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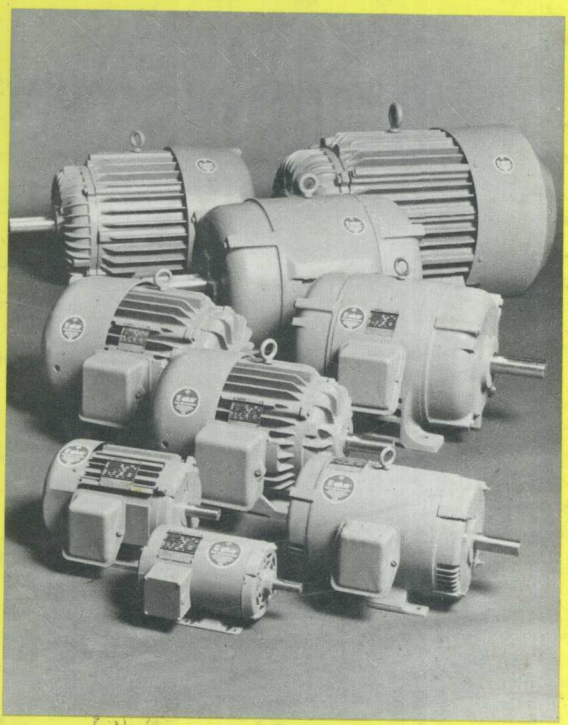
Energy-Efficient Electric Motors

Selection and Application

John C. Andreas



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Energy-Efficient Electric Motors

SELECTION AND APPLICATION

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ELECTRICAL ENGINEERING AND ELECTRONICS

A Series of Reference Books and Textbooks

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To my wife
Ruth E. Andreas
for her faith and encouragement

Preface

The number of electric motors in the 1- to 125-hp range was approximately 70 million in 1977 and is increasing 6 percent per year according to a recent study by the U.S. Department of Energy. This study also noted that 53 to 58 percent of the electric energy generated is consumed by electric-motor-driven systems. This presents us with an opportunity to save considerable energy by wisely selecting motors and the devices they drive. However, it should be recognized that the electric motor is a device for converting electrical energy to rotating mechanical energy. The only power consumed by the electric motor is the electrical and mechanical energy losses within the motor, and the balance of the electrical energy is transferred as mechanical energy to some driven device such as a pump, fan, or conveyor. Since the motor losses are 5 to 25 percent of the input power, it is important to consider the complete system, including the electric motor, when determining system efficiency and potential energy conservation.

Modern motors are precisely designed, taking advantage of computer-derived optimum designs, high-quality materials, and improved manufacturing technology. Hence, for many years the trend was toward smaller and lighter motors in order to lower cost, and no significant attention was given to efficiency and the power factor beyond the levels required to achieve allowable temperatures.

With the increasing cost of electric power, in 1975 motor manufacturers began addressing the problem of improving electric motor efficiencies to levels that would represent significant savings in energy.

Coincident with the trend toward smaller motors, many users

and original equipment manufacturers have been choosing to purchase the lowest-first-cost motor without considering the power factor and efficiency. Similarly, many textbooks and handbooks on electric motors discuss in great detail the design and performance characteristics of electric motors and the characteristics of various types of motor loads and how to match the motor to the load requirements. However, efficiency, the power factor, energy costs, and life-cycle costing have not been considered as major factors in the selection of an electric motor in most applications.

In many cases, electric motors have been selected and applied by engineers or other personnel who have a limited knowledge of electric motors, particularly a lack of understanding of the power factor, efficiency, and associated energy economies.

Today, with the high cost of electrical energy and the continuing trend toward higher costs, electric motors should be applied and selected on a life-cycle cost basis, including such factors as first cost, energy efficiency, the duty cycle, operating time, and energy costs.

My goal in this book is to provide guidelines for selecting and applying electric motors on an energy conservation and life-cycle cost basis. Particular emphasis is given to both single-phase and three-phase motors in the 1- to 125-hp range since this is the range that offers the maximum opportunities for energy savings. It is my intention to present these guidelines in a format that can be understood and effectively used by all personnel responsible for the application, selection, and procurement of electric motors, motor controls, and motor-driven products.

John C. Andreas

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1

Induction Motor Characteristics

1.1 THREE-PHASE INDUCTION MOTORS

In the integral horsepower sizes, i.e., above 1 hp, three-phase induction motors of various types drive more industrial equipment than any other means. The most common three-phase (polyphase) induction motors fall within the following major types:

NEMA* design B: Normal torques, normal slip, normal locked amps
NEMA design A: High torques, low slip, high locked amps
NEMA design C: High torques, normal slip, normal locked amps
NEMA design D: High locked-rotor torque, high slip
Wound rotor: Characteristics depend on external resistance
Multispeed: Characteristics depend on design—variable torque, constant torque, constant horsepower

There are many specially designed electric motors with unique characteristics to meet specific needs. However, the majority of needs can be met with the preceding motors.

NEMA Design B Motors

The NEMA design B motor is the basic integral horsepower motor. It is a three-phase motor designed with normal torque and normal starting current and generally has a slip at the rated load of less than 4 percent. Thus the motor speed in revolutions per minute is 96 percent or more

*National Electrical Manufacturers Association.

of the synchronous speed for the motor. For example, a four-pole motor operating on a 60-Hz line frequency has a synchronous speed of 1800 rpm or a full-load speed of

$$\begin{aligned} 1800 - (1800 \times \text{slip}) &= 1800 - (1800 \times 0.4) \\ &= 1800 - 72 \\ &= 1728 \text{ rpm} \end{aligned}$$

or

$$1800 \times 0.96 = 1728 \text{ rpm}$$

In general, most three-phase motors in the 1- to 125-hp range have a slip at the rated load of approximately 3 percent, or in the case of four-pole motors, a full-load speed of 1745 rpm. Figure 1.1 shows the typical construction for a totally enclosed, fan-cooled NEMA design B motor with a die-cast aluminum single-cage rotor.

Figure 1.2 shows the typical speed-torque curve for the NEMA design B motor. This type of motor has moderate starting torque, a

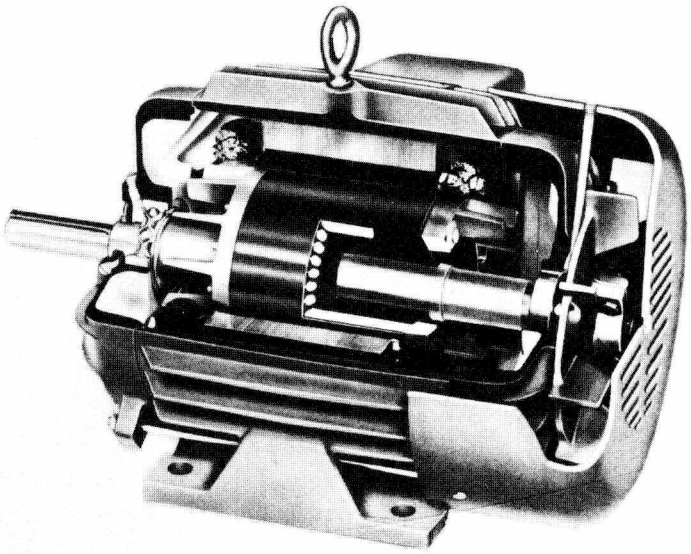

Fig. 1.1 NEMA design B totally enclosed, fan-cooled polyphase induction motor. (Courtesy of Gould Inc., Electric Motor Division, St. Louis.)

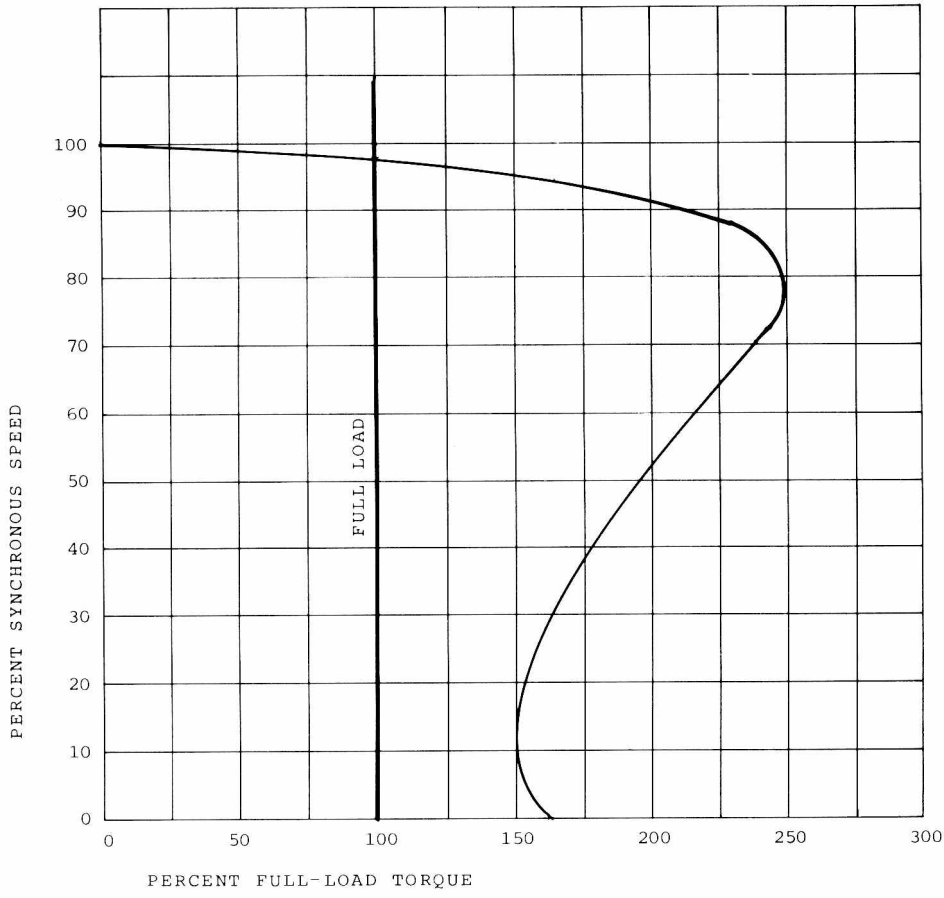

Fig. 1.2 NEMA design B motor speed-torque curve.

pull-up torque exceeding the full-load torque, and a breakdown torque (or maximum torque) several times the full-load torque. Thus it can provide starting and smooth acceleration for most loads and in addition can sustain temporary peak loads without stalling. The NEMA performance standards for design B motors are shown in Table 1.1, Table 1.2, and Table 1.3. There are no established standards for the efficiency or the power factor of NEMA design B motors. However, NEMA has established standards for testing and labeling motors; these standards are discussed in detail in Chap. 2.

Table 1.1 Locked-Rotor Torque of NEMA Design A and B Motors[a,b]

	Synchronous speed, 60 Hz			
hp	3600 rpm	1800 rpm	1200 rpm	900 rpm
1	—	275	170	135
1.5	175	250	165	130
2	170	235	160	130
3	160	215	155	130
5	150	185	150	130
7.5	140	175	150	125
10	135	165	150	120
15	130	160	140	125
20	130	150	135	125
25	130	150	135	125
30	130	150	135	125
40	125	140	135	125
50	120	140	135	125
60	120	140	135	125
75	105	140	135	125
100	105	125	125	125
125	100	110	125	120
150	100	110	120	120
200	100	100	120	120
250	70	80	100	100

[a]Single-speed, polyphase, squirrel-cage, integral horsepower motors with continuous ratings (percent of full-load torque).
[b]For other speeds and ratings, see NEMA Standard MG1-12.37.
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Table 1.2 Breakdown Torque of NEMA Design A and B Motors[a,b]

	Synchronous speed, 60 Hz			
hp	3600 rpm	1800 rpm	1200 rpm	900 rpm
1	—	300	265	215
1.5	250	280	250	210
2	240	270	240	210
3	230	250	230	205
5	215	225	215	205
7.5	200	215	205	200
10	200	200	200	200
15	200	200	200	200
20	200	200	200	200
25	200	200	200	200
30	200	200	200	200
40	200	200	200	200
50	200	200	200	200
60	200	200	200	200
75	200	200	200	200
100	200	200	200	200
125	200	200	200	200
150	200	200	200	200
200	200	200	200	200
250	175	175	175	175

[a]Single-speed, polyphase, squirrel-cage, integral horsepower motors with continuous ratings (percent of full-load torque).
[b]For other speeds and ratings, see NEMA Standard MG1-12.38.

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Table 1.3 Locked-Rotor Current of NEMA Design B, C, and D Motors[a,b]

hp	Locked-rotor current (A)[c]	NEMA design letter	Code letter
1	30	B, D	N
1.5	40	B, D	M
2	50	B, D	L
3	64	B, C, D	K
5	92	B, C, D	J
7.5	127	B, C, D	H
10	162	B, C, D	H
15	232	B, C, D	G
20	290	B, C, D	G
25	365	B, C, D	G
30	435	B, C, D	G
40	580	B, C, D	G
50	725	B, C, D	G
60	870	B, C, D	G
75	1085	B, C, D	G
100	1450	B, C, D	G
125	1815	B, C, D	G
150	2170	B, C, D	G
200	2900	B, C	G
250	3650	B	G

[a]Three-phase, 60-Hz, integral horsepower, squirrel-cage induction motors rated at 230 V.
[b]For other horsepower ratings, see NEMA Standard MG1-12.34.
[c]The locked-rotor current for motors designed for voltages other than 230 V shall be inversely proportional to the voltage.

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