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NEMA STANDARDS PUBLICATION

NEMA MG 10

ENERGY MANAGEMENT GUIDE FOR SELECTION AND USE OF POLYPHASE MOTORS

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NEMA Standards Publication MG 10-1994 (R1999)

Energy Management Guide for Selection and Use of Fixed Frequency Medium AC Squirrel-Cage Polyphase Induction Motors

Published by

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NEMA Standards Publication No. MG 10-1994

ENERGY MANAGEMENT GUIDE FOR SELECTION AND USE OF FIXED FREQUENCY MEDIUM AC SQUIRREL-CAGE POLYPHASE INDUCTION MOTORS

Published by

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Foreword

The Motor and Generator Section of NEMA published the first edition of MG 10 with the statement to periodically review the guide for the purpose of keeping it up to date with advancing technology. This edition, MG 10-1994, is the result of this commitment to address the requirements of the U.S. Energy Policy Act of 1992, and includes guidance for the application of the new Design E Motor.

The goal of this guide is to assist the reader in the choice of equipment for his application.

The practice of periodically reviewing and updating the guide will be continued. Comments on the guide from readers are welcomed and should be addressed to:

Vice President, Engineering Department
National Electrical Manufacturers Association
2101 L Street, N.W.
Washington, DC 20037-1526

Scope

This energy management guide provides practical information concerning the proper selection and application of medium AC squirrel-cage polyphase induction motors including installation, operation, and maintenance in fixed frequency applications.

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Section 1
REFERENCES AND INTRODUCTION

1.1 REFERENCES

Canadian Standards Association
178 Rexdale Blvd.
Rexdale (Toronto), Ontario, Canada M9W 1R3

C390-93 *Energy Efficiency Test Methods for Three-Phase Induction Motors*

Institute of Electrical and Electronics Engineers (IEEE)
445 Hoes Lane
Piscataway, NJ 08855

112-1991 *Standard Test Procedure for Polyphase Induction Motors and Generators*

National Electrical Manufacturer's Association (NEMA)
2101 L Street, N.W., Suite 300
Washington, D.C. 20037

MG 1-1993 *Motors and Generators*

1.2 INTRODUCTION

The shortage and large cost increases of vital national energy resources has demonstrated the need to conserve such resources. In 1992 the Energy Policy Act mandated minimum levels of nominal efficiency which some classes of motors must meet after October 27, 1997. It is important that motor users and specifiers understand the selection, application, and maintenance of electric motors in order to improve the management of electrical energy consumption. Energy management as related to electric motors is the consideration of the factors that contribute to reducing the energy consumption of a total electric motor-driven equipment system. Among the factors to be considered are the motor design and application.

An electric motor is an energy converter, converting electrical energy to mechanical energy. For this reason, an electric motor should be considered as always being connected to a driven machine or apparatus, with specific operating characteristics, which dictate the starting and running load characteristics of the motor. Consequently, the selection of the motor most suitable for a particular application is based on many factors, including the requirements of the driven equipment (e.g., starting and acceleration, speed, load, duty cycle), service conditions, motor efficiency, motor power factor, and initial motor cost. These application factors often conflict with one another. The driven system efficiency is the combination of the efficiencies of all of the components in the system. In addition to the motor, these components include the driven equipment (such as fans, pumps and compressors) power transmission components (such as belts, pulleys, gears and clutches). Other components which are not a part of the driven system will affect the overall system efficiency; some of these are refrigerator and air conditioning evaporator and condenser coils, piping associated with pumps, ducts and baffles associated with fans and blowers, and motor controllers (ac variable speed drives and power factor controller).

Good energy management is the successful application of the motor controller , motor, and the driven components that results in the least consumption of energy. Since all motors do not have the same efficiency, careful consideration must be given to their selection and application.

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Section 2
SELECTION AND APPLICATION

2.1 GENERAL

2.1.1 Medium Motors

The NEMA Standards Publication MG 1 defines a medium machine as: (1) being built in three- or four-digit frame number series in accordance with MG 1, 11.01.2 (or equivalent for machines without feet); and (2) having a continuous rating up to and including the following.

Synchronous Speed, RPM	Horsepower
1201–3600	500
901–1200	350
721–900	250
601–720	200
515–600	150
451–514	125

2.1.2 Usual Service Conditions

The proper selection and application of fixed frequency medium AC squirrel-cage polyphase induction motors involves the consideration of many factors affecting installation, operation, and maintenance. The basic steps in selecting a motor consist of determining the power supply, horsepower rating, speed, duty cycle, motor type, and enclosure. In addition, environmental conditions, mounting, connections of the motor to the load, and mechanical accessories or modifications must be considered. Motors must also be properly selected with respect to the known service conditions, often referred to as usual and unusual, as defined in NEMA Standards Publication MG 1. Usual service conditions are considered to be:

a. Exposure to an ambient temperature within the range of -15°C to 40°C.

b. Exposure to an altitude which does not exceed 3300 feet (1000 meters).

c. Installation in areas or supplementary enclosures which do not seriously interfere with the ventilation of the machine.

d. Operation within a tolerance of ±10 percent of rated voltage.

e. Operation from a sine wave of voltage source (not to exceed 10 percent deviation factor).

f. Operation within a tolerance of ±5 percent of rated frequency.

g. Operation within a voltage unbalance of 1 percent or less.

Operation at other than usual service conditions may result in the consumption of additional energy.

2.2 POWER SUPPLY

2.2.1 Ratings

In general, induction motors are designed for a rated voltage, frequency, and number of phases. The supply voltage must be known in order to select the proper motor. For alternating-current motors, the motor nameplate voltage will normally be less than the nominal power system voltage as shown in the following table for three-phase, 60-hertz motors:

Nominal Power System Voltage, Volts	Motor Utilization (Nameplate) Voltage, Volts
120	115
208	200
240	230
480	460
600	575
2400	2300
4160	4000
6900	6600

2.2.2 Effects of Variation in Voltage and Frequency

Operation outside of the rated conditions of voltage and frequency may decrease both efficiency and power factor and may adversely affect other performance characteristics. The same condition is true when operating the motor on other than a sine wave of voltage. The effect of a variation in supply voltage, wave form, or frequency on the motor's efficiency and power factor characteristics depends on the individual motor design.

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2.2.3 Effects of Voltage Unbalance

A balanced voltage of the three-phase power supply to the motor is essential to the efficient operation of the system. For example, a voltage unbalance of 3.5 percent can increase motor losses by approximately 20 percent. For this reason, single-phase loads taken from a three-phase power supply should be carefully allocated so that the voltage unbalance will be kept as low as possible at the motor terminals.

2.3 EFFICIENCY

Motor efficiency is a measure of the effectiveness with which electrical energy is converted to mechanical energy, and is expressed as the ratio of power output to power input:

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} = \frac{\text{Output}}{\text{Output} + \text{Losses}}$$

Motor efficiencies are usually given for rated load, 3/4 load and 1/2 load.

The efficiency of a motor is primarily a function of load, horsepower rating, and speed, as indicated below:

a. A change in efficiency as a function of load is an inherent characteristic of motors, see Figure 2-1. Operation of the motor at loads substantially different from rated load may result in a change in motor efficiency.

b. Generally, the full load efficiency of motors increases as the motor horsepower rating increases, see Figure 2-1.

c. For the same horsepower rating, motors with higher speeds generally, but not necessarily, have a higher efficiency at rated load than motors with lower rated speeds. This does not imply, however, that all apparatus should be driven by high-speed motors. Where speed-changing mechanisms, such as pulleys or gears, are required to obtain the necessary lower speed, the additional power losses could reduce the efficiency of the system to a value lower than that provided by a direct-drive lower-speed motor.

A definite relationship exists between the slip and the efficiency of a polyphase induction motor, i.e., the higher the slip, the lower is the efficiency, for slip is a measure of the losses in the rotor winding. Slip of an induction motor

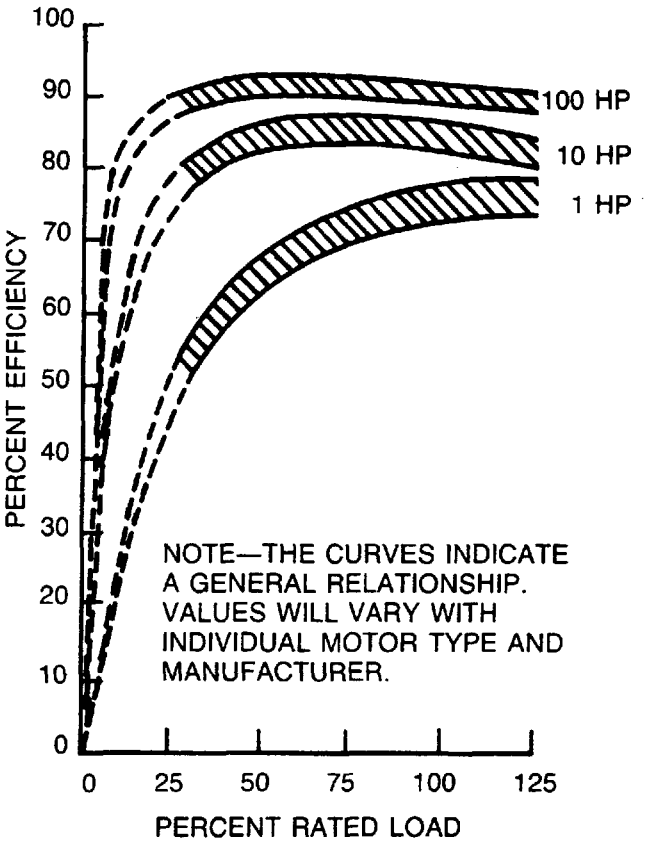


Figure 2-1
TYPICAL EFFICIENCY VERSUS LOAD CURVES FOR 1800-RPM THREE-PHASE 60-HERTZ DESIGN B SQUIRREL-CAGE INDUCTION MOTORS

is the difference between synchronous speed and full-load speed. Slip, expressed in percent, is the difference in speeds divided by the synchronous speed and multiplied by 100. Therefore, under steady load conditions, Design A, B, C, and E squirrel-cage induction motors having a slip of less than 5 percent are more efficient than Design D motors having a higher slip and should be used when permitted by the application (see Table 2-1). However, for applications involving pulsating inertia loads, such as punch press or oil well pumping, the overall efficiency of motors with high slip may be higher than that of motors having a slip of less than 5 percent. Additionally, high-slip motors may be necessary for applications requiring high starting (locked-rotor) torque.

If load permits, it may be possible to make a significant saving in energy by utilizing a multispeed motor operating

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when necessary. However, it should be noted that the efficiency of a multispeed motor at each operating speed is somewhat lower than that of a single-speed motor having a comparable rating. Single-winding multispeed motors are generally more efficient than two-winding multispeed motors.

Table 2-1
TYPICAL CHARACTERISTICS AND APPLICATIONS OF FIXED FREQUENCY MEDIUM AC POLYPHASE SQUIRREL-CAGE INDUCTION MOTORS

Classification	Locked Rotor Torque (Percent Rated Load Torque	Breakdown Torque (Percent Rated Load Torque)	Locked Rotor Current (Percent Rated Load Current)	Slip	Typical Applications	Relative Efficiency
Design B Normal locked rotor torque and normal locked rotor current	70–275*	175–300*	600–700	0.5–5%	Fans, blowers, centrifugal pumps and compressors, motor-generator sets, etc., where starting torque requirements are relatively low	Medium or High
Design C High locked rotor torque and normal locked rotor current	200–250*	190–225*	600–700	1–5%	Conveyors, crushers, stirring machines, agitators, reciprocating pumps and compressors, etc., where starting under load is required	Medium
Design D High locked rotor torque and and high slip	275	275	600–700	5–8%	High peak loads with or without flywheels such as punch presses, shears, elevators, extractors, winches, hoists, oil-well pumping and wire-drawing machines	Medium
Design E IEC 34-12 Design N locked rotor torques and current	75–190*	160–200*	800–1000	0.5–3%	Fans, blowers, centrifugal pumps and compressors, motor-generator sets, etc., where starting torque requirements are relatively low	High

Note —Design A motor performance characteristics are similar to those for Design B motors except that the locked-rotor starting current is higher than the values shown in the Table.

*Higher values are for motors having lower horsepower ratings.

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Motors which operate continuously or for long periods of time provide a significant opportunity for reducing energy consumption. Examples of such applications are processing machinery, air moving equipment, pumps, and many types of industrial equipment. A small change in motor efficiency will make a significant change in the total energy cost due to the lengthy operating time.

While many motors are operated continuously, some motors are used for very short periods of time and for a very low total number of hours per year. Examples of such applications are valve motors, dam gate operators, and industrial door openers. In these instances, a change in motor efficiency would not substantially change the total energy cost since very little total energy is involved.

A modest increase of a few percentage points in motor efficiency can represent a rather significant decrease in percentage of motor losses. For example, for the same output, an increase in efficiency from 75 to 78.9 percent, from 85 to 87.6 percent, or from 90 to 91.8 percent represents a 20 percent decrease in losses in each case.

2.3.1 Motor Losses

An electric motor converts electrical energy into mechanical energy and in so doing incurs losses which are generally described as follows:

a. Electrical (stator and rotor) losses (vary with load)–Current flowing through the motor windings produces losses which are proportional to the current squared times the winding resistance (FR).

b. Iron (core) losses (essentially independent of load)–These losses are confined mainly to the laminated core of the stator and rotor. The magnetic field, essential to the production of torque in the motor, causes hysteresis and eddy current losses.

c. Mechanical (friction and windage) losses (independent of load)–Mechanical losses occur in the bearings, fans, and seals of the motor. These losses are generally small in open, low speed motors, but may be appreciable in large, high-speed or totally enclosed fan-cooled motors.

d. Stray load losses–The additional fundamental and high-frequency losses in the iron; strand and circulating-current losses in the stator winding; and harmonic losses in the rotor conductors under load. These losses are assumed to be proportional to the torque squared.

Listed in Table 2-2 are the motor loss components, with the typical percent of the total motor losses they represent, and the design and construction factors which influence their magnitude.

In general, by increasing the active material in the motor, i.e., the type and quantity of conductors and magnetic materials, the losses can be reduced.

2.3.2 Variations in Motor Losses

In the manufacture of motors, there are periodic variations in the motor characteristics even in motors of duplicate design and repetitive manufacture. These are caused by normal variations in purchased raw materials such as copper and steel. In addition, there are variations caused by manufacturing processes and testing accuracy deviations. Thus in forecasting the efficiency of a given motor, one can speak of the nominal efficiency (the average efficiency of a population of motors of duplicate

Table 2-2
Motor Loss Components

	Typical Percent of Losses 4 Pole Motors	Factors Affecting These Losses
Stator Losses	35 to 40	Stator conductor size and material
Rotor Losses	15 to 20	Rotor conductor size and material
Core Losses	15 to 20	Type and quantity of magnetic material
Stray Load Losses	10 to 15	Primarily manufacturing and design methods
Friction and Windage	5 to 10	Selection/design of fans and bearings

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design), or the minimum efficiency (the level reached when both raw materials and manufacturing processes are at the least favorable end of their specified tolerances). Both of these values are of use to the prospective purchaser of a motor. The nominal efficiency should be used in estimating the power required to supply a number of motors. The minimum efficiency permits the motor user the assurance of having received the specified level of performance. Thus, the NEMA system of specifying efficiency is required to include both values.

2.3.3 Efficiency Testing Methods

There are a number of test methods for determining motor efficiency. The standard method for testing induction machines in the United States is IEEE Standard 112, which recognizes several methods for determining motor efficiency, each of which has certain advantages as to accuracy, cost, and ease of testing, depending primarily on motor rating. The common practice for 1 to 500 horsepower is to test the motor with a load absorption device, called a dynamometer, and to carefully measure the power input and output to determine loss components and thus efficiency. This is IEEE 112— Method B and forms the basis of determining the NEMA nominal efficiency. In Canada the equivalent testing method is Method 1, as described in Canadian Standards Association Standard C390.

2.3.4 Testing Variations

Even with the use of a consistent and accurate efficiency test method, variations in results do occur, primarily due to test equipment and instrument characteristics, and in the case of non-automated testing, personnel factors.

IEEE 112 — Method B includes a defined calculation procedure for segregating the various types of losses from the raw data and smoothing the stray-load loss by linear regression analysis. This can reduce the effect of errors introduced in making measurements over the range of loads from 25 percent to 150 percent of rated full load.

Standardization of the test procedures and adherence to laboratory quality control standards through a national laboratory accreditation program can further assist in minimizing variations in results which occur when a motor is tested at different facilities.

2.3.5 Manufacturing Variations

All manufactured products are subject to variances associated with materials and manufacturing methods. No two products will perform exactly the same, even though they are of the same design and produced on the same assembly line.

This is also true for electric motors. Product variances in materials, such as steel used for laminations in the stator and rotor cores, will lead to variances in electromagnetic properties and ultimately affect losses and motor efficiency. Using a 10 horsepower motor as an example, a 10 percent increase in iron loss (300 to 330 watts), which is within the tolerance offered by steel suppliers, would increase total motor losses from 1167 to 1197 watts and reduce efficiency from 86.5 to 86.2 percent.

Variances also occur as the result of manufacturing process limitations. There is an economic limit to the practical dimensional tolerances on motor parts. Combinations of mating parts contribute to dimensional variations, such as the size of the air gap, which cause variations in stray load loss and hence motor efficiency.

2.3.6 NEMA Standards on Efficiency Nomenclature and Labeling

NEMA Standards Publication MG 1, 12.58 defines efficiency nomenclature and labeling for polyphase induction motors 1 to 500 horsepower. This standard establishes a table of efficiencies defined by a nominal and minimum numeric full load efficiency value.

The NEMA nominal efficiency is defined as the average efficiency of a large population of motors of the same design. The spread between nominal efficiencies in the table is based on increments of 10 percent losses. The spread between the nominal efficiency and the associated minimum is based on an increment of 20 percent losses, reflected in variations in efficiency from testing, manufacturing and materials.

Nominal Efficiency		Minimum Efficiency
93.6	— 20% Greater Losses —>	92.4
	10 % Greater Losses	
93.0		

The motor nameplate efficiency marking is selected from the table of nominal efficiencies (Table 12-8 in MG 1) and represents the average efficiency of a population of motors as determined by the previously defined testing method. The use of a series of defined values for labeling was selected to avoid the inference of unrealistic accuracy that might be assumed from an infinite number of nominal efficiency values.

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NEMA Standards Publication MG 1 requires that all polyphase squirrel-cage integral horsepower motors, 1 to 500 horsepower, designated as Design A and B (and equivalent Design C and E ratings) shall have the NEMA nominal efficiency value on the nameplate.

With this carefully defined data in accordance with NEMA Standards, a motor purchaser or user can determine the relative efficiencies and resultant economics of alternate motors. This data allows a common basis for comparison of the alternative motors available, and in conjunction with other motor application information it may be utilized to compute relative energy and energy cost savings.

2.4 EVALUATION OF EFFICIENCY ECONOMICS

In order to obtain accurate results during the economic evaluation process, it is extremely important that only efficiencies determined by the same method are compared. There are a number of ways to evaluate the economic impact of motor efficiency. Two of these methods are simple payback analysis and present worth life cycle analysis. A third method, not detailed here, is the cash flow and payback analysis. This method considers motor cost premium, motor depreciation life, energy cost and energy cost inflation rate, corporate tax rate, tax credit, and the motor operating parameters covered in the simple payback analysis. Details of this method are explained in current financial management texts.

2.4.1 Simple Payback Analysis

The simple payback method gives the number of years required to recover the differential investment for higher efficiency motors. To determine the payback period, the premium for the higher efficiency motor is divided by the annual savings. First, the annual savings must be determined using the following formula:

$$S = 0.746 \times HP \times L \times C \times N \left(\frac{100}{E_B} - \frac{100}{E_A} \right)$$

Where:

S = Annual dollar savings
HP = Horsepower
L = Percentage load ÷ 100
C = Energy cost in dollars per kilowatt hour
N = Annual hours of operation
E_B = Lower motor efficiency
E_A = Higher motor efficiency

The efficiencies for the percent load at which the motor will be operated must be used, since motor efficiency varies with load.

Then, the motor cost premium is divided by the annual savings to compute the payback period for the higher efficiency motor. If motor A costs $300 more than motor B and yields annual savings of $100, the simple payback period is $300/$100 or 3 years. The $100 payback method is easy to apply but ignores savings occurring after the end of the payback period and does not consider the time value of money or changes in energy costs.

2.4.2 Present Worth Life Cycle Analysis

For greater precision, the present worth method of life cycle savings may be employed. This method considers both the time value of money and energy cost inflation. First, the user will determine the required internal rate of return and expected energy cost inflation. Then, the effective interest rate can be determined using the following formula:

$$i = \frac{100 + R_2}{100 + R_1} - 1$$

Where:

i = Effective percent interest rate ÷ 100
R_1 = Expected annual rate of energy cost inflation
R_2 = Required internal rate of return on investments

The next step is to determine present worth by inserting the effective interest rate into the basic formula for the present value of an annuity.

$$PW = \frac{(1 + i)^n - 1}{i\,(1 + i)^n}$$

Where:

PW = Present worth
n = Expected operating lifetime of the motor

Once PW is solved, the present worth evaluation factor (PWEF) can be calculated.

PWEF (dollars per kilowatt) = C x N x PW

Where:

C = Energy cost in dollars per kilowatt hour
N = Annual hours of operation
PW = Present worth

Finally, the present worth of the life cycle savings resulting from the higher efficiency motor can be computed:

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Present worth of savings =

$$0.746 \times HP \times PWEF \left(\frac{100}{E_B} - \frac{100}{E_A}\right)$$

HP = Horsepower
E_B = Lower motor efficiency
E_A = Higher motor efficiency

The present worth of savings due to the investment is the basis on which the investment decision is made.

Sample Calculation

Given: 100 HP Motor A 95% efficient
100 HP Motor B 92% efficient
Assumed: $0.06 Kw•hr
9% inflation of energy costs
35% Return on Investment
8 year Expected life
4000 hr/yr (2 shift 5 day/wk)

$$i = \left(\frac{135}{109} - 1\right) = 0.238$$

$$PW = \frac{1.238^{8} - 1}{0.238 \times 1.238^{8}} = 3.440$$

$$PWEF = 0.060 \times 4000 \times 3.440 = 826$$

PW Saving:

$$0.746 \times 100 \times 826 \times \left(\frac{100}{92} - \frac{100}{95}\right) = \$2115$$

2.5 MOTOR SELECTION

2.5.1 Induction Motors

The selection of the induction motor required depends on the performance characteristics of the driven machine and these, in turn, determine the operating characteristics of the motor.

The following lists the types of motors and the machines on which they are typically applied:

a. Design A, B and E—Used on machines, such as most fans, blowers, centrifugal pumps, and compressors, requiring a relatively low starting torque followed by an increasing torque with increasing speed up to the full-load speed and torque. Design A and E motors have a higher locked rotor current than Design B motors.

b. Design C—Used on machines, such as reciprocating air compressors and conveyors, requiring relatively high starting torque which is normally greater than the torque required at full-load speed.

c. Design D—Used on machines which impose pulsating loads or require frequent starting of the motor, such as punch press, oil well pumping, and hoist applications.

A summary of characteristics, typical applications and relative efficiencies for several types of induction motors is given in Table 2-1. Figure 2-2 shows representative speed-torque curves for Design A, B, C, D, and E motors.

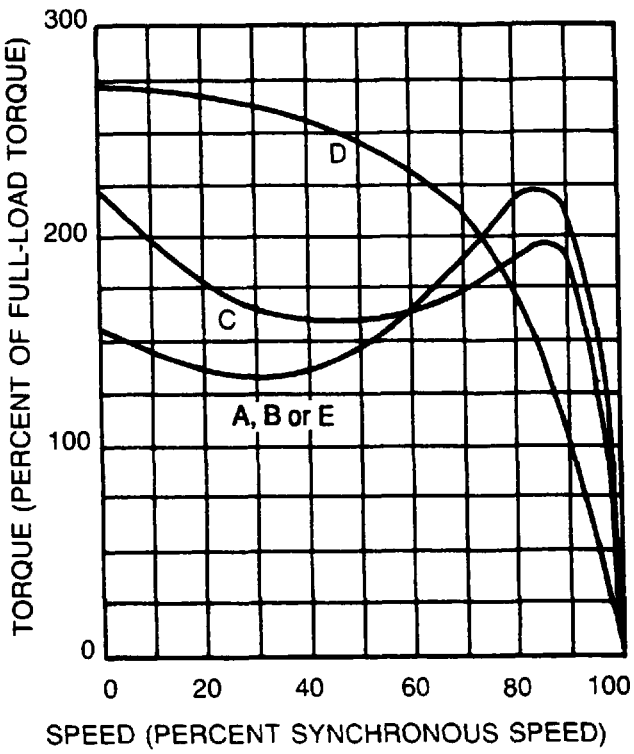


Figure 2-2
GENERAL SHAPE OF SPEED-TORQUE CURVES FOR MOTOR WITH NEMA DESIGN A, B, C, D AND E

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2.5.2 Multispeed Motors

Multispeed motors can be designed to have speed torque characteristics similar to those of Design A, B, C, D, or E motors of the equivalent rating. They can be designed for variable torque, constant torque or constant horsepower. For the highest efficiency, it is important to select the correct multispeed motor characteristic for the load at all operating speeds.

The following lists motor characteristics and the machines on which they are typically applied:

a. Variable-torque—Used on fans, centrifugal pumps, and compressors.
b. Constant-torque—Used on conveyors, positive displacement pumps, and compressors.
c. Constant-horsepower—Used on machine tools and winches.

2.6 POWER FACTOR

The connected motor load in a facility is usually a major factor in determining the system power factor. Low system power factor results in increased losses in the distribution system. Induction motors inherently cause a lagging system power factor.

The power factor of an induction motor decreases as the load decreases, as shown in Figure 2-3. Figure 2-4 indicates that rated load power factor increases with an increase in the horsepower rating of the motor. A number of induction motors, all operating at light load, can cause the electrical system to have a low power factor. The power factor of induction motors at rated load is less for low-speed motors than for high-speed motors as shown in Figure 2-4. A small increase in voltage (≤ 10 percent) above rated voltage will decrease the power factor, and a small decrease in voltage (≤ 10 percent) below rated voltage will improve the power factor of an induction motor. However, other performance characteristics may be adversely affected by such a change in voltage; and operation as close as possible to the nameplate voltage and horsepower rating is recommended.

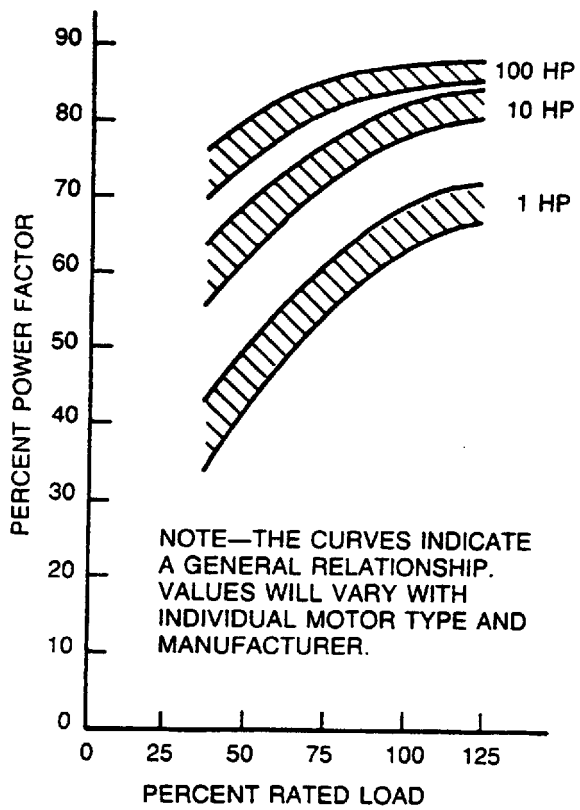


Figure 2-3
TYPICAL POWER FACTOR VERSUS LOAD CURVES FOR 1800-RPM THREE-PHASE 60-HERTZ DESIGN B SQUIRREL-CAGE INDUCTION MOTORS

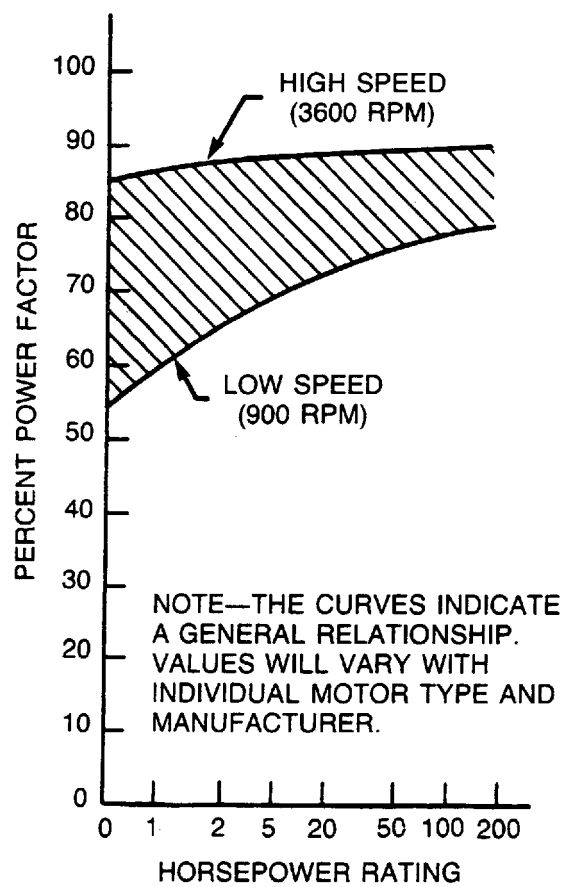


Figure 2-4
TYPICAL FULL-LOAD POWER FACTOR VERSUS HORSEPOWER RATING CURVES FOR THREE-PHASE 60-HERTZ DESIGN B SQUIRREL-CAGE INDUCTION MOTORS

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Power-factor-correction capacitors can be used to improve power factor of the electrical system. However, if they are used, they should be carefully selected and applied to avoid unsafe operating conditions. It is recommended that the motor manufacturer be consulted for the proper value of corrective capacitance.

An analysis of the electrical system will indicate whether improvement in the power factor is needed and whether capacitors, synchronous motors, or other corrective measures should be used.

2.7 APPLICATION ANALYSIS

When the device being driven by an electric motor is producing a relatively constant and continuous level of useful work, the primary motor selection concern is its rated load efficiency. However, many applications are cyclic in nature. In these cases specific application techniques can be used to obtain substantial energy savings.

Other applications require intermittent or continuous absorption of energy. Again, there are application techniques that will recover a significant percentage of the otherwise wasted energy.

A few of these cases are cited here to illustrate the technology that is available to the user. The motor manufacturer should be consulted to determine the most effective solution.

2.7.1 Applications Involving Load Cycling

Some applications require running at load for a period of time followed by a period during which no useful work is being done by the driven machine. In this case energy may be saved by stopping the motor and restarting it at the beginning of the next load period.

The following example illustrates the savings to be realized by start-stop cycling. This example assumes that the friction and windage loss of the driven machine is 2.5 HP.

Assumptions:

a. Motor rating ..... 10 HP
b. Motor full load efficiency 89.2%
c. Motor output with drive machine running idle ..... 2.5 HP
d. Motor efficiency at 2.5 HP 86%
e. Motor acceleration loss plus system stored energy ($Wk^2 = 1.4$ lb•ft^2) ..... 3750 watt-sec.
f. Driven machine is loaded for 15 minutes followed by a 15 minute idle period.
g. Utilization ..... 2000 hours per year
h. Cost of energy ..... $0.06 Kw•hr
i. Motor inertia ..... 0.7 lb•ft^2
j. Driven machine inertia ..... 0.7 lb•ft^2

Annual cost of energy if motor runs continuously:

a. Cost to run full load:

$$\$ = \frac{\text{RUN HOURS} \times \text{HP} \times .746 \times \$/\text{KW HR}}{\text{FL EFF}/100}$$

$$\$ = \frac{1000 \times 10 \times .746 \times .06}{.892} = 501$$

b. Cost to run driven machine idle:

$$\$ = \frac{1000 \times 2.5 \times .746 \times .06}{.86} = 130$$

Total Cost $ = 501 + 130 = $631

Annual cost of energy if motor is shut down after each load period:

a. Cost to run full load--same as above: $ = 501
b. Cost to restore system energy and to supply motor acceleration losses:

$$\$ = \frac{N_s \times J \times \$/\text{KW HR}}{1000 \times 60 \times 60}$$

Where:

N_s = number of starts per year
J = motor acceleration loss plus system stored energy in watt•sec.

$$\$ = \frac{4000 \times 3750 \times .06}{1000 \times 60 \times 60} = \$.25$$

Total Cost = 501 + .25 = $501.25

Energy savings per year - 631 - 501.25 - $129.75

When making a decision to stop a motor or to run at no load a number of factors must be considered; these include motor type, horsepower rating, speed, starting frequency, restrictions on inrush current, power demand charges, and the extra winding stress imposed by repeated accelerations and associated reduction in life expectancy.

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NEMA Standards Publication MG 1, 12.54 provides guidance on the number of successive starts (i.e. two starts from ambient or one start from rated load operating temperature), however, the information in MG 1, 12.54 is not applicable to repetitive start-run-stop-rest cycles resulting from energy management programs. Accordingly, Table 2-3 has been prepared as a guide to: (1) the minimum off time required to allow the motor to cool sufficiently to permit another start: (2) the maximum number of starts per hour (irrespective of load Wk^2) to minimize the effect of winding stress imposed by repeated starts; and (3) a means of adjusting the number of starts per hour as a function of the load inertia. It should be recognized that each start is one factor in the life expectancy and reliability of the motor, and, as a result, some reduction in life expectancy and reliability must be accepted when a motor is applied at the upper range of the starting duty determined by Table 2-3.

Example 1:

50 HP, 4 Pole, Design B motor directly connected to a pump with a Wk^2 of 20 lb•ft^2

From Table 2-3:

A = 6.8

B/Load Wk^2 = 232/20 = 11.6

Minimum off time = C = 72 seconds

The value of B/Load Wk^2 exceeds the maximum number of starts per hour. Therefore, the motor must be limited to the maximum of 6.8 starts per hour with a minimum off time between starts of 72 seconds.

Example 2:

25 HP, 2 pole, 3550 rpm, Design B motor belt connected to a 5000 rpm blower with a Wk^2 of 3.7 lb•ft^2

Load Wk^2 referred to motor shaft =

$$\left(\frac{5000}{3550}\right)^2 \times 3.7 = 7.34 \text{ lb} \bullet \text{ft}^2$$

From Table 2-3:

A = 4.4

B/Load Wk^2 = 26/7.34 = 3.5

Minimum off time = C = 115 seconds

The value of B/Load Wk^2 is less than the maximum number of starts per hour and therefore the motor must be limited to 3.5 starts per hour with a minimum off time between starts of 115 seconds.

2.7.2 Applications Involving Extended Periods Light Load Operation

A number of methods have been proposed to reduce the voltage applied to the motor in response to the applied load, the purpose of this being to reduce the magnetizing losses during periods when the full torque capability of the motor is not required. Typical of these devices is the power factor controller. The power factor controller is a device that adjusts the voltage applied to the motor to approximate a preset power factor.

These power factor controllers may, for example, be beneficial for use with small motors operating for extended periods of light loads where the magnetization losses are a relatively high percentage of the total loss. Care must be exercised in the application of these controllers. Savings are achieved only when the controlled motor is operated for extended periods at no load or light load.

Particular care must be taken when considering their use with other than small motors. A typical 10 horsepower motor will have idle losses in the order of 4 or 5 percent of the rated output. In this size range the magnetization losses that can be saved may not be equal to the losses caused by the distorted voltage wave form introduced by the controller.

2.7.3 Applications Involving Throttling or Bypass Control

Many pump and fan applications involve the control of flow or pressure by means of throttling or bypass devices. Throttling and bypass valves are in effect series and parallel power regulators that perform their function by dissipating the difference between source energy supplied and the desired sink energy.

These losses can be dramatically reduced by controlling the flow rate or pressure by controlling the speed of the pump or fan with a variable speed drive.

Figure 2-5 illustrates the energy saving potential of the application of variable speed drive to an application that traditionally uses throttling control. For additional information on adjustable speed motors see MG 1, Parts 14, 30, and 31.

A simplistic example will serve to illustrate the savings to be achieved by the use of this powerful energy conservation tool.

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Assumptions:

a. Line Power Required by Fan at full CFM without flow control device ..... 100 HP
b. Full CFM required ..... 1000 hours per year
c. 75% CFM required ..... 3000 hours per year
d. 50% CFM required ..... 2000 hours per year
e. Cost of energy ..... $0.06 per KW/HR

% Power consumption with various flow control methods per Figure 2-5.

Annual Cost of Energy:

$$\$ = \frac{(\text{HRS} \times \text{HP} \times 746 \times \%\ \text{ENERGY CONSUMPTION} \times \$/\text{KW} \bullet \text{HR})}{1000 \times 100}$$

Table 2-3
ALLOWABLE NUMBER OF STARTS AND MINIMUM TIME BETWEEN STARTS FOR DESIGN A AND DESIGN B MOTORS

HP	2 Pole			4 Pole			6 Pole		
	A	B	C	A	B	C	A	B	C
1	15	1.2	75	30	5.8	38	34	15	33
1.5	12.9	1.8	76	25.7	8.6	38	29.1	23	34
2	11.5	2.4	77	23	11	39	26.1	30	35
3	9.9	3.5	80	19.8	17	40	22.4	44	36
5	8.1	5.7	83	16.3	27	42	18.4	71	37
7.5	7.0	8.3	88	13.9	39	44	15.8	104	39
10	6.2	11	92	12.5	51	46	14.2	137	41
15	5.4	16	100	10.7	75	50	12.1	200	44
20	4.8	21	110	9.6	99	55	10.9	262	48
25	4.4	26	115	8.8	122	58	10.0	324	51
30	4.1	31	120	8.2	144	60	9.3	384	53
40	3.7	40	130	7.4	189	65	8.4	503	57
50	3.4	49	145	6.8	232	72	7.7	620	64
60	3.2	58	170	6.3	275	85	7.2	735	75
75	2.9	71	180	5.8	338	90	6.6	904	79
100	2.6	92	220	5.2	441	110	5.9	1181	97
125	2.4	113	275	4.8	542	140	5.4	1452	120
150	2.2	133	320	4.5	640	160	5.1	1719	140
200	2.0	172	600	4.0	831	300	4.5	2238	265
250	1.8	210	1000	3.7	1017	500	4.2	2744	440

Where:

A = Maximum number of starts per hour
B = Maximum product of starts per hour times load Wk^2
C = Minimum rest or off time in seconds between starts

Allowable starts per hour is the lesser of (1)A or (2)B divided by the load Wk^2 i.e.

$$\text{Starts per hour} \leq A \leq \frac{B}{\text{Load } Wk^2}$$

Note — Table 2-3 is based on following conditions:

a. Applied voltage and frequency in accordance with MG 1, 12.44.

b. During the accelerating period, the connected load torque is equal to or less than a torque which varies as the square of the speed and is equal to 100 percent of rated torque at rated speed.

c. External load Wk^2 equal to or less than the values listed in MG 1, 12.54.

For other conditions, the manufacturer should be consulted.

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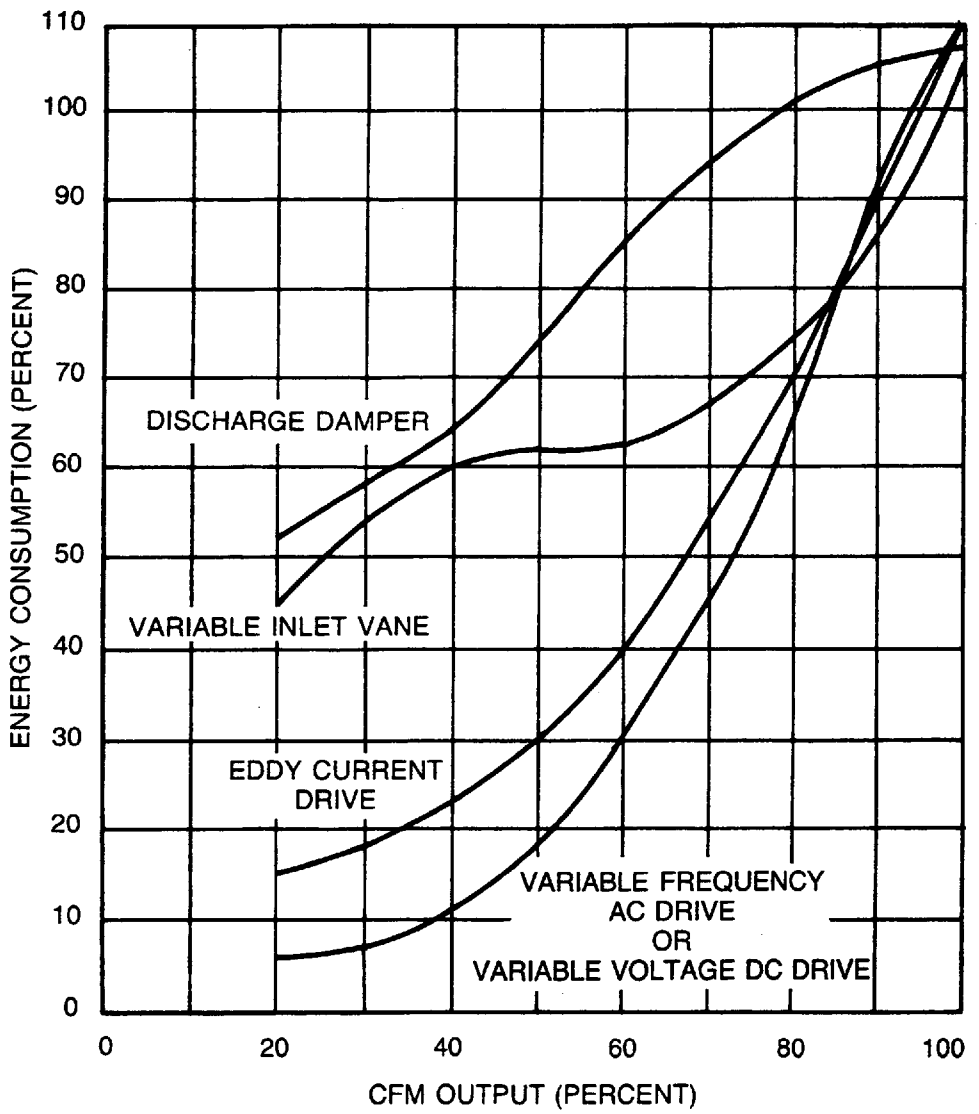


Figure 2-5
TYPICAL ENERGY CONSUMPTION OF A CENTRIFUGAL FAN SYSTEM WITH DISCHARGE DAMPER CONTROL, VARIABLE INLET VANE CONTROL, AND VARIABLE SPEED CONTROL WITH EDDY CURRENT AND VARIABLE FREQUENCY DRIVES

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Annual Cost of Energy Summary:

a. Discharge Damper $24,600
b. Variable Inlet Vane $19,600
c. Eddy Current Drive $15,900
d. Variable Frequency AC Drive or Variable Voltage DC Drive $13,900

2.7.4 Applications Involving Overhauling Loads

Overhauling loads typically result in energy waste if some form of dissipative braking is used. Examples of overhauling loads are: deceleration of high inertia loads, absorption test stands, unwind stands, web process stands, and downhill conveyors. In these cases energy can be saved by the use of regenerative devices.

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Section 3
MAINTENANCE

The electric motor generally needs little maintenance, therefore proper maintenance is often forgotten. There are a number of common abnormalities which have an adverse effect on a motor's performance:

a. Insufficient ventilation
b. High ambient temperatures
c. Mechanical misalignment
d. Improper V-belt application
e. Improper lubrication
f. Excessive moisture
g. Contamination
h. Sustained overload
i. Abnormal voltage

Insufficient ventilation or high ambient temperatures result in higher resistance in the winding. On the average, the efficiency of a motor will decay by 0.2 to 1.0 percentage points from room temperature to its operating temperature. Furthermore, excessive temperature rises caused by poor maintenance or misapplication reduces the operating life of the motor and increases energy consumption.

Sometimes additional friction gradually develops within the driven machine. This could be caused by a buildup of dust on a fan, the wearing of parts, misalignment of gears or belts, or insufficient lubrication in the driven machine. These conditions cause the driven machine to become less efficient, which reduces system efficiency and increases energy consumption. To assure continued efficient operation and long motor life, a regular schedule for inspecting motors and driven equipment should be established.

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