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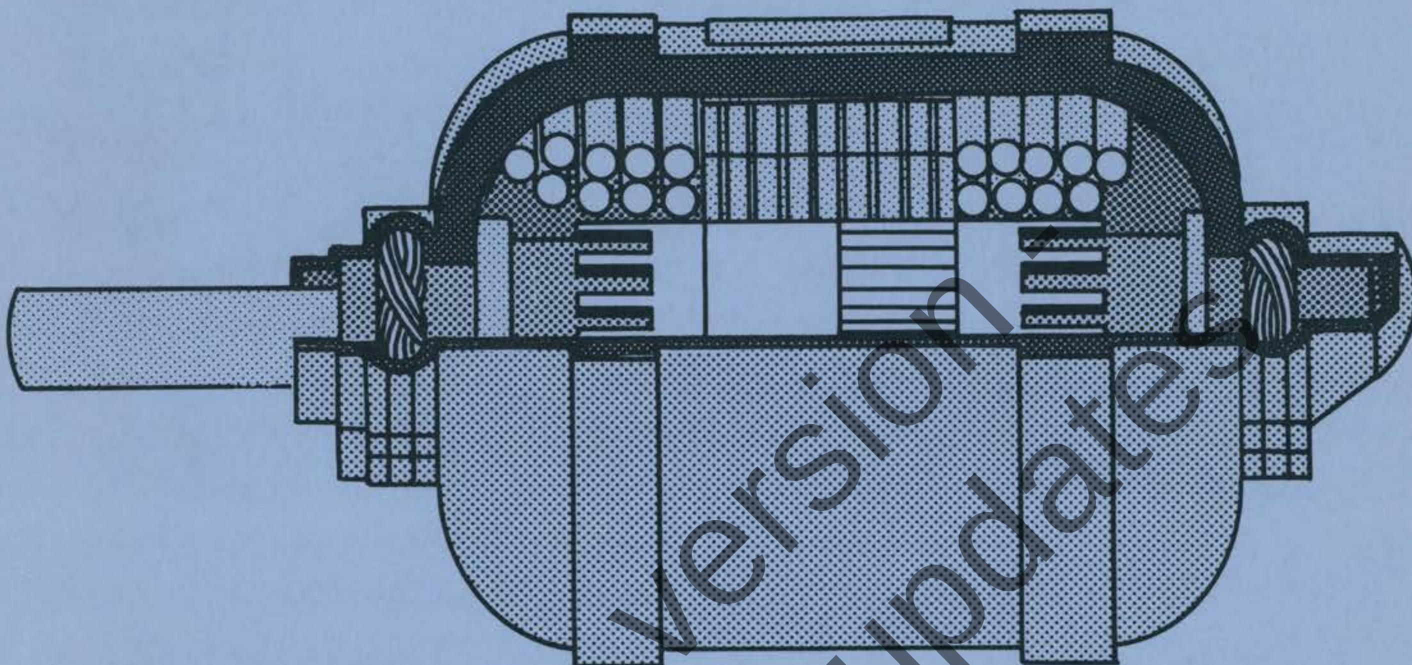
Electric Motor Selection



Missouri Farm Electrification Council, Inc.
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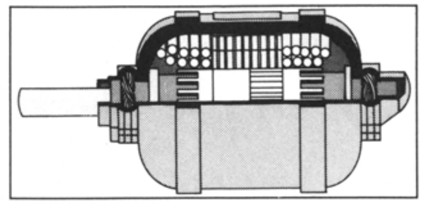
MISSOURI FARM ELECTRIFICATION COUNCIL, INC.
ELECTRIC POWER SUPPLIERS COOPERATING WITH
THE DEPARTMENT OF AGRICULTURAL ENGINEERING

UNIVERSITY OF MISSOURI-COLUMBIA
Department of Agricultural Engineering

Electric Motor Selection



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Written by

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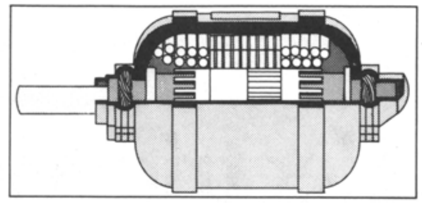
Professional Engineer

Electric Motor Selection



Electric motors are used for a multitude of tasks. The use of this equipment has relieved us from tedious and time-consuming chores. For example, a 1 horsepower (HP) motor that is about 75 percent efficient will consume approximately 1,000 watts. Thus, a general rule for electric motors is 1 horsepower-hour equals 1 kilowatt-hour. One horsepower-hour is equivalent to one person working 10 hours. A 1 HP motor can do in one hour for about 6¢ what it would take a person about 10 hours to do. Electric motors will continue to be used for new jobs around the farm as long as the price and scarcity of labor continue to increase.

Once you determine that a motor is required for a particular task, you must decide on one of a variety of types, classes, efficiencies, and makes. This booklet provides an explanation of the various terms used and compares different electric motors.

Determining motor requirements

HP and RPM. The type of work to be performed by the electric motor usually dictates requirements for an electric motor. A given application will necessitate a certain amount of horsepower delivered at a given RPM. These values are usually obtained from the manufacturer's data or from tables or curves from government and extension publications (for example, MWPS, S&E Handbook).

Phase and voltage. The electrical service will usually dictate the required voltage and the number of phases available for the motor. If questions arise about the availability of three-phase power or transformer capacity, the power supplier will be able to provide information and a cost estimate for upgrading the service.

Duty rating. Duty rating concerns the durability designed into the motor and is very important. Motors are designed for either *continuous* or *limited* duty. Continuous-duty motors deliver rated horsepower for an indefinite period of time without overheating. On the other hand, limited-duty motors deliver rated horsepower for a specified period of time before overheating and will burn out if continuously operated at rated load. A general purpose motor should always be a continuous-duty type.

Special purpose motors are designed for a particular job and must be selected for a duty cycle longer than the job normally requires. For example, a job requires 7 minutes, so a motor with a 10-minute duty cycle would be acceptable if the off period will last at least 10 minutes.

Enclosure. The environment and space that the motor will operate in must be carefully considered. Figure 1 shows the standard NEMA motor frame dimension used by domestic suppliers. Selecting the proper motor enclosure will not only result in a longer lasting motor but will also insure safety in hazardous locations. The most common classifications are

- **Dripproof (DP).** Ventilation openings in end shields and shell placed so drops of liquid falling within an angle of 15 degrees from vertical will not affect performance. Usually used indoors, in fairly clean locations.
- **Splashproof (SP).** Ventilation openings in end shield and shell placed so liquid or solids falling directly or within an angle of 100 degrees from vertical will not affect performance.
- **Totally enclosed.** No ventilation openings in motor housing (but not airtight). Used in locations which are dirty, damp, oily, etc.
- **Totally enclosed, fan-cooled (TEFC).** Includes an external fan in a protective shroud to blow cooling air over the motor.
- **Totally enclosed, non-ventilated (TCNV).** Not equipped with an external cooling fan. Depends on convection air for cooling or an air flow from a driven device.
- **Explosion-proof (EX PRF).** A totally enclosed motor designed to withstand an internal explosion of specified gases or vapors and not allow the internal flame or explosion to escape. EX PRF motors are further classified into different classes based on the particular hazard.

Temperature rise and insulation class. Temperature rise

Electric Motor Selection

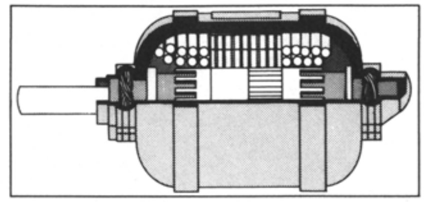
Figure 1. NEMA (National Electrical Manufacturers' Association) Motor Frame Dimensions.

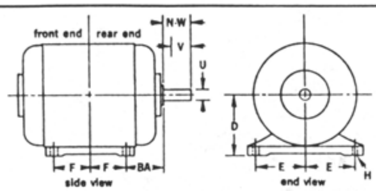
Standardized motor dimensions as established by the National Electrical Manufacturers Association (NEMA) are tabulated below and apply to all base-mounted motors listed herein which carry a NEMA frame designation.

This information is reproduced with the permission of the National Electrical Manufacturers Association from NEMA Standards Publication No. MG. 1-1978, *Motors and Generators,* 1982.

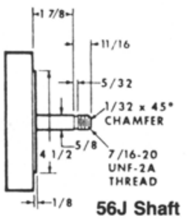
NEMA	—All Dimensions in Inches—							V(§)	Key			NEMA
FRAME	D(*)	2E	2F	BA	H	N-W	U	Min.	Wide	Thick	Long	FRAME
42	2 5/8	3 1/2	1 11/16	2 1/16	9/32 slot	1 1/8	3/8	—	—	3/64 flat	—	**42**
48	3	4 1/4	2 3/4	2 1/2	11/32 slot	1 1/2	1/2	—	—	3/64 flat	—	**48**
56	3 1/2	4 7/8	3	2 3/4	1/32 slot	1 7/8(†)	5/8(†)	—	3/16(†)	3/16(†)	1 3/8(†)	**56**
56H			3&5(‡)									**56H**
56HZ	3 1/2	**	**	**	**	2 1/4	7/8	2	3/16	3/16	1 3/8	**56HZ**
66	4 1/8	5 7/8	5	3 1/8	13/32 slot	2 1/4	3/4	—	3/16	3/16	1 7/8	**66**
143T			4									**143T**
145T	3 1/2	5 1/2	5	2 1/4	11/32 dia.	2 1/4	7/8	2	3/16	3/16	1 3/8	**145T**
182			4 1/2			2 1/4	7/8	2	3/16	3/16	1 3/8	**182**
184			5 1/2									**184**
	4 1/2	7 1/2		2 3/4	13/32 dia.							
182T			4 1/2									**182T**
184T			5 1/2			2 3/4	1 1/8	2 1/2	1/4	1/4	1 3/4	**184T**
203#			5 1/2									**203#**
	5	8		3 1/8	13/32 dia.	2 1/4	3/4	2	3/16	3/16	1 3/8	
204#			6 1/2									**204#**
213			5 1/2			3	1 1/8	2 3/4	1/4	1/4	2	**213**
215			7									**215**
	5 1/4	8 1/2		3 1/2	13/32 dia.							
213T			5 1/2									**213T**
215T			7			3 3/8	1 3/8	3 1/8	5/16	5/16	2 3/8	**215T**
224#			6 3/4									**224#**
225#	5 1/2	9	7 1/2	3 1/2	13/32 dia.	3	1	2 3/4	1/4	1/4	2	**225#**
254#	6 1/4	10	8 1/4	4 1/4	21/32 dia.	3 3/8	1 1/8	3 1/8	1/4	1/4	2 3/8	**254#**
254U			8 1/4			3 3/4	1 3/8	3 1/2	5/16	5/16	2 3/4	**254U**
256U			10									**256U**
	6 1/4	10		4 1/4	17/32 dia.							
254T			8 1/4									**254T**
256T			10			4	1 5/8	3 3/4	3/8	3/8	2 7/8	**256T**
284#	7	11	9 1/2	4 3/4	21/32 dia.	3 3/4	1 1/4	3 1/2	1/4	1/4	2 3/4	**284#**
284U			9 1/2									**284U**
286U			11			4 7/8	1 5/8	4 5/8	3/8	3/8	3 3/4	**286U**
	7	11	9 1/2	4 3/4	17/32 dia.							
284T			11			4 5/8	1 7/8	4 3/4	1/2	1/2	3 1/4	**284T**
286T												**286T**
324#			10 1/2									**324#**
326#	8	12 1/2	12	5 1/4	21/32 dia.	4 7/8	1 5/8	4 5/8	3/8	3/8	3 3/4	**326#**
324U												**324U**
326U			10 1/2			5 5/8	1 7/8	5 3/8	1/2	1/2	4 1/4	**326U**
			12									
324T	8	12 1/2	10 1/2	5 1/4	21/32 dia.							**324T**
326T			12			5 1/4	2 1/8	5	1/2	1/2	3 7/8	**326T**
326TS			12			3 3/4(ø)	1 7/8(ø)	3 1/2(ø)	1/2	1/2	2(ø)	**326TS**
364#			11 1/4			5 5/8	1 7/8	5 3/8	1/2	1/2	4 1/4	**364#**
364S#	9	14	11 1/4	5 7/8	21/32 dia.	3 1/4	1 5/8	3	3/8	3/8	1 7/8	**364S#**
365#			12 1/4			5 5/8	1 7/8	5 3/8	1/2	1/2	4 1/4	**365#**
364U	9	14	11 1/4	5 7/8	21/32 dia.	6 3/8	2 1/8	6 1/8	1/2	1/2	5	**364U**
365U			12 1/4									**365U**

(*) Dimension D will never be greater than the above values on rigid mount motors, but it may be less so that shims up to 1/32″ thick (1/16″ on 364U and 365U frames) may be required for certain machines.
(‡) Dayton motors designated 56H have two sets of 2F mounting holes—3″ and 5″.
(ø) Standard short shaft for direct-drive applications.
(#) Discontinued NEMA frame.





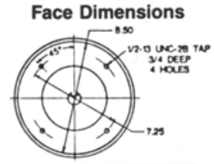
NEMA C and J-Face Mount Dimensions



56J Shaft

56C, 56J, 143TC and 145TC Face Dimensions

182TC thru 215TC Face Dimensions

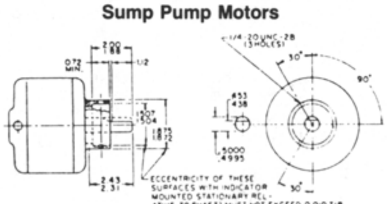


Mounting dimensions of the 56J face are exactly the same as the NEMA 56C, 143TC and 145TC faces.

56J face has a threaded shaft of stainless steel while all others have a keyed steel shaft. See illustrations and table at right for specifics.

NEMA Face	Dia. (U) — Shaft —	Long (N-W) — Shaft —	Type	Rabbet Diameter	Bolt Circle Diameter
56C	⅝"	1⅞"	Key	4½"	5⅞"
56J	⅝	2⅜	Thd	4½	5⅞
143TC & 145TC	⅞	2¼	Key	4½	5⅞
182TC & 184TC	1⅛	2¾	Key	8½	7¼
213TC & 215TC	1⅜	3⅜	Key	8½	7¼

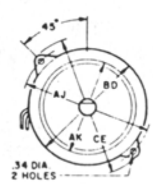
NEMA 48K and 56K Hub Dimensions Sump Pump Motors



NEMA 48M, 48N and 56N Flange Mount Dimensions

Oil Burner Motors

AJ	6¾"	7¼"
BD	6¼"	7" max.
AK	5½"	6⅜"
CE	7¾" max.	8¼" max.



NEMA Letter Designations Following Frame Number

C — Face mount; dimensions are shown above.

H — Has 2F dimension larger than same frame without H suffix.

J — Face mount to fit jet pumps; dimensions are shown above.

K — Has hub for sump pump mounting; dimensions are shown above.

M — Flange mount for oil burner; dimensions are shown above.

N — Flange mount for oil burner, dimensions are shown above.

T, U — Integral HP motor dimension standards set by NEMA in 1964 and 1963, respectively.

Y — Non-standard mounting; see manufacturer's drawing for mounting dimensions.

Z — Non-standard shaft extension (NW, U dimensions)

For their own identification, manufacturers may use a letter before the NEMA frame number. This has no reference to mounting dimensions.

(**) Base of Dayton 56HZ frame motors has holes and slots to match NEMA 56, 56H, 143T and 145T mounting dimensions.

(†) Certain NEMA 56Z frame motors have ½" dia. x 1½" long shaft with 3/32" flat. These exceptions are noted in this Motor Index.

(§) Dimension "V" is shaft length available for coupling, pinion or pulley hub—this is a minimum value.

is the extent (in numbers of degrees Celsius) which motor temperatures will exceed the surrounding air temperature at a rated load. A motor with continuous-duty rating and a 40 degrees C (72 degrees F) temperature rise is a good general purpose motor. It is capable of operating satisfactorily for an indefinite period of time. A manufacturer will also usually state the insulation class of a particular motor. This refers to the maximum operating temperature of the motor. For every 10 degrees a motor is operated above this rating, the insulation life is halved. The maximum operations temperatures for the insulation classes are

- Class A: 105 degrees C (221 degrees F)
- Class B: 130 degrees C (266 degrees F)
- Class F: 155 degrees C (311 degrees F)

Motor protection. Short circuit protection is usually incorporated in the feeder circuit through fuses or circuit breakers. Generally, however, they provide no motor overload protection. A *motor overload protection device* simulates the heating of the motor. If the motor exceeds a preset temperature, then the device opens the circuit. Overload devices can be located either in the motor itself or in the feed circuit. It is suggested that you purchase a *Manual Safety Overload Service* built within the motor. It will disconnect the motor when trouble develops. The motor cannot be put back into operation until the overload device is reset, thus eliminating any danger of start-up while you have your hands within the equipment. (**Note:** If the overload button continues to trip, check for low voltage or possible overload). *Automatic Overloads* can be built in a motor. However, once the Overload Device cools down it will place the equipment back on the power line. Automatic Overload Devices are normally for motors used on fans but are definitely not recommended for general purpose motors or motors for grain handling systems or pumps.

Motor types. When selecting an electric motor for a particular job, the type of load and how it is applied should be considered carefully. Some loads like a fan do not require a high starting torque. Figure 2 shows the common speed-torque terminology and relationships. Different motors vary in their torque-speed relationships. Breakdown torque is defined as the maximum torque developed when a motor is continuously loaded beyond full-load torque. This will occur at a specific shaft speed, and any loading beyond this point will cause the speed to decrease. When the motor is completely stopped, this is called locked rotor conditions. Break-away torque, locked rotor torque, and starting torque are used synonymously to describe the torque developed under these conditions. The current draw will be maximum at locked rotor conditions and is usually identified by manufacturers as starting current. For example, if a motor is susceptible to a momentary heavy load like a slurry pump or auger moving wet grain, it should have a high breakdown torque.

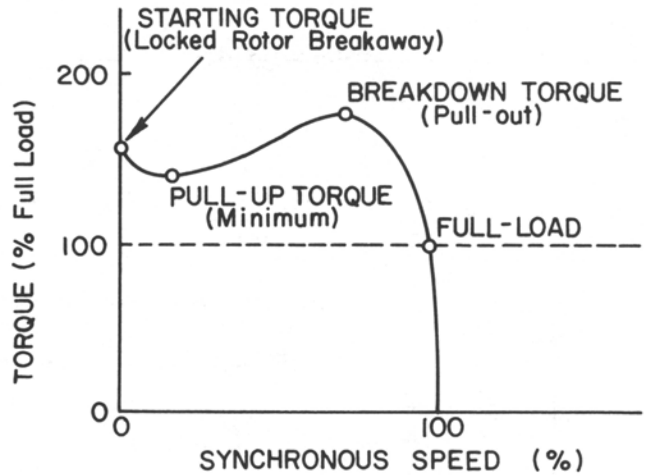


Figure 2. Speed-Torque Relationships.

Speed-torque relationships. When buying an electric motor, many manufacturers provide either some speed-torque information or list a NEMA (National Electrical Manufacturers Association) Design Standard. The load requirement should dictate the type of motor and the speed-torque relationship to use in making comparisons. Tables 1 and 2 illustrate the differences between the NEMA design classes for three phase motors and the different types of single-phase motors.

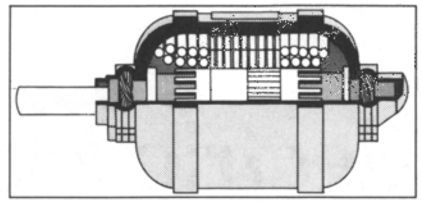
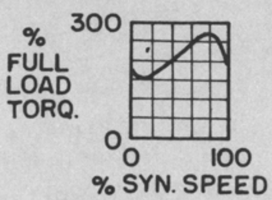
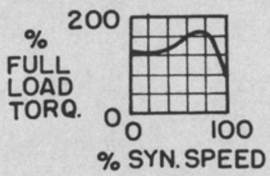
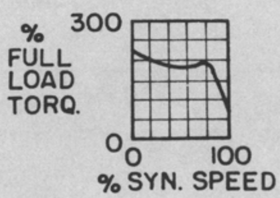
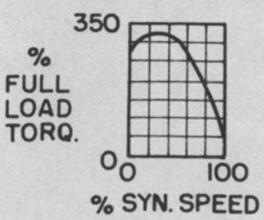


Table 1. NEMA Design Classes of Commonly Used 3-Phase Motors.

NEMA design		Starting torque (% of full load)	Breakdown/ pullup (% of full load)	Starting current (times full load current)	Description
A		150	275/200	6-10	Design A covers a wide variety of motors similar to Design B except that their breakdown torque and starting current are higher.
B		150	225/150	5	Design B Motors are the standard general purpose design. They have low starting current-normal torque and normal slip. Their field of application is very broad and includes fans, blowers, pumps, and machine tools.
C		200	240/180	3-5	Design C Motors have high breakaway torque, low starting current, and normal slip. The higher breakaway torque makes this motor advantageous for "hard-to-start" applications, such as plunger pumps, conveyors, and compressors.
D		275	—	—	Design D Motors have a high breakaway torque combined with high slip. Breakaway torque for 4, 6, and 8 pole motors is 275% or more of full load torque. Two slip groups are designated.

Electric Motor Selection

Table 2. Single-Phase Motor Characteristics.

Load type	Motor type	Size HP range	Typical uses	Starting torque	Starting current
Easy-Starting Loads	Shaded-pole induction	1/20-1/4	Small fans, freezer blowers, arc welders, hair dryers, small tool grinders	Very low 50-100%	Low
	Split-phase	1/20-3/4	Fans, furnace blowers, lathes, small shop tools, jet pumps	Low 100-150%	High 6 to 8 times running current
	Permanent-split, capacitor-induction	1/20 1	Air compressors, fans	Very low 50-100%	Low
	Soft-start	7½-50	Centrifugal pumps, crop dryer fans, feed grinder	Very low 50-100%	Low 2 to 2¼ times running current
Difficult Starting Loads	Capacitor-start, induction-run	1/6-10	Water systems, air compressors, ventilating fans, grinders, blowers	High 300-400%	Medium 3 to 6 times running current
	Repulsion-start, induction-run	1/6-20	Grinders, deep-well pumps, silo unloaders, grain conveyors, barn cleaners	High 400%	Low 2½ to 3 times running current

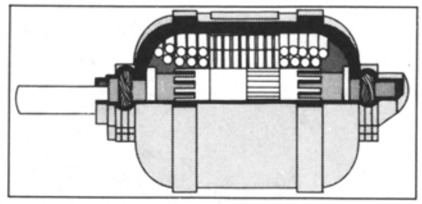


Table 2. Continued.

Load type	Motor type	Size HP range	Typical uses	Starting torque	Starting current
Difficult-Starting Loads	Capacitor-start, capacitor-run	½-25	Pumps, air compressors, drying fans, large conveyors, feed mills	High 350-450%	Medium 3 to 5 times running current
	Repulsion-start, capacitor-run	1-15	Conveyors, deep-well pump, feed mill, silo unloader	High 400%	Low 2½ to 3 times running current

Have all the requirements been satisfied?

Be sure that all the motors under consideration meet or exceed the requirements identified in the previous section. Compare the temperature and environmental conditions to each manufacturer's published statements. The speed-torque-current features of the motor should match or exceed the load requirements and your farmstead's capabilities. Use the **Qualifying Table** provided on this page and at the back of this booklet to make sure the motors meet the requirements.

Qualifying Table **Are these criteria satisfied? (yes/no)**

Motor	*HP*	*RPM*	*Voltage*	*Enclosure*	*Duty rating*	*Temperature rise*	*Motor protection*	*Speed-torque*
Requirements								
A								
B								
C								
D								

Electric Motor Selection

Making a selection

Once the motor requirements have been identified and the type or types of motors that can fulfill them have been identified, you can then choose among a range of possible selections. It is quite common for a manufacturer to have four or five motors in a given horsepower range, each with subtle differences. This section will help you select the best motor.

Service factor. Service factor is an inherent overload ability built into a motor to assure that motor operating temperatures stay within the safe limits for long motor insulation life. For example, if a ⅓ HP motor has a 1.0 S.F. (Service Factor), this means the maximum HP that this motor will produce is ⅓ HP. If you have a ⅓ HP motor with 1.35 S.F, this means the motor has a 35 percent more HP capability. It should be noted, however, that this applies only when the motor winding temperature does not exceed the maximum temperature for the insulation class. The service factor may not apply under conditions of poor ventilation, direct sunlight, high ambient temperature, or voltage imbalance.

Efficiency. Manufacturers from other countries do not use the same testing techniques for measuring efficiency; as a result, ratings stamped on the nameplate can be misleading.

The National Electrical Manufacturers' Association (NEMA) has recommended that U.S. manufacturers follow a standard procedure for measuring efficiency to assure that a comparison of motors will be meaningful. (IEEE Standard 112, Test Method B). Foreign manufacturers use different testing methods, which in most cases do not yield the same results as those obtained by measuring efficiencies in accordance with NEMA's recommendations because they do not include all of the losses. In fact, experience has shown that the three techniques most widely used by foreign manufacturers consistently over-state efficiencies. The three measurement techniques most often used by foreign manufacturers are the International, British and Japanese standards.

Theoretically, motor efficiency is defined as the work output divided by the energy input. There are, however, many different definitions of efficiency in use by domestic motor manufacturers. It is important that when comparing among different manufacturers that the same definition of efficiency be used. The three most commonly stated efficiencies are:

Table 3. NEMA Efficiency Marking Standard.

Index letter	Nominal efficiency	Minimum efficiency
A	—	>95.0
B	95.0	94.1
C	94.1	93.0
D	93.0	91.7
E	91.7	90.2
F	90.2	88.5
G	88.5	86.5
H	86.5	84.0
K	84.0	81.5
L	81.5	78.5
M	78.5	75.5
N	75.5	72.0
P	72.0	68.0
R	68.0	64.0
S	64.0	59.5
T	59.5	55.0
U	55.0	50.5
V	50.5	46.0
W	—	<46.0

- **Average expected and nominal efficiency** mean approximately the same thing. The motor user can expect that a large number of the same motor model will meet the average value. However, individual motors can vary widely from the average. Therefore, average expected and nominal values should not be accepted as guaranteed values.
- **Minimum or expected minimum efficiency** are more clearly definitive. All motors should be equal to or higher than the value specified. However, there can still be some room for doubt. One motor manufacturer states that minimum means 95 percent of the motor

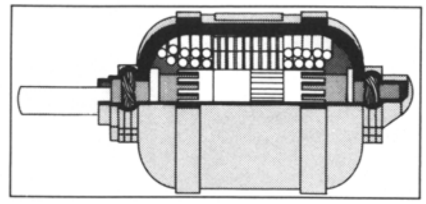


Figure 3. Calculating Savings and Payback.

$$S = 0.746 \times HP \times C \times N \; \frac{1}{E_B} - \frac{1}{E_A}$$

S = Savings/Yr
C = Energy Cost ($/kWh)
N = Hrs/Yr Running Time
E_A = Premium Motor Efficiency (decimal)
E_B = Standard Motor Efficiency (decimal)

Years for Payback = EMC/S

EMC = Extra motor cost for more expensive motor

will have efficiencies of at least the minimum value. Minimum efficiency can be calculated given nominal efficiency by

$$EFF_{min} = \frac{1}{1.2/EFF_{nom}-.2}$$

- **Apparent efficiency** is the product of the motor power factor and efficiency. A guaranteed apparent efficiency doesn't tell the motor user exactly what to expect since the power factor can be high and the efficiency low. Or the reverse can be true, as long as the product of the two meets the guaranteed value. Normally, this should never be used to compare motors. Only if the user is penalized for a low power factor by the power supplier does this enter into the selection criteria.

NEMA has adopted a standard marking system for motor nameplates and manufacturers published data. Table 3 illustrates the NEMA efficiency marking standard.

The real value in comparing efficiencies is that it indicates the amount of money that can be saved. Usually, a motor with a higher efficiency rating costs more. In this case, the buyer compares the energy savings with the higher purchasing costs. The equation in Figure 3 can be used to determine the annual savings and the simple payback.

Demand change and power factor. The amount of loading on the electric motor affects the efficiency and power factor. Figure 4 illustrates the typical relationships between efficiency and the power factor.

Power factor is a ratio for expressing what part of the consumed power is used efficiently.

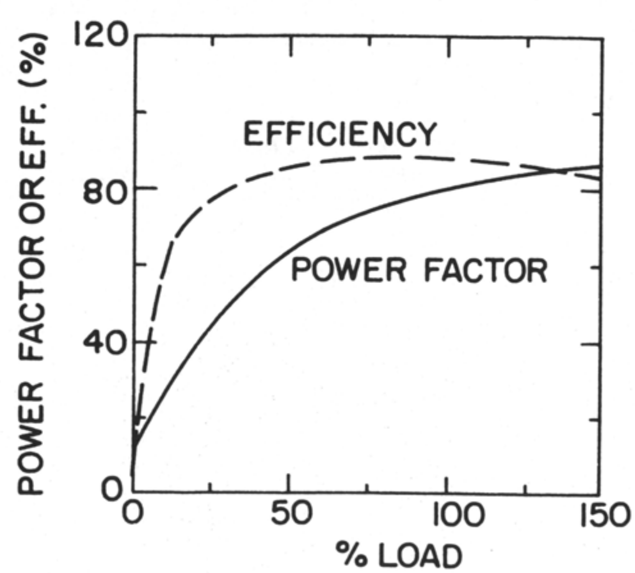
$$\text{Power Factor} = \frac{kW}{kV{\cdot}A}$$

At unity power factor, the kW and kV·A are equal. At any power factor other than unity (leading or lagging power factor), the kV·A are greater than the kW. When this is true, there is a reactive component of the total kV·A flowing in the circuit.

With a low-power factor load, the reactive component is larger, and thus, more kV·A capacity is required of the generator supplying the power. Power factor is particularly important for the larger services with metered demand, as a high power factor results in a lower demand.

Many non-residential electrical users are being placed on a demand metering schedule by their electrical power supplier. When buying large motors

Figure 4. Relationships of Efficiency and Power Factor



or when the total connected horsepower load is large, the demand charges may become a serious economic factor. Demand is usually metered in kV·A. When a motor is operating at full load the following formula assists in determining the increase in demand due to addition of another motor.

$$\text{Demand in kV·A} = \frac{\text{HP x .746}}{\text{Efficiency x Power factor}}$$

(Efficiency expressed as a decimal.)

Tabulating the possibilities

The following tables have been provided to help the purchaser evaluate the possibilities. The **Comparison Table** will be easier to use if the cheapest motor is listed first and the least efficient motor (if different from the first) is listed second.

Qualifying Table **Are these criteria satisfied? (yes/no)**

Motor	*HP*	*RPM*	*Voltage*	*Enclosure*	*Duty rating*	*Temperature rise*	*Motor protection*	*Speed-torque*
Requirements								
A								
B								
C								
D								

Comparison Table

Motor	*Service factor*	*Power factor*	*kV·A demand*	*Efficiency*	*Savings*	*Initial cost*	*Payback*
A							
B							
C							
D							

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