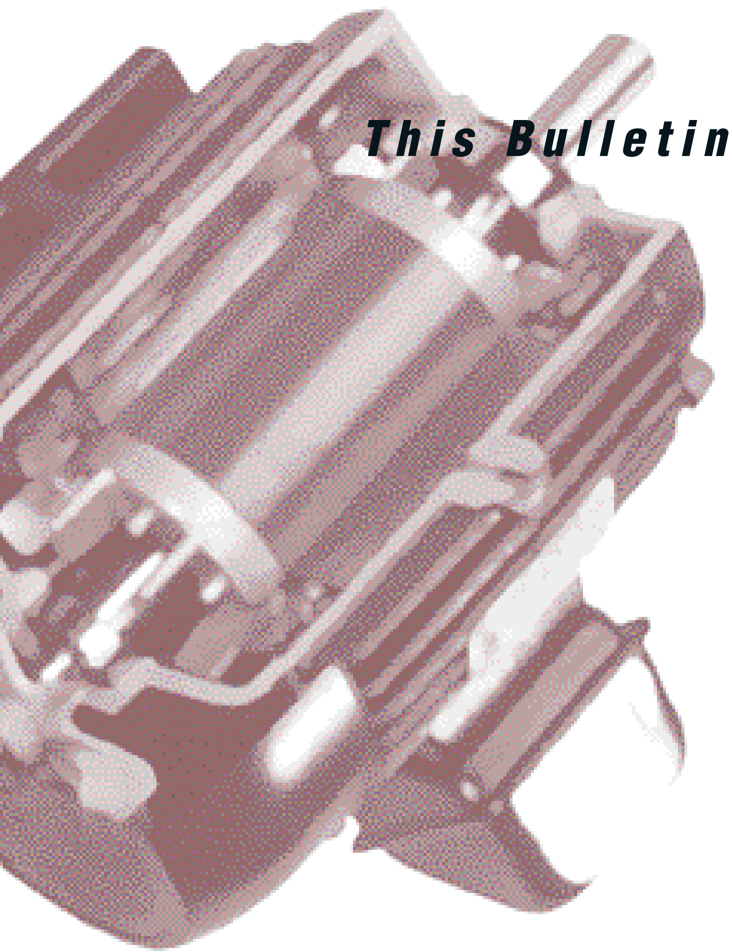
Metric MOTORS

...solutions for industry



This Bulletin:

- Offers help for the difficulties encountered during the operation and repair of metric motors, along with tools and solutions for handling these problems.
- Provides the results of investigating the use and replacement of foreign motors (3-phase, AC induction) in U.S. industrial facilities.

Advanced ENERGY

Why Worry About Metric Motors?

Many U.S. industries rely on foreign-made industrial process machinery, most of which are supplied with metric motors. Since these metric motors are typically designed for 380 volts @ 50Hz (versus standard 460 volts or 575 volts @ 60Hz), they may present special problems to the efficient, cost-effective operation and maintenance of the machinery. In some cases, the motors are re-rated (or simply re-nameplated) for sale to American users while other motors are simply supplied as they are. In either case, the results are sub optimal motors that run hotter and consume more energy than properly designed motors.

Metric motors are often more expensive to purchase and repair than their NEMA counterparts because of the unavailability of metric-sized winding wire in the U.S. Limited access to foreign winding design specifications also hampers the proper repair of metric motors. In addition, the long lead time required to purchase replacement metric motors from the OEM (Original Equipment Manufacturer) further complicates the situation.

The Problem

Motors are typically selected by machinery manufacturers to meet two criteria: the ability to handle the torque requirements of the machine, and a low purchase price. This applies to most motors supplied with machinery, regardless of country of origin. Motors arriving in this country mounted on foreign-made equipment often have a confusing array of different voltage markings on their nameplates. Some display their original 380 volt/50Hz designation. Others show 460 (or 575) volt/60Hz designations. Still others indicate a rating for both 50 and 60 Hz power systems. It is impossible to know whether any of these motors are actually redesigned for operation on 60Hz US voltages. What is known is that a motor cannot be designed for optimized operation at more than one voltage (230/460 volt motors are the only exception). Even motors that have been properly designed for use at 380 volts/50Hz cannot be expected to perform as well at 460/60 or 575/60.

Some special-purpose machinery motors are designed to meet specific operational characteristics. However, given the barriers of international communication, differing standards, and the lack of design identification on foreign motor nameplates, it is often difficult to recognize these specialty motors. Actual motor testing is often the only reliable method for accurately identifying these motors.

Performance of Foreign Motors Under US Conditions

The results of testing foreign-built motors at Advanced Energy confirm that these motors typically demonstrate low efficiencies and high operating temperatures under US voltage conditions. Efficiency improvements as great as 10% have been accomplished by switching from old, repaired, foreign motors to new, energy-efficient NEMA motors. Advanced Energy is currently compiling test data on foreign motors to allow for a more in-depth analysis of this situation.

Repair of Foreign Motors

Motor repair pricing is often based on a percentage of new motor cost. Since new foreign motors are generally more expensive to buy than their NEMA counterparts, the cost of repairing these metric motors is also higher than normal.

Foreign motors contain metric-sized winding wire, which is difficult to purchase in the US. Most motor repair shops must try to match the metric wire size as closely as possible with AWG (American Wire Gauge) winding wire, often using smaller wire than the original. This decrease in wire diameter increases motors losses, reduces motor efficiency, increases operating costs, and increases the motor's operating temperature, possibly shortening the motor's life.

> *EASA, the trade association of the motor repair industry, recommends that winding design never be altered at time of repair. Winding design changes are far more likely to degrade motor performance than to improve it.*

Motor repair shops need accurate winding design information in order to accomplish a proper repair. For NEMA motors, this is simply a matter of calling the motor manufacturer for the needed information, or contacting EASA (the Electric Apparatus Service Association) for access to its motor database.

For foreign motors, however, winding design data is often not available, forcing the repair shop to attempt to determine the winding design during disassembly. This not only slows the repair process, but also increases the possibility that the motor's performance characteristics may be unintentionally altered during the repair. And, of course, the possibility always exists that the motor winding may have **already** been altered by a previous repair, leaving the rewinder with little accurate design information.

Replacement of Foreign Motors

The key to a successful retrofit with a NEMA frame motor is to choose the replacement option **before** the original motor fails. Since some slight modification to the motor or its mounting surface may be necessary, it is best to identify the appropriate replacement in advance, allowing sufficient time to plan or perform the needed modifications.

> *Waiting until a motor fails before addressing this replacement issue can result in making a less-than-optimal, and often less cost-effective, choice in order to get the production machinery back on line quickly. The* quickest *replacement option is usually not the* best *option, unless you've planned properly in advance.*

Motor Retrofit

Most foreign motors are manufactured to standards written by IEC (International Electrotechnical Commission) and are based on dimensions and ratings using the metric system. Domestic motor standards are written by NEMA and are based on the English system. While these standards vary significantly in such areas as test methods and enclosure definitions, there are many similarities in frame dimensions and ratings. If proper care is taken in the selection and installation process, most foot-mounted metric motors can be successfully replaced with NEMA motors.

The following is an example of how to use the metric conversion table.

Example #1:

An existing metric motor shaft measures 1.102 inches in diameter. What is the shaft diameter in millimeters?

1.102 inches x 25.4 mm/in. = 28 mm shaft diameter

The following list of conversion factors is useful when comparing metric and English data.

Table 1

Metric & English Conversion Factors

Length	*1 inch = 25.4 millimeters (mm)*
	1 mm = .03937 inches (in)
	1 mm = 39.37 MILS
Mass	*1 lb. = .4536 kilograms (kg)*
Power	*1 Hp = 746.0 Watts (W)*
	1 Hp = 0.746 kilowatts (kW)
	1 kW = 1.341 Hp
Torque	*1 ft-lb. = 1.3558 Newton-meters (Nm)*
	1 Nm = 0.7376 ft-lbs
Temp	*°F = (9/5 x °C) + 32*
	°C = 5/9 (°F - 32)

The units of: Volts, Amps, Ohms, & Watts are common to all standards

Identify Existing Motor Output Rating

Metric motor output ratings are given in units of kilowatts (kW), rather than in horsepower (Hp). To determine a motor's output rating in Hp, divide the kW rating by .746 kW/Hp. This value will typically not match a NEMA Hp exactly, but will be close enough to begin narrowing the list of potential replacement motors. Table 2 provides a comparison of IEC and NEMA output ratings.

TO RETROFIT AN EXISTING METRIC MOTOR WITH A NEMA REPLACEMENT MOTOR, EACH OF THE STEPS LISTED BELOW MUST BE TAKEN.

Detailed instructions for each step are provided in the following sections:

- **Identify the Existing Motor Output Rating.**
- **Determine the Percent of Loading on the Motor.**
- **Determine the Existing Motor Speed.**
- **Identify the Existing Frame Size and Mounting Dimensions.**
- **Identify the Existing Shaft Size.**
- **Select the Closest Replacement NEMA Motor.**
- **Determine the Necessary Modifications.**

Table 2

IEC kW and NEMA Hp

IEC kW1	IEC HP2	NEMA HP3
1.1	1.47	1.5
1.5	2.01	2
2.2	2.95	3
3.7	4.96	5
5.5	7.37	7.5
7.5	10.05	10
11	14.75	15
15	20.11	20
18.5	24.80	25
22	29.49	30
30	40.21	40
37	49.60	50
45	60.32	60
55	73.73	75
75	100.54	100
90	120.64	125
110	147.45	150
132	176.94	
150	201.07	200
160	214.48	
185	247.99	250
200	268.10	
220	294.91	300
250	335.12	350
280	375.34	
300	402.14	400
315	422.25	
335	449.06	450
355	475.87	
375	502.68	500

1) IEC output ratings
2) IEC ratings converted to Hp
3) NEMA output ratings

Determine Percent Loading of the Motor

Knowing the actual percent load on the motor can be useful for determining the required Hp of the replacement motor. The load on the motor must be determined during normal operation and prior to motor failure.

The ideal method for measuring motor load is to use a True RMS Wattmeter. An alternative method is to measure the motor's amperage and divide by the nameplate full-load current rating for an approximate percent of loading. Note that this method is only valid for loading greater than 50%. Below 50% load, there is no good correlation between measured amps and nameplate amps. The amperage method also is not applicable if the existing motor is operating at other than rated conditions (e.g., a motor nameplated for 380 Volts operating on a 480 Volt system).

The often-used method of comparing measured speed and nameplate speed to determine percent loading is not recommended by Advanced Energy. This method can result in very large errors, giving poor estimates of actual motor load.

Determine Existing Motor Speed

A motor's full load speed is typically listed on the nameplate. Motor speed is dependent upon the number of poles, the operating frequency, and load. Typical AC Induction motors come in 2, 4, 6, and 8 pole configurations. See Table 3 for a comparison of motor speeds at different operating frequencies and different pole configurations.

Warning!

Motors that are designed for special applications have unique operational characteristics (such as high starting torque) that may not be noted on the nameplate. To ensure a successful NEMA retrofit, the equipment's load characteristics and torque requirements must be fully understood. High torque applications may require a NEMA design C or design D motor to meet the load requirements.

Table 3

Motor Speed Under Various Configurations

	@50 Hz		@60 Hz	
Number of Poles	*Synchronous Speed*	*Full Load Speed (Typical)*	*Synchronous Speed*	*Full Load Speed (Typical)*
2	3000 rpm	2875 rpm	3600 rpm	3475 rpm
4	1500 rpm	1450 rpm	1800 rpm	1750 rpm
6	1000 rpm	960 rpm	1200 rpm	1160 rpm
8	750 rpm	720 rpm	900 rpm	870 rpm

If the motor nameplate is incomplete, the following formula can be used to calculate the missing information.

NP=120f where: *N = Motor synchronous speed (RPM)*

P = the number of poles

f = operating frequency (Hz)

Example #1:

What is the synchronous speed of a 4 pole motor operating at 60 Hz?

$$N = \frac{120f}{P} \Rightarrow \frac{(120) \times (60\ Hz)}{4\ poles} = 1800\ RPM$$

Example #2:

What is the number of poles in a motor at 1460 RPM and 50 Hz?

$$P = \frac{120f}{N} \Rightarrow \frac{(120) \times (50\ Hz)}{1500\ RPM} = 4\ poles$$

Note: Per Table 3, 1460 RPM full load speed represents a synchronous speed of 1500 RPM.

Identify Existing Frame Size and Mounting Dimensions

IEC frame sizes are specified in millimeters, while NEMA frames are specified in inches. In spite of this difference in design standards and units of measurement, many foot-mounted frame sizes correspond very closely between the two standards. **NOTE:** IEC face- and flange-mounted motor dimensions are not compatible with NEMA dimensions and cause a real problem for conversions. In most cases, metric flange-mounted motors must be replaced with metric motors if a NEMA to IEC adaptor flange is not available. Refer to **When All Else Fails** for additional information.

Table 4 summarizes the dimensions for those NEMA and IEC frames that provide close matches. **NOTE:** IEC dimensions have been converted to inches to simplify the comparison.

The first step in locating an equivalent frame is to determine the shaft height. This dimension (D) is measured from the shaft centerline to the bottom of the motor feet and determines the frame size of the IEC motor. For example, a 112 frame IEC motor would have a shaft height of 112 mm, the closest NEMA frame is a 182T or a 184T with a 4.50 inch shaft height.

Determine Necessary Equipment Modifications

In order to mount a NEMA-frame motor where its metric counterpart once resided, some slight modifications are often necessary. One option is to enlarge and/or relocate the boltholes located on the host equipment in order to match those on the NEMA motor frame to the existing bolt pattern on the equipment. Commercially available adapter plates and flanges also exist in some cases to facilitate this effort. Once the new motor has been mounted properly, the shaft height usually can be adjusted by simply placing shims under the motor or its driven load. If all other options are exhausted, machining of the motor frame or mounting surface may be necessary.

Identify Existing Shaft Size

Unlike NEMA, the IEC standard does not assign a shaft dimension to a specific frame size. It is therefore necessary to measure the size of the metric motor's shaft in order to help select the proper NEMA replacement motor frame. Some NEMA frame sized come in two different shaft configurations. These configurations are distinguished by their frame number extensions: 284T or 284TS. Table 4 lists the shaft diameters (U) and shaft lengths (N-W) for those NEMA frames that correspond closely to IEC frames. Table 5 lists the shaft diameters of both metric and NEMA frame motors.

Determine the Necessary Shaft/Coupling Modifications

Once the proper replacement motor has been selected, the best shaft/coupling configuration must be determined. Possible solutions are to bore the existing coupling, to machine the new shaft, or to purchase new couplings.

Advanced Energy recommends modifying the couplings whenever possible. If the purchase of new couplings is required, there are many inexpensive models commercially available for either metric or English shaft sized. This makes it possible to order a coupling set with a metric bore for the load and an English bore for the NEMA motor.

Table 4

IEC vs NEMA Frame Dimensions

for closely corresponding frames only

Frame Size		*D*		*2E*		*2F*		*H*		*BA*		*U*		*N-W*	
IEC	NEMA	IEC	NEMA	IEC	NEMA	IEC	NEMA	IEC	NEMA	IEC	NEMA	IEC	NEMA	IEC	NEMA
90S	143T	3.543	3.50	5.512	5.50	3.937	4.00	0.394	0.34	2.205	2.25	*	0.8750	*	2.25
90L	145T	3.543	3.50	5.512	5.50	4.921	5.00	0.394	0.34	2.205	2.25	*	0.8750	*	2.25
112S	182T	4.409	4.50	7.480	7.50	4.488	4.50	0.472	0.41	2.756	2.75	*	1.1250	*	2.75
112M	184T	4.409	4.50	7.480	7.50	5.512	5.50	0.472	0.41	2.756	2.75	*	1.1250	*	2.75
132S	213T	5.197	5.25	8.504	8.50	5.512	5.50	0.472	0.41	3.504	3.50	*	1.3750	*	3.38
132M	215T	5.197	5.25	8.504	8.50	7.008	7.00	0.472	0.41	3.504	3.50	*	1.3750	*	3.38
160M	254T	6.299	6.25	10.000	10.00	8.268	8.25	0.571	0.53	4.252	4.25	*	1.625	*	4.00
160L	256T	6.299	6.25	10.000	10.00	10.000	10.00	0.571	0.53	4.252	4.25	*	1.625	*	4.00
180M	284T	7.087	7.00	10.984	11.00	9.488	9.50	0.571	0.53	4.764	4.75	*	1.875	*	4.62
180M	284TS	7.087	7.00	10.984	11.00	9.488	9.50	0.571	0.53	4.764	4.75	*	1.625	*	3.25
180L	286T	7.087	7.00	10.984	11.00	10.984	11.00	0.571	0.53	4.764	4.75	*	1.875	*	4.62
180L	286TS	7.087	7.00	10.984	11.00	10.984	11.00	0.571	0.53	4.764	4.75	*	1.625	*	3.25
200M	324T	7.874	8.00	12.520	12.50	10.512	10.50	0.728	0.66	5.236	5.25	*	2.125	*	5.25
200M	324TS	7.874	8.00	12.520	12.50	10.512	10.50	0.728	0.66	5.236	5.25	*	1.875	*	3.75
200L	326T	7.874	8.00	12.520	12.50	12.008	12.00	0.728	0.66	5.236	5.25	*	2.125	*	5.25
200L	326TS	7.874	8.00	12.520	12.50	12.008	12.00	0.728	0.66	5.236	5.25	*	1.875	*	3.75
225S	364T	8.858	9.00	14.016	14.00	11.260	11.25	0.728	0.66	5.866	5.88	*	2.375	*	5.88
225S	364TS	8.858	9.00	14.016	14.00	11.260	11.25	0.728	0.66	5.866	5.88	*	1.875	*	3.50
225M	365T	8.858	9.00	14.016	14.00	12.244	12.25	0.728	0.66	5.866	5.88	*	2.375	*	5.88
225M	365TS	8.858	9.00	14.016	14.00	12.244	12.25	0.728	0.66	5.866	5.88	*	1.875	*	3.75
250S	404T	9.843	10.00	15.984	16.00	12.244	12.25	0.945	0.81	6.614	6.62	*	2.875	*	7.25
250S	404TS	9.843	10.00	15.984	16.00	12.244	12.25	0.945	0.81	6.614	6.62	*	2.125	*	4.25
250M	405T	9.843	10.00	15.984	16.00	13.740	13.75	0.945	0.81	6.614	6.62	*	2.875	*	7.25
250M	405TS	9.843	10.00	15.984	16.00	13.740	13.75	0.945	0.81	6.614	6.62	*	2.125	*	4.25
280S	444T	11.024	11.00	17.992	18.00	14.488	14.50	0.945	0.81	7.480	7.50	*	3.375	*	8.50
280S	444TS	11.024	11.00	17.992	18.00	14.488	14.50	0.945	0.81	7.480	7.50	*	2.375	*	4.75
280M	445T	11.024	11.00	17.992	18.00	16.496	16.50	0.945	0.81	7.480	7.50	*	3.375	*	8.50
280M	445TS	11.024	11.00	17.992	18.00	16.496	16.50	0.945	0.81	7.480	7.50	*	2.375	*	4.75
315S	504T	12.402	12.50	20.000	20.00	15.984	16.00	1.102		8.504	8.50	*		*	
315S	504TS	12.402	12.50	20.000	20.00	15.984	16.00	1.102		8.504	8.50	*		*	
315S	504TS	12.402	12.50	20.000	20.00	15.984	16.00	1.102		8.504	8.50	*		*	
315M	505T	12.402	12.50	20.000	20.00	17.992	18.00	1.102		8.504	8.50	*		*	
315M	505TS	12.402	12.50	20.000	20.00	17.992	18.00	1.102		8.504	8.50	*		*	
355S	585T	13.976	14.50	24.016	23.00	19.685	20.00	1.102		10.000	10.00	*		*	
355S	585TS	13.976	14.50	24.016	23.00	19.685	20.00	1.102		10.000	10.00	*		*	
355M	586T	13.976	14.50	24.016	23.00	22.047	22.00	1.102		10.000	10.00	*		*	
355M	586TS	13.976	14.50	24.016	23.00	22.047	22.00	1.102		10.000	10.00	*		*	
400S	684T	15.748	17.00	27.008	27.00	22.047	22.00	1.378		11.024	11.50	*		*	
400S	684TS	15.748	17.00	27.008	27.00	22.047	22.00	1.378		11.024	11.50	*		*	
400M	685T	15.748	17.00	27.008	27.00	24.803	25.00	1.378		11.024	11.50	*		*	
400M	685TS	15.748	17.00	27.008	27.00	24.803	25.00	1.378		11.024	11.50	*		*	

Definitions

D - shaft center line height from bottom of feet
2E - foot mount hole spacing perpendicular to shaft
2F - foot mount hole spacing parallel to shaft
H - foot mouting hole diameter
BA - front foot mount hole to base of shaft
U - shaft diameter
N-W - shaft length

All dimensions in inches.

* Shaft diameters not assigned to specific frames. See Table 5 for a listing of shaft diameters.

Table 5

Shaft Diameter Comparison

IEC MM[1]	IEC IN[2]	NEMA IN[3]
7	0.2756	
9	0.3543	0.3750
11	0.4331	
14	0.5512	0.5000
16	0.6299	0.6250
18	0.7087	
19	0.7480	0.7500
22	0.8661	0.8750
24	0.9449	
28	1.1024	1.1250
32	1.2598	
38	1.4961	1.3750
42	1.654	1.625
48	1.890	1.875
55	2.165	2.125
60	2.362	2.375
65	2.559	
70	2.756	
75	2.953	2.875
80	3.150	
85	3.346	3.375
90	3.543	
95	3.740	
100	3.937	
110	4.331	

1) IEC shaft diameters
2) IEC shaft diameters converted to inches
3) NEMA shaft diameters

When All Else Fails

When your specific situation makes it impossible to replace your metric motor with a NEMA model, some options still remain. Some IEC metric motor manufacturers produce metric frame motors designed for operation at US voltages and frequency. In addition, their high efficiency models meet the minimum efficiency levels established by EPACT 92 (Energy Policy Act of 1992). There are also some NEMA manufacturers that offer select motor models in metric frames, but expect to pay a 20% premium for this option.

New Motor Specifications

It is important to keep in mind that foreign equipment doesn't **have** to be supplied with foreign motors. Advanced Energy has successfully assisted industrial users in purchasing equipment from overseas with NEMA motors already installed — or with **no** motor installed, allowing the customer to select and install the motor of their choice. In these instances, proper planning and cooperation with the equipment manufacturer resulted in an easy fit between the machine and its new NEMA motors. The results of these efforts are less expensive machines with higher operating efficiencies and cooler running motors.

The following list of motor specifications can be supplied to an equipment manufacturer to aid in proper motor selection.

Supplemental Specifications for Three Phase Induction Motors on Foreign Equipment

- All motors shall meet or exceed efficiencies required to be classified as "energy efficient" per **NEMA MG1-1998**, Revision 2, paragraph **12.59** or **NEMA Premium™ Efficiency** paragraph **12.60** and meet testing and labeling requirements per **NEMA MG-1998**, Revision **2**, paragraphs **12.58.1** and **12.58.2.**
- All motors shall be designed with voltage ratings specified in **NEMA MG1-1998**, Revision **2**, paragraph **10.30**, line c.1 for polyphase motors operating at 60 cycles.
- Winding design data, **ABMA** bearing identification number and torque vs. speed curves shall be supplied with each motor on foreign equipment. (You may consider allowing an exception to this if a US phone/fax number is provided where the data could be obtained promptly on request).
- All motors shall comply with the frame assignments of **NEMA MG1-1998**, Revision **2**, **Part 13**.
- Motors for adjustable speed drive applications shall be designed to provide adequate auxiliary cooling which will permit operation over normal operating loads and speed ranges without exceeding the temperature rise limits defined per **NEMA MG1-1998**, Revision **2**, **Paragraph 31.4.1.1.** Motors designated as "inverter duty" shall comply with all standards defined in **NEMA MG1-1998**, Revision **2**, **Part 31.**
- All motors shall be identified with a permanently affixed nameplate which contains information as specified in **NEMA MG1-1998**, Revision **2**, paragraph **10.40.1.**

Advanced Energy is a...

...problem solving center that focuses on process technologies that are energy-efficient and environmentally responsible. Advanced Energy is an independent nonprofit organization established in 1980 to help utilities, residential, and industrial customers improve the return on their energy investment. Advanced Energy's mission is to provide economic and environmental benefits through innovative approaches to energy.

Testing the performance and viability of emerging technologies is what turns great ideas into workable solutions. At Advanced Energy's Motor Resource Center motor users and motor manufacturers gain access to testing, consulting, and research from the only independent lab in the nation to be accepted by Underwriters Laboratories Energy Verification Services Laboratory Program and the first to be accredited by NVLAP for EPCA testing. Motor users gain knowledge and experience in efficiency, reliability, motor management practices, and motor applications. Motor manufacturers evaluate efficient motor designs, gain compliance with federal regulations, and improve their own motor testing capabilities. Both benefit from our research and how it affects motor driven systems in industry.

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Advanced Energy provides access to state-of-the-art motors and drives testing and cutting-edge industrial process technologies.

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