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

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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 evolving technology. MG 10-2013 is the result of this commitment to include typical characteristics of IEC Design H and N induction motors and information on the NEMA energy efficient and Premium efficiency motor standards.

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 from readers are welcomed and should be addressed to:

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Scope

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

Section 1
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 that some classes of motors were required to meet after October 27, 1997. As a result of market demand for standardization in the identification of motors having efficiency that exceeded the levels set by the Energy Policy Act, NEMA introduced the new Premium efficiency motor standard in June 2001.

In 2007 the U.S. Congress passed the Energy Independence and Security Act (EISA), increasing the level of the efficiency standards on existing covered electric motors and adding efficiency standards for additional types of electric motors manufactured on or after December 19, 2010. In February 2011 NEMA revised Premium efficiency motor tables for medium motors by adding efficiency values for 8-pole Premium efficiency motors.

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 factors that contribute to reducing the energy consumption of a total electric motor–driven 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 that 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) and power transmission components (such as belts, pulleys, gears and clutches). Other components that 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.

1.1 Referenced Standards

Canadian Standards Association
178 Rexdale Boulevard
Toronto, Ontario, Canada M9W 1R3

CSA C390-10 (R2015)	*Test methods, marking requirements, and energy efficiency levels for three-phase induction motors*

Institute of Electrical and Electronics Engineers (IEEE)[1]
445 and 501 Hoes Lane
Piscataway, NJ 08854-4141

IEEE Std 112-2011 *Standard Test Procedure for Polyphase Induction Motors and Generators*

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NEMA MG 1-2011 *Motors and Generators*

1.2 General

1.2.1 Medium Motors

The standards publication NEMA MG 1 *Motors and Generators* defines a medium machine as a machine: (1) built in three- or four-digit frame number series in accordance with MG 1-4.2.1 (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

1.2.2 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 *Motors and Generators*. 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 that does not exceed 3300 ft. (1000 m).

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

d) Operation within a tolerance of ±10%of rated voltage.

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

f) Operation within a tolerance of ±5%of rated frequency.

g) Operation within a voltage unbalance of 1% or less.

[1] Also available from ANSI.

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

1.3 Power Supply

1.3.1 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 ac motors, the motor rated voltage will normally be equal to the utilization voltage, which is less than the nominal power system voltage as shown in the following table for three-phase, 60 Hz motors.

Nominal Power System Voltage, V	Utilization Voltage, V
120	115
208	200
240	230
480	460
600	575
2400	2300
4160	4000
6900	6600

In situations where the available voltage is equal to the system voltage, the motor rated voltage should be chosen appropriately.

1.3.2 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.

1.3.3 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%can increase motor losses by approximately 20%. 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.

1.4 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:

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

Motor efficiencies are usually given for rated load, ¾ load and ½ 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 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 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.

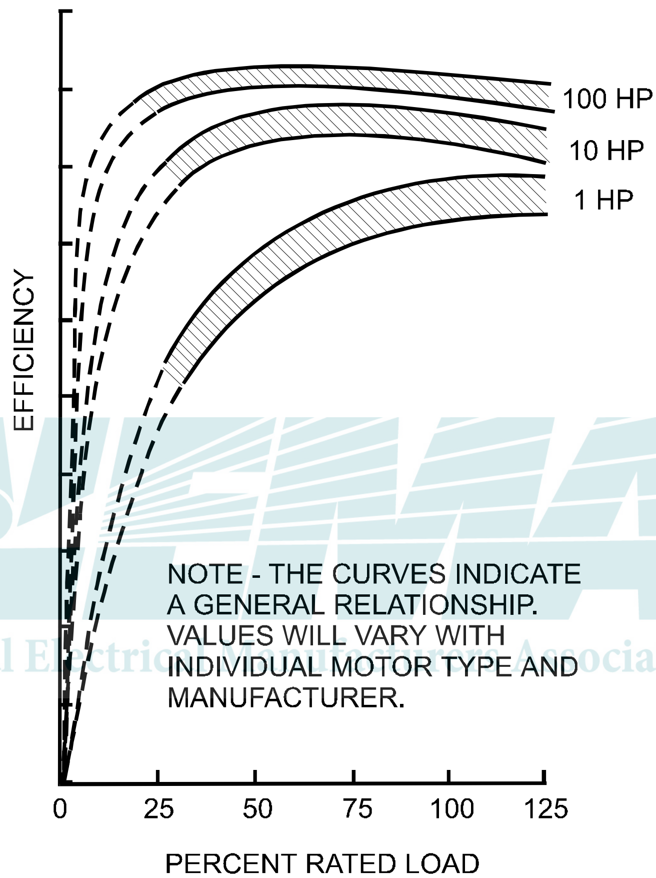

Figure 1
Typical Efficiency Versus Load Curves for 1800 RPM Three-Phase 60 HZ Design B Squirrel-Cage Induction Motors

A definite relationship exists between the slip and the efficiency of a polyphase induction motor, i.e., the higher the slip, the less the efficiency for slip is a measure of the losses in the rotor. Slip of an induction motor 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, NEMA Design A, B, and C, and IEC Design H and N squirrel-cage induction motors having a slip of less than 5% are more efficient than NEMA Design D motors having a higher slip and should be used when permitted by the application (see Table 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%. 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 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.

Motors that 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.

Table 1
Typical Characteristics and Applications of Fixed-Frequency Medium AC Squirrel-Cage Induction Motors

Polyphase Characteristics	Locked-Rotor Torque (Percent Rated Load Torque)	Pull-Up Torque (Percent Rated Load Torque)	Breakdown Torque (Percent Rated Load Torque)	Locked-Rotor Current (Percent Rated Load Current)	Slip	Typical Applications	Relative Efficiency
Design A Normal locked-rotor torque and high locked-rotor current	70–275*	65–190*	175–300*	Not Defined	0.5–5%	Fans, blowers, centrifugal pumps and compressors, motor-generator sets, etc., where starting torque requirements are relatively low	Medium or high
Design B Normal locked-rotor torque and normal locked-rotor current	70–275*	65–190*	175–300*	600–800	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	200–285*	140–195*	190–225*	600–800	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 high slip	275	Not Defined	275	600–800	≥5%	High peak loads with or without flywheels, such as punch presses, shears, elevators, extractors, winches, hoists, oil-well pumping and wire-drawing machines	Medium
IEC Design H High locked-rotor torque and high locked-rotor current	200–285*	140–195*	190–225*	800–1000	1–5%	Conveyors, crushers, stirring machines, agitators, reciprocating pumps and compressors, etc., where starting under load is required	Medium
IEC Design N Normal locked-rotor torque and high locked-rotor current	75–190*	60–140*	160–200*	800–1000	0.5–3%	Fans, blowers, centrifugal pumps and compressors, motor-generator sets, etc., where starting torque requirements are relatively low	Medium or high

Note: These typical characteristics represent common usage of the motors. For further details, consult the specific performance standards for the complete requirements.

*Higher values are for motors having lower horsepower ratings.

While many motors are operated continuously, some 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%, from 85% to 87.6%, or from 90% to 91.8% represents a 20% decrease in losses in each case.

1.4.1 Motor Losses

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

a) Electrical (stator and rotor) Losses (vary with load)—Current flowing through the motor windings produces losses that are proportional to the current squared times the winding resistance (I^2R).

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 below are the motor loss components, with the typical percent of the total motor losses they represent, and the design and construction factors that influence their magnitude.

Table 2
Motor Loss Components

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

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.

1.4.2 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 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 based on both values.

1.4.3 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 1–500 HP 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 it is the basis for determining the NEMA nominal efficiency. In Canada the equivalent testing method is Method 1, as described in Canadian Standards Association Standard C390.

1.4.4 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% to 150% of rated full load.

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

1.4.5 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 will affect losses and motor efficiency. Using a 10 HP motor as an example, a 10% increase in iron loss (300 to 330 W), which is within the tolerance offered by steel suppliers, would increase total motor losses from 1167 to 1197 W and reduce efficiency from 86.5% to 86.2%.

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.

1.4.6 NEMA Standards on Efficiency Nomenclature and Labeling

1.4.6.1 NEMA Nominal Efficiency and Minimum Efficiency

The variation in efficiency from one motor to another of the same design that might result from variations in material properties, manufacturing processes, and testing led to the development of the concept of the term “NEMA nominal efficiency” and an associated minimum efficiency. NEMA nominal efficiency is defined as the average efficiency of a large population of motors of the same design. The full-load efficiency of any motor in the population is to be not less than the associated minimum efficiency when the motor is operating at rated voltage and frequency.

NEMA MG 1-12.58 defines efficiency nomenclature and labeling for polyphase induction motors 1 to 500 horsepower. To avoid the inference of unrealistic accuracy that might be assumed from the use of an infinite number of nominal efficiency values, a standard set of values was selected for use in motor labeling. These values and associated minimums are shown in Table 3 (Table 12-10 of MG 1).

Table 3
Nema Nominal Efficiency and Associated Minimum Efficiency

Nominal Efficiency	Minimum Efficiency Based on 20% Loss Difference	Nominal Efficiency	Minimum Efficiency Based on 20% Loss Difference	Nominal Efficiency	Minimum Efficiency Based on 20% Loss Difference
99.0	98.8	94.1	93.0	72.0	68.0
98.9	98.7	93.6	92.4	70.0	66.0
98.8	98.6	93.0	91.7	68.0	64.0
98.7	98.5	92.4	91.0	66.0	62.0
98.6	98.4	91.7	90.2	64.0	59.5
98.5	98.2	91.0	89.5	62.0	57.5
98.4	98.0	90.2	88.5	59.5	55.0
98.2	97.8	89.5	87.5	57.5	52.5
98.0	97.6	88.5	86.5	55.0	50.5
97.8	97.4	87.5	85.5	52.5	48.0
97.6	97.1	86.5	84.0	50.5	46.0
97.4	96.8	85.5	82.5	48.0	43.5
97.1	96.5	84.0	81.5	46.0	41.0
96.8	96.2	82.5	80.0	43.5	38.5
96.5	95.8	81.5	78.5	41.0	36.5
96.2	95.4	80.0	77.0	38.5	34.5
95.8	95.0	78.5	75.5	36.5	32.5
95.4	94.5	77.0	74.0	34.5	30.5
95.0	94.1	75.5	72.0		
94.5	93.6	74.0	70.0		

The spread between nominal efficiencies in the table is based on increments of 10% losses. The spread between the nominal efficiency and the associated minimum is based on an increment of 20% 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 NEMA MG 1 standard requires that all 60 Hz polyphase squirrel-cage integral horsepower motors, 1–500 HP, designated as Design A and B (and equivalent Design C 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 available alternative motors, and in conjunction with other motor application information it can be utilized to compute relative energy and energy cost savings.

1.4.6.2 **Energy Efficient Polyphase Squirrel-Cage Induction Motors**

As emphasis was placed on motor efficiency and various marketing terms came into use to describe the efficiency of motors, it became clear that some standard needed to be established to provide the purchaser or user with a clear means to distinguish between the various efficiency levels of motors. This led to the development of a definition for an “energy efficient” motor as a motor for which the nominal full-load efficiency is not lower than the level given in Table 4 (Table 12-11 of MG 1). The efficiency of each energy efficient motor must also be not less than the minimum efficiency given in Table 3 corresponding to its nominal efficiency. These nominal efficiency levels for 2-, 4-, and 6-pole motors were adopted by the U.S. Congress in the Energy Policy Act of 1992. As of October 1997, most general purpose polyphase induction motors manufactured for sale in the U.S. must be energy efficient motors. In 2007 Congress passed EISA legislation, increasing the efficiency requirements on some motors and including more motors within the scope of legislation.

Table 4
Nominal Full-Load Efficiencies of Energy Efficient Motors

	Open Motors				Enclosed Motors			
HP	**2-Pole**	**4-Pole**	**6-Pole**	**8-Pole**	**2-Pole**	**4-Pole**	**6-Pole**	**8-Pole**
1.0	...	82.5	80.0	74.0	75.5	82.5	80.0	74.0
1.5	82.5	84.0	84.0	75.5	82.5	84.0	85.5	77.0
2.0	84.0	84.0	85.5	85.5	84.0	84.0	86.5	82.5
3.0	84.0	86.5	86.5	86.5	85.5	87.5	87.5	84.0
5.0	85.5	87.5	87.5	87.5	87.5	87.5	87.5	85.5
7.5	87.5	88.5	88.5	88.5	88.5	89.5	89.5	85.5
10.0	88.5	89.5	90.2	89.5	89.5	89.5	89.5	88.5
15.0	89.5	91.0	90.2	89.5	90.2	91.0	90.2	88.5
20.0	90.2	91.0	91.0	90.2	90.2	91.0	90.2	89.5
25.0	91.0	91.7	91.7	90.2	91.0	92.4	91.7	89.5
30.0	91.0	92.4	92.4	91.0	91.0	92.4	91.7	91.0
40.0	91.7	93.0	93.0	91.0	91.7	93.0	93.0	91.0
50.0	92.4	93.0	93.0	91.7	82.4	93.0	93.0	91.7
60.0	93.0	93.6	93.6	92.4	93.0	93.6	93.6	91.7
75.0	93.0	94.1	93.6	93.6	93.0	94.1	93.6	93.0
100.0	93.0	94.1	94.1	93.6	93.6	94.5	94.1	93.0
125.0	93.6	94.5	94.1	93.6	94.5	94.5	94.1	93.6
150.0	93.6	95.0	94.5	93.6	94.5	95.0	95.0	93.6
200.0	94.5	95.0	94.5	93.6	95.0	95.0	95.0	94.1
250.0	94.5	95.4	95.4	94.5	95.4	95.0	95.0	94.5
300.0	95.0	95.4	95.4	...	95.4	95.4	95.0	...
350.0	95.0	95.4	95.4	...	95.4	95.4	95.0	...
400.0	95.4	95.4	...	...	95.4	95.4	...	...
450.0	95.8	95.8	...	...	95.4	95.4	...	...
500.0	95.8	95.8	...	...	95.4	95.8	...	...

1.4.6.3 Premium® Efficiency Polyphase Electric Motors

With the establishment of a standard for Premium® efficiency electric motors in 2001, further clarification was provided for the purchaser or user of those motors having efficiency levels greater than that required to be identified as energy efficient. The nominal full-load efficiency of Premium® efficiency motors must not be less than the level given in Table 5 for random wound motors rated 600 V or less (Table 12-12 of NEMA MG 1) or in Table 6 for form wound motors rated 5000 V or less (Table 12-13 of NEMA MG 1). The efficiency of each Premium® efficiency motor must also be not less than the minimum efficiency given in Table 3 corresponding to its nominal efficiency.

Table 5

Nominal Full-Load Efficiencies for 60 Hz Premium Efficiency Electric Motors Rated 600 V or Less (Random Wound)

	Open Motors				Enclosed Motors			
HP	**2-Pole**	**4-Pole**	**6-Pole**	**8-Pole**	**2-Pole**	**4-Pole**	**6-Pole**	**8-Pole**
1	77.0	85.5	82.5	75.5	77.0	85.5	82.5	75.5
1.5	84.0	86.5	86.5	77.0	84.0	86.5	87.5	78.5
2	85.5	86.5	87.5	86.5	85.5	86.5	88.5	84.0
3	85.5	89.5	88.5	87.5	86.5	89.5	89.5	85.5
5	86.5	89.5	89.5	88.5	88.5	89.5	89.5	86.5
7.5	88.5	91.0	90.2	89.5	89.5	91.7	91.0	86.5
10	89.5	91.7	91.7	90.2	90.2	91.7	91.0	89.5
15	90.2	93.0	91.7	90.2	91.0	92.4	91.7	89.5
20	91.0	93.0	92.4	91.0	91.0	93.0	91.7	90.2
25	91.7	93.6	93.0	91.0	91.7	93.6	93.0	90.2
30	91.7	94.1	93.6	91.7	91.7	93.6	93.0	91.7
40	92.4	94.1	94.1	91.7	92.4	94.1	94.1	91.7
50	93.0	94.5	94.1	92.4	93.0	94.5	94.1	92.4
60	93.6	95.0	94.5	93.0	93.6	95.0	94.5	92.4
75	93.6	95.0	94.5	94.1	93.6	95.4	94.5	93.6
100	93.6	95.4	95.0	94.1	94.1	95.4	95.0	93.6
125	94.1	95.4	95.0	94.1	95.0	95.4	95.0	94.1
150	94.1	95.8	95.4	94.1	95.0	95.8	95.8	94.1
200	95.0	95.8	95.4	94.1	95.4	96.2	95.8	94.5
250	95.0	95.8	95.4	95.0	95.8	96.2	95.8	95.0
300	95.4	95.8	95.8		95.8	96.2	95.8	
350	95.4	95.8	95.0		95.8	96.2	95.8	
400	95.8	95.8			95.8	96.2		
450	95.8	96.2			95.8	96.2		
500	95.8	96.2			95.8	96.2		

Table 6
Full-Load Efficiencies for 60 Hz Premium Efficiency Electric Motors
Rated 5000 V or Less (Form Wound)

	Open Motors				Enclosed Motors			
HP	**2-Pole**	**4-Pole**	**6-Pole**	**8-Pole**	**2-Pole**	**4-Pole**	**6-Pole**	**8-Pole**
250	94.5	95.0	95.0	93.6	95.0	95.0	95.0	94.1
300	94.5	95.0	95.0		95.0	95.0	95.0	
350	94.5	95.0	95.0		95.0	95.0	95.0	
400	94.5	95.0			95.0	95.0		
450	94.5	95.0			95.0	95.0		
500	94.5	95.0			95.0	95.0		

1.4.6.4 Super Premium Polyphase Electric Motors

IEC has established levels of IE4 efficiency for electric motors also phrased as Super Premium. The nominal full-load efficiency of NEMA Super Premium efficiency enclosed motors must not be less than the level given in Table 7 for random wound motors of 600 V and less. The efficiency level of each Super Premium enclosed motor must also not be less than the minimum efficiency given in Table 3 corresponding to its nominal efficiency.

Table 7
Full-Load Efficiencies for 60 Hz Super-Premium Efficiency Enclosed Electric Motors (IEC IE4)
Rated 600 V or Less (Random Wound)

HP	**2-Pole Efficiency**	**4-Pole Efficiency**	**6-Pole Efficiency**	**8-Pole Efficiency**
1	82.5	85.5	84.0	78.5
1.5	85.5	87.5	88.5	81.5
2	86.5	88.5	89.5	85.5
3	88.5	91.0	90.2	87.5
5	89.5	91.0	90.2	88.5
7.5	90.2	92.4	91.7	88.5
10	91.7	92.4	92.4	91.0
15	92.4	93.6	93.0	91.0
20	92.4	94.1	93.0	91.7
25	93.0	94.5	94.1	91.7
30	93.0	94.5	94.1	93.0
40	93.6	95.0	95.0	93.0
50	94.1	95.4	95.0	93.6

Continued on next page

60	94.5	95.4	95.4	93.6
75	94.5	95.8	95.4	94.5
100	95.0	96.2	95.8	94.5
125	95.4	96.2	95.8	95.0
150	95.4	96.2	96.2	95.0
200	95.8	96.5	96.2	95.4
250	96.2	96.5	96.2	95.4
300	96.2	96.8	96.5	95.4
350	96.2	96.8	96.5	95.8
400	96.2	96.8	96.5	95.8
450	96.2	96.8	96.5	95.8
500	96.2	96.8	96.5	95.8

1.5 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.

1.5.1 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:

$$\$ = .746 \text{ x } HP \text{ x } L \text{ x } C \text{ x } N \left(\frac{100}{E_B} - \frac{100}{E_A} \right)$$

Where:

$ = 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 simple 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.

1.5.2 Present Worth Life Cycle Analysis

For greater precision, the present worth method of life cycle savings can 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 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:

Present worth of savings =

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

Where:

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 95.4% efficient
100 HP Motor B 92% efficient
Assumed: $0.06 KW x 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 x 4000 x 3.440 = 826

$$\left[\text{PW Saving } = 0.746 \times 100 \times 826 \times \left(\frac{100}{92} - \frac{100}{95.4}\right) = \$2387\right]$$

1.6 Motor Selection

1.6.1 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) NEMA Design A and B and IEC Design N—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 motors have a higher locked-rotor current than Design B motors.

b) NEMA Design C and IEC Design H—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) NEMA Design D—Used on machines that 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 1. Figure 2 shows representative speed-torque curves for NEMA Design A, B, C, and D and IEC Design H and N motors.

1.6.2 Multispeed Motors

Multispeed motors can be designed to have speed torque characteristics similar to those of NEMA Design A, B, C, or D and IEC Design H and N 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.

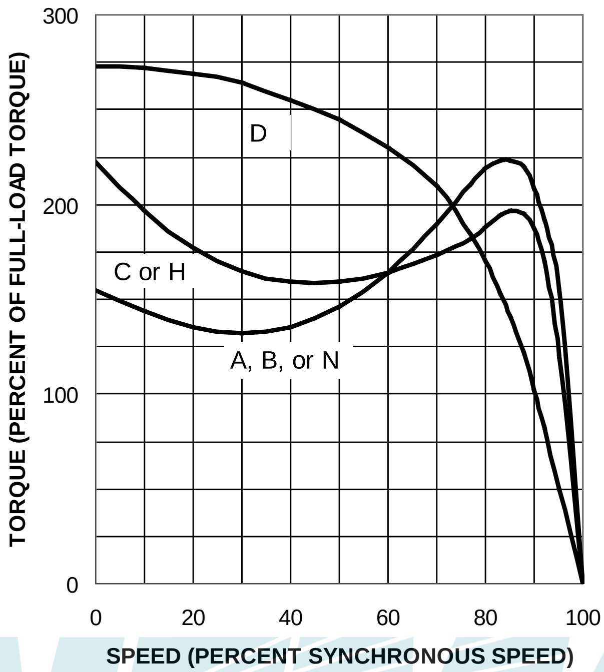

Figure 2
General Shape of Speed-Torque Curves for Motors
NEMA Design A, B, C, and D
IEC Design H and N

1.7 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 3. Figure 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 4. A small increase in voltage (≤10%) above rated voltage will decrease the power factor, and a small decrease in voltage (≤10%) 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. Operation as close as possible to the nameplate voltage and horsepower rating is recommended.

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.

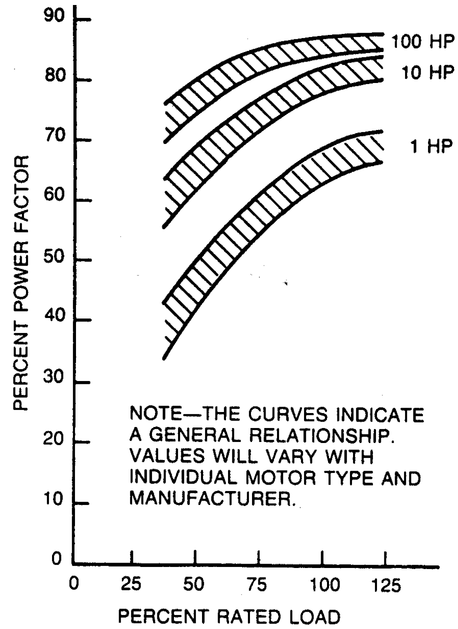

Figure 3
Typical Power Factor Versus Load Curves For 1800 RPM Three-Phase 60 Hz Design B Squirrel-Cage Induction Motors

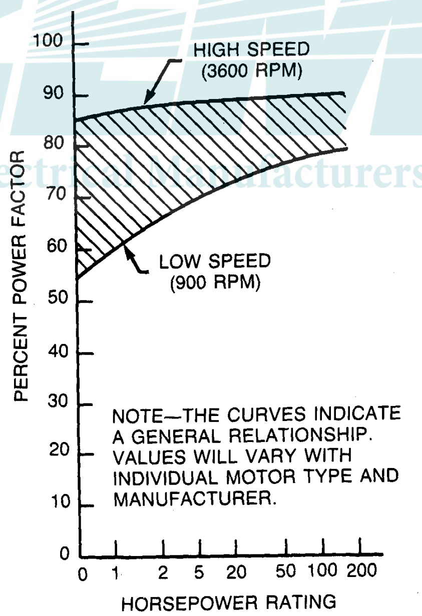

Figure 4
Typical Full-Load Power Factor Versus Horsepower Rating Curves for Three-Phase 60 Hz Design B Squirrel-Cage Induction Motors

1.8 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. Consult the motor manufacturer to determine the most effective solution.

1.8.1 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:

1. Motor rating ……………………………………………………………………… 10 HP
2. Motor full load efficiency ………………………………………………………… 91.7%
3. Motor output with drive machine running idle ………………………………… 2.5 HP
4. Motor efficiency at 2.5 HP ……………………………………………………… 89% HP
5. Motor acceleration loss plus system stored energy (Wk^2 = 1.4 lb×ft^2) ……. 3750 watt-sec.
6. Driven machine is loaded for 15 minutes followed by a 15-minute idle period.
7. Utilization ………………………………………………………………………… 2000 hours per year
8. Cost of energy …………………………………………………………………… $0.06 per KW•HR
9. Motor inertia ……………………………………………………………………… 0.7 lb•ft^2
10. Driven machine inertia ………………………………………………………… 0.7 lb•ft^2

Annual cost of energy if motor runs continuously:

a) Cost to run full load:

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

$$\$ = \frac{1000\ x\ 10\ x\ .746\ x\ .06}{.917} = 488$$

Cost to run driven machine idle:

$$\$ = \frac{1000\ x\ 2.5\ x\ .746\ x\ .06}{.89} = 126$$

Total Cost \$ = 488 + 126 = 614

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

a) Cost to run full load—same as above: $ = 488

b) Cost to restore system energy and to supply motor acceleration losses:

$$\$ = \frac{N_S \ x \ J \ x \ \$/KW \bullet HR}{1000 \ x \ 60 \ x \ 60}$$

Where:

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

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

Total Cost $ = 488 + .25 = 488.25

Energy savings per year $ = 614 - 488.25 = 125.75

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.

NEMA 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 8 has been prepared as a guide to:

a) The minimum off time required to allow the motor to cool sufficiently to permit another start;
b) The maximum number of starts per hour (irrespective of load Wk^2) to minimize the effect of winding stress imposed by repeated starts; and
c) 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 8.

Example 1:

50 HP, 4-pole, Design B motor direct-connected to a pump with a Wk^2 of 20 lb•ft.^{2} From Table 8:

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 $lb \bullet ft.^2$
Load Wk^2 referred to motor shaft =

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

From Table 8:

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. Therefore, the motor must be limited to 3.5 starts per hour with a minimum off time between starts of 115 seconds.

Table 8
Allowable Number of Starts and Minimum Time Between Starts for Design A and Design B Motors

	2-Pole			**4-Pole**			**6-Pole**		
HP	**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	110	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 8 is based on the 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 that varies as the square of the speed and is equal to 100% of rated torque at rated speed.
c) External load Wk^2 is equal to or less than the values listed in MG 1-12.54.
d) For other conditions, consult the manufacturer.

1.8.2 Applications Involving Extended Periods of 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 motors rated less than 5 HP 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 motors other than those rated less than 5 HP. A typical 10 HP motor will have idle losses in the order of 4% or 5% 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.

1.8.3 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 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.

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—$.06 per KW/HR

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

Annual Cost of Energy:

$$\$ = \frac{HRS\ x\ HP\ x\,746\ x\ \%\ ENERGY\ CONSUMPTION\ x\ \$\,/KW \bullet HR}{1000\ x\,100}$$

Annual Cost of Energy Summary:

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

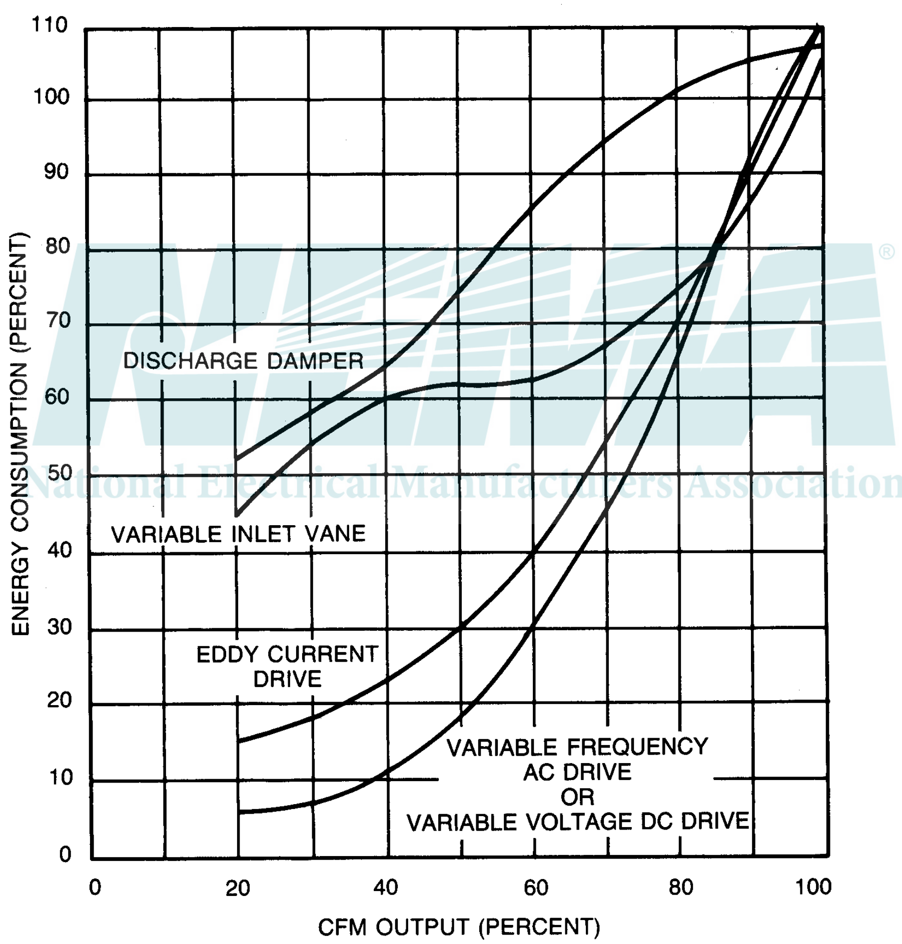

Figure 5
Typical Energy Consumption of a Centrifugal Fan System with Discharge Damper Control, Variable Inlet Vane Control, and Variable Speed Control with Eddy Current and Variable Frequency Drives

1.8.4 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.

Section 2
Maintenance

The electric motor generally needs little maintenance. Therefore, proper maintenance is often forgotten. A number of common abnormalities 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 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 increases caused by poor maintenance or misapplication reduce the operating life of the motor and increase 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.

§