-temperature, also provide immediate conducting paths for shorting or grounding leakage currents wherever the electrical circuit is contacted. Normal differential expansion, rotational stresses, and thermal expansion of trapped air in voids within the insulation system eventually open the insulated circuit at unpredictable locations. Depending on the severity of the operating voltage, service life may be measured in years, months, days, or hours.

Oil deposits promote easy adhesion of contaminants to the internal insulated and exposed un-insulated surfaces to promote early service life problems.

Water from splashing or condensation seriously degrades an insulation system. The water alone is conducting. Nonconducting contaminants are readily converted into leakage current conductors. Intermittent or occasional wetness ultimately causes service failure because successive leakage situations gradually deposit a permanent path for continuation of the damaging shorting or grounding currents.

VIBRATION

High vibration promotes service life problems by subjecting the shaft to stress, which finally results in actual shorting of conductors between turns or between layers. In addition, the severe stress causes fissures and cracks in the conductor insulation exposing the electrical circuit to contamination failure. Another important factor is the work hardening effect that this vibration has on the conductor itself, resulting in an open circuit by conduction or cracking. Commutation problems may arise because of brush bouncing. Continued severe vibration fatigues metals and could cause failure in casting or bearings.

ALTITUDE

Standard motor ratings are based on operation at any altitude up to 3300 feet (1000 meters). All altitudes up to and including 3300 feet are considered to be the same as sea level. High altitude derating is required because of lower air density which requires a greater amount of cooling.

DC motors are derated by 3% per 1000 feet above the 3300 feet. In some cases, a blower will be sufficient to cool the motor instead of using a larger frame motor.

AMBIENT TEMPERATURE

Motors for use in abnormally hot places are usually designed to accommodate the higher ambient by having a lower winding temperature rise. If the ambient temperature is above 50°C, special consideration must also be made of the lubricant. Although it's possible to operate in ambients above 50°C, application should be referred to the manufacturer to determine what steps must be taken.

In general, the simplest method of derating for high ambients is to derate the horsepower rating and operate the motor at field weakening. In this way, both the armature and field will be operating at reduced current. For ambients lower than 40°C, a standard 40°C machine is normally used at rated load. In the case when the ambient is maintained well below 40°C, a standard ambient motor may be used at overload, provided the following factors are known:

1. That the ambient is known always to be low.
2. Shaft stresses, bearing loading and commutation are approved by the factory.
3. That overload protection for the motor from an over load or stalled condition is available and used.

Operation of motors in ambients below O°C results in severe duty on the machine component parts. Of major concern are the lubrication system and the insulation system.

TROUBLE SHOOTING

Faults observed when a machine first goes into service or during subsequent operation should be identified and cleared without delay, since this will almost invariably prevent development of serious damage later on.

The trouble-shooting hints on the next few pages will provide a useful guide for locating and remedying running faults. They cover most common forms of trouble, but please consult Company if in doubt.

Always disconnect the machine from the supply before you investigate a fault or work on a machine.

MECHANICAL FAULTS

Fault	Possible Cause	Remedy
NOISY RUNNING		
Motor vibrating badly or running noisily when coupled up, but normally when uncoupled	Defective transmission components, or fault in the driven machine	Inspect transmission and drive components. Check alignment
	Belt too tight	Slacken belt, check belt connection, fit tensioning roller if required
	Subsiding foundation	Realign machine set, restore foundation level
	Gear drive fault	Align drive, check driving and driven gear pitch circles
	Incorrectly balanced drive or driven machine components	Re-balance
Motor running rough when uncoupled	Bearing damage	See under appropriate headings below
	Loose mounting bolts	Re-tighten and lock
	Inter-turn short	See under "Electrical Faults"
	Fitted drive components affecting rotor balance (e.g. couplings or pulleys)	Balance rotor with coupling or pulley fitted
ROLLING-CONTACT BEARING DAMAGE		
Machine overheats immediately after starting or lubrication	Bearing overfilled with grease	Only fill with correct amount of grease or add prescribed quantity. The machine will stop overheating in time
	No grease in the bearing	Grease bearing
Machine overheats after prolonged running	Rubbing bearing cover seal	Skim bearing cover, change defective seal
Bearing emits scratching, rubbing, rumbling noise		Dismantle bearing from machine, have cause of trouble established by Company
Whistling noise from a grease-lubricated bearing	Bearing run dry	Grease (with gun)
	Faulty cage	Change bearing
Excessive bearing wear	Bearing overload	Check alignment, belt tension, gear pressure, coupling thrust, etc. Reduce bearing load, if necessary eliminate additional axial load
Scoring when motor inoperative	Bearing subjected to vibration from an outside source	Isolate motor from source of vibration, or keep rotor turning over
Scoring when motor running	Current leakage	Contact Company

ELECTRICAL FAULTS

Fault	Possible Cause	Remedy
Motor fails to start off-load	Break in the armature supply	Correct connection
	Blown fuse	Fit new fuse
	Starter damaged or wrongly connected	Check starter for break in circuit. Correct connection
	Armature coils burnt out or short-circuiting	Remedy short-circuit. This usually requires special workshop attention and should be done at the factory
	Brushes not bearing down correctly	Check brush position and bearing pressure. Replace worn brushes.
	Break in field winding	Remedy break
	Break in field control circuit	Remedy break
Jerky starting	Break in the starter circuit	Remedy break
	Armature short-circuit	Contact Company
	Commutator short-circuit	Check commutator and remedy short-circuit
Motor will not pick load	Short-circuit in the supply	Locate short-circuit and remedy
	Overloading	Check current input and remedy overload
	Voltage drop	Increase supply line cross-section
	Brushes moved in d.o.r. from neutral area	Reset brushes to neutral area as marked
Motor overspeeding, and hunting under load	Brushes moved against d.o.r. from neutral area	Reset brushgear assembly to coincide with mark
	Break in field circuit or field resistor set too high	Set field resistor to correct value
	Auxiliary series winding wrongly connected	Check and correct circuit
Overheating in service	Overloading	Check voltage and current. Remedy overload
	Insufficient air flow	Improve cooling conditions
	Cooling air or water temperature too high. Insufficient cooling water flow.	Clean air passages inside and outside the machine.
	Dirty heat exchanger or filter	
	Armature or field winding short-circuit	Check windings and soldered connections Repair coils or windings
	Servicing cover open	Close cover

DC MOTOR APPLICATION CONSIDERATIONS - QUIZ

1. What is the most common way to provide DC voltage to a motor from an AC line?

2. NEMA Power Code E is the most popular power supply used in current generation DC drives today.
   True ___ False ____
3. Which power code(s) can be used for single phase DC motors?

4. Speed regulation is better in a series motor as compared to a shunt motor. True _____ False _____
5. Which type of DC motor has the highest starting torque?

6. Which one of the DC motor types requires only one source of power supply?

7. Which type of speed variation would you utilize to obtain increased motor speed over the base speed of the motor?

8. A DC motor operated with armature voltage control is commonly called constant torque capacity.
   True _____ False _____

9. What type of enclosure would you choose for a clean environment, where you required constant torque down to 5% of base speed?

10. What type of enclosure has its airflow ducted in and ducted out and can deliver its rated torque down to 5% of base speed?

11. A TEFC type enclosure is not suitable for low RPM applications. True _____ False _____
12. U.S. Motor's TEUC enclosure is a water-to-air type heat exchanger. True _____ False _____

13. Name two contaminants that can not only cause over-temperature but also provide conducting paths for shorting or grounding leakage currents.

14. Do DC motors need to be derated for high altitudes?

15. Name two possible causes of a motor experiencing jerky starting.

PRODUCT OFFERING

U.S. MOTORS OFFERS THE FOLLOWING DC PRODUCTS:

Permanent magnet motors, from 1/4 - 3 HP, frames 56C thru 184TC in totally enclosed fan cooled design.

Single phase shunt wound motors, from 1/4 - 5 HP, frames 56C thru 256C in totally enclosed fan cooled. **Three phase shunt wound motors,** from I - 150 HP, frames 186AT thru 508AT in

Totally enclosed fan cooled,
Totally enclosed non-ventilated,
Totally enclosed air over, and
Totally enclosed unit cooled.

Three phase shunt wound motors, from 1 - 600 HP,
frames 186AT thru 5010ATZ, in
Dripproof,
Dripproof blower ventilated,
Dripproof separate ventilated, and
Totally enclosed separate ventilated.

In addition, U.S. Motors can supply additional specialty rotating products, such as battery operated DC motors, alternators, generators and MG sets. For these types of products, please contact your U.S. Motors representative with details of your requirements.

U.S. Motors is also one of the few motor manufacturers who can offer their own accessories, such as AC and DC tachs, brush monitors and blowers.

GLOSSARY OF TERMS

ALTERNATING CURRENT

Alternating current changes direction periodically with current. In the United States, power is generally supplied with a 60 cycle per second rate in a sinusoidal wave form.

ALTITUDE

Standard motor ratings are based upon operation at any altitude up to 3300 feet (1000 meters). Identify any altitudes above 3300 feet-motors for these applications may require a special design, a change in insulation class, and/or an increase in frame size.

AMBIENT TEMPERATURE

The temperature of the cooling medium immediately surrounding an object. Standard motors are designed for operation in a 40°C ambient at altitudes up to 3300 feet above sea level. For higher ambients, derating or frame oversizing may be necessary.

ARMATURE CURRENT

The rated current at which a DC motor develops specific horsepower at base speed. Also, any current drawn by the armature.

ARMATURE VOLTAGE

The maximum continuous duty voltage applied to the armature during operation. Varying armature voltage will result in speed variation. Standard armature voltages are 180, 240, 440, 500, and 550.

BASE SPEED

Base speed is the certified speed at which the motor will operate at rated armature voltage and field voltage. Base speeds between 300 and 3500 RPM are available. For any base speed below 300 or above 3500 RPM, refer to the company.

BLOWER MOTOR FILTER

A motor mounted blower can be supplied with or without a filter. Filters are recommended when the motor will be operating in a dusty or particle contaminated atmosphere.

COMMUTATION

The process of current reversal in each of the individual loops of an armature as that armature approaches the moment of maximum magnetic attraction to the field.

CONDUIT BOX

The conduit box is the receptacle for incoming power.

CONSTANT TORQUE SPEED RANGE

The constant torque speed range is the range of RPM where the motor will maintain a constant torque.

DRIVE CONTROL

The regulator in a control system which governs system output.

DUTY

Every motor has a time rating associated with it. Most motors will be rated for continuous duty. When motors are to be used for specific well defined applications, where they will be operating for short periods of time, it is possible to reduce their size, weight and cost by loading them to higher torques than would be possible if they were to operate continuously. Options available are: continuous, 60 minutes, 30 minutes, or other. Please identify “other”.

DUTY CYCLE
The ratio of operating time to total cycle time.

DUTY TIME
The time during which a control system is doing work in a cyclical operation.

ENCLOSURE
Standard enclosures include dripproof, fully guarded (which has no external cooling and is modifiable to separate vent), dripproof blower ventilated (which has a blower mounted on the commutator end of the motor to provide constant air flow for cooling), totally enclosed non-ventilated (which has no external cooling, but does have an internal fan that moves air within the motor), totally enclosed fan cooled (which has an external fan for cooling), and totally enclosed unit cooled (air to air heat exchanger).

FIELD
Stationary pole winding in a DC motor.

FIELD VOLTAGE
Field voltage is voltage applied to the field during operation. This voltage is typically held constant. Any change in field voltage will result in speed variation. Standard field voltages include 100/200, 150/300, and 120/240 VDC. Describe any nonstandard requirement.

FIELD WEAKENING
A method of controlling motor torque, speed, or voltage by controlling the field strength.

FRAME
The motor frame is a rolled steel ring structure that provides a mounting surface for the end brackets and serves as a return path for the magnetic flux that passes from the field poles to the armature. The frame size is shown on the price pages for each horsepower rating and speed. Please identify the frame size if your customer requires a specific size. Otherwise, the horsepower and modification requirements will dictate the size of the frame.

FREQUENCY
Number of periodic cycles per unit of time.

FULL WAVE POWER CONVERTER
SCR rectifier which rectifies both the positive and the negative half cycles of an AC supply.

GENERATOR
An electrical machine which converts rotary power into electrical power.

HORSEPOWER/KW
Unit of measuring the amount of work done in a given amount of time. State the horsepower of the unit required. If your customer gives you his requirements in KW, please identify it as such. 1 KW is equal to 1000 watts; I horsepower is equal to 746 watts.

INTERPOLE
A winding in series with the armature in a DC motor positioned to reduce arcing at commutation. Also called “commutating pole”.

MOTOR
An electrical machine which converts electrical power to mechanical power.

MOTOR-GENERATOR (MG) SET
Any paired combination of a motor and a generator used to develop a controlled supply voltage.

MOTOR MOUNTED BLOWER
A blower is used to provide continuous cooling to a DC motor during operation. The use of a blower on dripproof motors will permit continuous constant torque operation over a wide speed range. Operation with reversing cycles or other severe duty cycles is also possible as the full amount of cooling air is available at all speeds.

SILICON CONTROLLED RECTIFIER (SCR)
Solid state device that blocks current in the reverse direction, and only passes current in the forward when the gate electrode is excited with a signal.

SPECIAL REGULATION
Tachometers are available for special regulation of speed. Indicate the percent accuracy required at no load and at full load when ordering.

TACHOMETERS
Several types of tachometers are available for use with standard DC motors, including AC tachs, DC tachs, tach generators, and pulse generators. Where special tachometer requirements are necessary, refer all details to the company.

TOP SPEED
The top speed of a DC motor is the maximum speed a motor will develop with increased armature or field voltage.

TORQUE
The turning force that tends to produce rotation on a shaft.

TYPE OF WINDING
Types of windings available include shunt, compound, and series.

TYPE OF RECTIFIED POWER
DC motors can be operated on various types of rectified power supplies. Identify the power code that the motor will be used on. USEM's DC motors are suitable for use on power codes A, C, or D. Derating may be required for use on other power supplies.

QUIZ ANSWERS

DC MOTOR FUNDAMENTALS

1. A motor is a device that converts electric power to mechanical power. It is also known as a torque producing device.
2. Electromagnets are the same as magnets except that they only have magnetic properties when electric power is applied to the coil.
3. The six components of a DC motor are: the motor frame, end bells, armature, field coil and pole assemblies, interpole coils, and brush rigging.
4. To accommodate and support the armature coils.
5. Carbon, carbon graphite, or a carbon filled graphite mixture.
6. The commutator.
7. A turning force that tends to produce shaft rotation.
8. Speed variation and torque.

DC MOTOR APPLICATION CONSIDERATIONS

1. An electronic drive.
2. False.
3. Power Code A and Power Code K.
4. False.
5. Series wound.
6. Permanent magnet.
7. Shunt field control.
8. True.
9. Dripproof Fully Guarded Blower Ventilated (DPBV).
10. Totally Enclosed Separately Ventilated (TEPV or TESV).
11. True.
12. False.
13. Metal dust, carborundum, carbon and salt.
14. Yes. 3% per 1000 feet above 3300 feet.
15. A break in the stator circuit; armature short circuit or continutator short-circuit.

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REGIONAL OFFICES	PHONE	FAX
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