A GUIDE FOR MOTOR BUYERS & USERS

EPACT & ENERGY EFFICIENT ELECTRIC MOTORS

LEESON®

FOREWORD

January 1998
Grafton, Wisconsin

Today is truly an exciting and challenging time for specifiers, buyers, users and manufacturers of industrial electric motors. It is a time of change in the motor industry rivaled, in recent times, only by the introduction of re-rated “T” frame motors in the 1960s. But there is a difference between that change and this one. The “T” frame evolution was perpetuated by the motor industry itself, driven by economics and market force realities. Today, however, we have seen a government mandate.

As the law of the land, most industrial motors produced after October 24, 1997, were required to operate at the mandated efficiency levels prescribed by the Energy Policy Act of 1992. These legislated efficiencies are not challenging from a design or manufacturing viewpoint. In fact, mandated efficiency levels are generally lower than the “premium-efficiency” motors available from major manufacturers for many years. The major change of EPACT has been felt in the increased cost to motor users, as mandated-efficiency Design B motors became the new “standard” used in many industrial applications and as components in a wide variety of industrial machinery. In addition, many motor users have found that NEMA Design C torque motors, which are not covered by EPACT mandates, are excellent choices for many applications where a bit more torque is desirable. And their “standard” efficiencies may be perfectly adequate when balanced against actual duty cycle or the lower up-front cost.

Guidelines as to what constitutes a motor that can be used for general purposes – and is therefore covered by EPACT – have been clarified. The clarifications have come from NEMA (the National Electrical Manufacturers Association) and from the Department of Energy, which has the official responsibility for rulemaking and enforcement of EPACT mandates. These guidelines are included in Appendix A of this booklet. Also included in this revised booklet, in Appendix B, is information on IEEE 112B, the required efficiency testing procedure under EPACT.

As always, LEESON welcomes your comments and suggestions. Please write, fax, or e-mail us through our World Wide Web site (www.leeson.com), and leave your message. We will be delighted to respond.

We look forward to helping serve you in your industrial electric motor needs.

It has probably been a topic of discussion since the beginnings of the electric motor industry. Certainly, it has been a major topic since the Arab oil embargo of the 1970s and, it seems, THE topic of discussion in the motor industry since the federal government's passage of the Energy Policy Act (EPACT) in 1992. Motor efficiency: How completely an electric motor converts electricity into mechanical work. Does 80% of the electrical energy we feed into a motor become work "at the end of the shaft"? Does 90%? Yesterday, it was mostly a question for the curious. Today, driven first by higher energy costs, then by incentive programs of electric utilities, and most recently by federal legislation in the form of EPACT, which took effect in late 1997, motor efficiency has become an imperative.

Here, in a nutshell, is what the law means to the industrial motor user, whether the motors are for replacement use on existing applications, or components of another machine. Three-phase, general-purpose, NEMA T frame motors of 1 through 200 HP, manufactured after October 24, 1997, must meet government-mandated efficiency levels. These EPACT levels are higher than those of most manufacturers' previous standard efficiency motors, but generally not higher than many manufacturers' long-standing "premium-efficiency" lines. So, in that sense, motors of the "new" efficiencies are not really all that new at all. The real difference is in how much more widespread their manufacture, availability and ***required*** became as of late 1997.

Why Is Motor Efficiency Important?

Electric motors have a huge impact on overall energy usage. Between 30 and 40 percent of all fossil fuels burned in the world are used to generate electricity, and a large portion of that electricity goes to run motors. Nearly all estimates say that at least 60% of electricity in the United States is used to power motors. Given the overwhelming number of small motors in consumer use, well over half of "motor power demand" falls to this (for now) unregulated motor segment. But that still leaves a sizable power demand within the industrial motor population, at current electric rates perhaps $30 billion worth of electrical power per year. This means that within the overall industrial motor segment, every percentage point gain in overall motor efficiency translates into $300 million of yearly savings. Maximizing industrial electric motor efficiency is clearly important. This is true in public energy policy terms, and environmentally in reduction of "greenhouse gases" associated with fossil fuel burning. Plus it is also good business practice.

Full-Load Efficiencies of Energy Efficient Motors

Open Motors

	2 POLE	4 POLE	6 POLE
HP	**Nominal Efficiency**	**Nominal Efficiency**	**Nominal Efficiency**
1.0	—	82.5	80.0
1.5	82.5	84.0	84.0
2.0	84.0	84.0	85.5
3.0	84.0	86.5	86.5
5.0	85.5	87.5	87.5
7.5	87.5	88.5	88.5
10.0	88.5	89.5	90.2
15.0	89.5	91.0	90.2
20.0	90.2	91.0	91.0
25.0	91.0	91.7	91.7
30.0	91.0	92.4	92.4
40.0	91.7	93.0	93.0
50.0	92.4	93.0	93.0
60.0	93.0	93.6	93.6
75.0	93.0	94.1	93.6
100.0	93.0	94.1	94.1
125.0	93.6	94.5	94.1
150.0	93.6	95.0	94.5
200.0	94.5	95.0	94.5
250.0*	94.5	95.4	95.4
300.0*	95.0	95.4	95.4
350.0*	95.0	95.4	95.4
400.0*	95.4	95.4	—
450.0*	95.8	95.8	—
500.0*	95.8	95.8	—

** motors larger than 200 HP are not covered by EPACT `92.*

Enclosed Motors

1.0	75.5	82.5	80.0
1.5	82.5	84.0	85.5
2.0	84.0	84.0	86.5
3.0	85.5	87.5	87.5
5.0	87.5	87.5	87.5
7.5	88.5	89.5	89.5
10.0	89.5	89.5	89.5
15.0	90.2	91.0	90.2
20.0	90.2	91.0	90.2
25.0	91.0	92.4	91.7
30.0	91.0	92.4	91.7
40.0	91.7	93.0	93.0
50.0	92.4	93.0	93.0
60.0	93.0	93.6	93.6
75.0	93.0	94.1	93.6
100.0	93.6	94.5	94.1
125.0	94.5	94.5	94.1
150.0	94.5	95.0	95.0
200.0	95.0	95.0	95.0

NEMA 12-10 efficiency levels — the basis for EPACT mandates.

Under EPACT, many kinds of industrial motors are required to have efficiency levels nearly as high as these premium-efficiency WATTSAVER® motors.

EPACT '92 Covers...

- **General purpose**
- **T-frame(143T-447T)**
- **Foot mounted**
- **Single speed motors**
- **NEMA Design A or B performance**
- **Continuous duty**
- **1 - 200 HP**
- **3600, 1800, 1200 RPM designs**
- **230/460 V, 3 phase, 60 Hz**

What EPACT Specifically Says About Motors

Three-phase, 1 through 200 HP, general-purpose, T frame . . . those are the key elements to remember about which motors will or will not be covered by the EPACT guidelines in late 1997. Here are the specifics:

Any ***non-exempt*** motor ***manufactured*** after October 24, 1997, must meet the EPACT efficiency levels, as administered by the Department of Energy and related agencies. These levels are the same as those listed in the MG-1-1993 standards published by NEMA, the National Electrical Manufacturers Association. They are shown in Table 12-10 of that publication, so you will often hear the EPACT efficiency levels equated with "NEMA 12-10." (See the table on previous page.)

Note the emphasis in the previous paragraph on "manufactured." The law clearly does not require any motor user to replace an existing motor with a

Two types of industrial motors: the ribbed frame version in the foreground is a good example of a NEMA T frame motor covered under EPACT through 200 HP. The larger motor is "above" NEMA frame size; therefore, it is exempt from EPACT mandates as now written.

higher-efficiency model (though in some applications you might want to do so for economic reasons based on energy dollars saved.) And because motor companies are manufacturing motors and filling inventory channels all the time, there will certainly be standard motors "in the pipeline" for months and probably even years to come. Customers may buy and install these pre-EPACT-manufactured motors (presumably at a lower price than the newer high-efficiency models) as long as they're available. Similarly, the law makes no reference to used or rewound motors. Those may be bought at will, regardless of efficiency, though, over time, it's likely that the marketplace will demand a proven, if not certified, level of efficiency from rewound or otherwise reworked motors as well.

Note also the term "non-exempt" motor. While its scope is certainly widespread, covering perhaps half of all industrial motors, EPACT does not address all types of motors. Its focus is on small to medium-horsepower AC motors used in general industrial applications. For example, it states only three-phase 230/460 VAC motors from 1 through 200 HP. Further, these must be general-purpose, T frame motors with three-digit frame numbers, NEMA Design A or B, rated for continuous duty. Open and enclosed motors are included, as are two-pole, four-pole and six-pole designs (3600, 1800 and 1200 RPM). Imported motors, as well as those manufactured in the United States, are covered. These can be sold for replacement applications or incor-porated into other machinery. Motors requiring third-party approvals such as explosion-proof de-signs are to come under the law's scope in October 1999. The law specifically applies to horizontal foot-mounted motors, and that includes foot-mounted motors that also have a NEMA C face mounting.

What Kinds of Motors Are Not Included in EPACT?

"Definite-purpose" or "special-purpose" motors are exempt. The law defines definite-purpose motors as, among other things, those "which cannot be used in most general purpose applications.” The law defines special-purpose motors as “other than general-purpose or definite-purpose motors, which have special operating characteristics or special mechanical consideration, or both, designed for a particular application.” High-slip (NEMA Design D) or high-torque (NEMA Design C) motors are examples of special-purpose motors under this definition. Other examples are multi-speed or low-RPM motors and those designed for special voltages.

In addition, single-phase motors are exempt, as are any motors built in double-digit frames (42, 48 and 56, which are defined as fractional-horsepower frames), or for that matter in sub-fractional horsepower frame sizes. Of course, it’s not uncommon to find motors of up to 3 HP built in NEMA 56 frames. Even though they are clearly 1 HP or greater, these are exempt.

In reality, the whole issue of how much or how little single-phase or fractional-horsepower motors are affected revolves around setting standards for what the law generically refers to as “small motors,” meaning under 1 HP, any motors in two-digit NEMA frame sizes, or sub-fractional motors. The law does not differentiate between single-phase and three-phase “small motors,” but the greatest population of fractional and sub-fractional motors are, in fact, single phase. (There are plenty of single-phase motors also built in 140, 180 and 210 frame sizes, and the federal government may eventually address those as well.)

Exempt From EPACT

- **Motors with no base or provisions for a base (example: NEMA C face, less base)**
- **Motors having customer-defined base or feet**
- **A motor having a customer-defined shaft, if the motor cannot be used as general purpose**
- **Two-digit frames (example: NEMA 56 or 56HZ)**
- **TENV and air over – TEAO and open air over designs**
- **Inverter duty motors (but “inverter rated” general purpose motors covered)**
- **Multi-speed motors**
- **Frame size larger than NEMA assignment (NEMA 182T to 213T, not 182T to 184T). Frame size smaller motors are covered, i.e., 184T instead of 213T.**
- **50 Hertz motors (but 50/60 Hertz are covered)**
- **200, 575 volt or other special voltage motors (that cannot be used at 230 or 460 volts)**
- **Motors having NEMA Design C or D torques**

As written, EPACT requires the Department of Energy to adopt standards for most "small motors," to be effective by October 24, 2001. Subsequent legislation has made this deadline unlikely. There are other issues peculiar to single-phase motors that must also be resolved. These include what types of single phase motors are covered, how the term "general purpose" applies, what efficiencies will be mandated, and what test method will be used.

Because there are many types of single-phase motors, would there have to be differing standards for each type? IEEE 114, the standard that prescribes single-phase motor test procedures, was inactivated in 1992. More fundamentally, would inherently inefficient designs, such as the inexpensive shaded pole motors often used in consumer appliances, be exempt from regulation — or at the other extreme possibly even prohibited, either by direct legislation or as part of requirements for overall appliance efficiency? (In many cases, however, small motors on appliances may well already be affected within the scope of overall appliance efficiency requirements.) However it all shakes out, it seems plausible that if nothing else, logistical problems will likely keep single-phase motors out from under the EPACT umbrella for some time to come.

At the other extreme, will motors larger than 200 HP come under the scrutiny of the Department of Energy? It's possible, at least from 250 to 500 HP in low-voltage, because NEMA has already established efficiency values in this range. Larger than 500 HP, and especially in medium-voltage (2300/4000 VAC), it seems very unlikely for at least three reasons. First, there is a relatively small population of these motors. Second, and most important, the enormous energy demands of these large motors have already driven buyers and manufacturers alike toward higher efficiencies. And third, particularly with motors above 1,000 HP, few truly standard, general-purpose motors exist; they are almost always application-specific.

Finally, EPACT gives the Secretary of Energy the option of excluding other motors for which standards-setting would not be feasible, or those where the energy savings would not be "significant." No definition of "significant" has been offered. These are just some of the areas where the Department of Energy must still complete, or even undertake, additional rulemaking.

What Makes One Motor More Efficient Than Another?

Before we answer this question, let's be sure we're comfortable with one key fact: Industrial-duty electric motors are, across the board, extremely efficient means of converting energy into useful work. This is especially true for three-phase motors, plus the majority of single-phase designs used in industrial applications. These motor designs include permanent split capacitor, capacitor start, and capacitor start/capacitor run. After all, in a 94% efficient motor, only 6% of the electrical energy is not converted to useable mechanical power. Internal combustion engines are less than half as efficient as even most standard-efficiency electric motors.

Electric motor users, designers and manufacturers have nothing to be ashamed of. It’s just that — for a cost in active material, primarily copper and steel — there are ways to make what’s good even better. That’s what EPACT is all about.

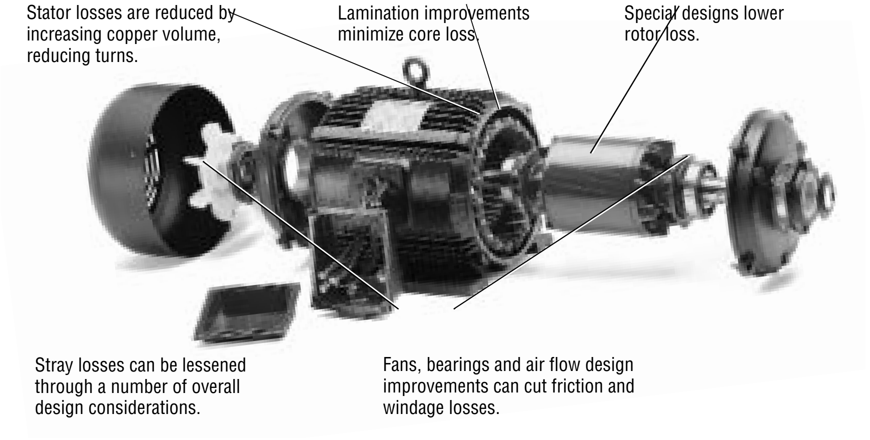
So back to the question of what makes a motor efficient or, for that matter, inefficient. We’ve already provided a working man’s definition of efficiency: *The ability of a motor to convert electrical energy into mechanical work.* But why is one motor — sometimes as if by magic — more efficient than another?

Well, first of all, it’s not magic. In fact, the processes for increasing motor efficiency are well-known and not at all mystical. Without getting too deeply into the disciplines of electrical or mechanical engineering, here are the basics:

Maximizing motor efficiency involves minimizing energy lost during the motor’s operation. For AC polyphase motors, this lost energy comes in several different forms, all clearly delineated in, among other places, NEMA standards:

- Core loss, the energy needed to magnetize the steel lamination stack of a motor.
- Friction and windage loss, the result of bearing friction and air resistance caused by motor cooling fans and the rotor itself.
- Stator winding resistance, which creates heat as current attempts to flow through stator windings.
- Rotor resistance, again showing up as heat, this time from electrical resistance in rotor bars and end rings.
- Stray load loss, the sum of the remaining small electrical and magnetic losses that cannot be measured directly.

MAXIMIZING MOTOR EFFICIENCY



Core loss and friction and windage loss are considered "no-load losses" because they exist in essentially the same amounts regardless of the motor load, including no load at all. Taken together, these "no-load losses" account for one third or less of total motor losses when a motor is operating under typical loading. Stator, rotor and stray load losses change as the motor is loaded and will increase with load. Combined, these losses account for two-thirds or more of the total loss in a typical design.

Just as the definitions of losses are straightforward, so are the means to control them.

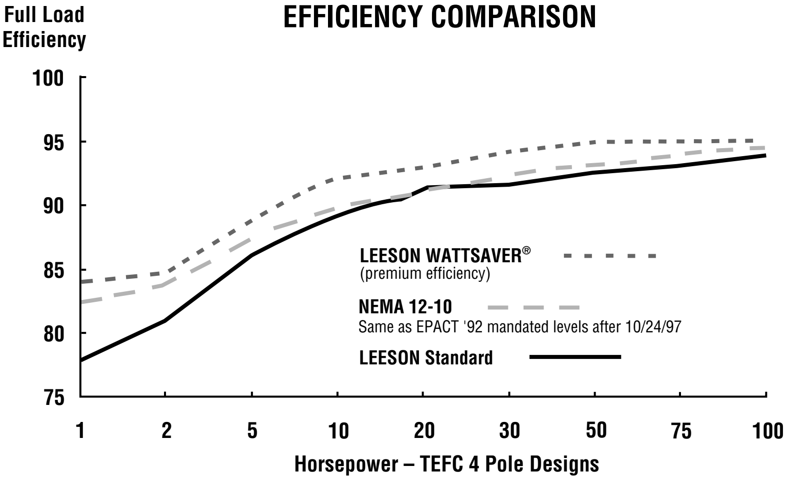
- Core loss is minimized through higher grades of lamination steel, thinner laminations, and a longer lamination stack.
- Friction and windage losses are decreased by improved bearings, plus smaller fans and better air flow design.
- Stator losses are lessened by using more wire or heavier gauge wire, or by reducing end turns.
- Rotor losses can be reduced through special designs and larger conductive bars.
- Stray losses are typically reduced by a combination of design factors, including an optimized air gap between the rotor and stator, and the number and shape of lamination slots.

Given the fact that the majority of motor losses are attacked by adding costly material, it's not hard to see why today's premium-efficiency motors cost about 20-25% more than comparable standard efficiency designs. As one engineer has put it, "To make a higher efficiency motor, you don't sprinkle it with pixie dust, you sprinkle it with dollar bills."

How Is Motor Efficiency Measured?

Earlier, in the discussion of whether single-phase motors would or would not eventually come under the EPACT umbrella, we mentioned that the test standard for single-phase motors, IEEE 114, had been inactivated. The three-phase motor standard, IEEE 112, is by contrast very much in regular use. That's why IEEE 112, or the essentially identical CSA Standard C390, have been adopted as the authoritative procedures for determining motor efficiency under EPACT. Both standards, because they take into account all losses, are

Dynamometer testing is required to determine accurate motor efficiencies.



Example of how one manufacturer's standard and premium efficiency motors compare today with EPACT mandates. In most cases, EPACT, or NEMA 12-10 levels, are higher than standard, but lower than today's current premium efficiency motors.

by most accounts more stringent than the other standards common throughout the world, including IEC 34.2, the essentially identical British standard BS 269, or the Japanese standard JEC 37, which ignores stray load losses altogether. With either the IEEE or CSA standards, for motors from 1 through 200 HP, the approved method of testing under EPACT (called Method B) involves using a dynamometer, a device that can place a motor under measurable and repeatable load. (See Appendix B for a full discussion of IEEE 112 Method B)

Under EPACT, as currently written, motor manufacturers must have a testing/certification program in place to demonstrate compliance. Some manufacturers, including LEESON, already have undergone third party certification of their test labs.

The result of this testing, as far as meeting EPACT requirements, will be to gather data to establish a "nominal full-load efficiency." Nominal efficiency can be thought of as the average efficiency measured over a defined sample of the same motor model. The exact nominal efficiency will not actually be stamped on the nameplate, however. That value will be selected from a table of standard nominal efficiency values. For example, if a sample of 10 HP open motors has an average efficiency of at least 87.6%, it will be stamped with a "NEMA Nominal Efficiency" of 87.5%. These efficiency bands are intended to eliminate minor, essentially irrelevant efficiency differences that may well be the result of ordinary testing variances. Motors having efficiencies within the bands can be treated as operationally equivalent. In addition to nameplating requirements, EPACT also calls for disclosure of efficiency information in marketing materials.

The Economics of Motor Efficiency

There had been concern that EPACT, by mandating general-purpose motor efficiencies, would limit the motor buyer’s options and take economics out of the buying equation. In fact, by increasing the range of efficiency choices, EPACT has expanded the possibilities. Buyers can choose from EPACT-efficiency motors, or perhaps premium-efficiency NEMA Design B motors exceeding EPACT mandates. On the other hand, higher-torque NEMA Design C motors, which are exempt from EPACT mandates, may provide a lower-cost alternative for applications requiring four-pole or six-pole speeds. And some standard-efficiency motors manufactured before the EPACT deadline continue to be available for sale from suppliers’ stocks. You can use the Annual Energy Cost Worksheet (shown on page 13) to help calculate how much given motors will cost to operate for a year, then draw your own comparisons as to the payback you want.

The key factors in any energy-saving equation may be the number of hours the motor is run and at what load. If it runs a lot at nearly full load, chances are the balance will tip toward higher efficiency. At the extreme, the savings may be so great as to warrant taking a perfectly serviceable older motor off line and upgrading to a new, higher-efficiency one. If the usage is less continuous or at lower loads, it’s unlikely that upgrading a working motor will make sense.

Other application considerations also come into play. For example, on some direct drive centrifugal applications, such as a fan or pump, the somewhat higher operating RPM common on higher-efficiency motors (the result of less “slip”) can drive up the load and output enough to offset the energy savings. On centrifugal loads, the horsepower needed increases by the cube of the speed, so a small increase in speed will have a correspondingly greater impact on load. Of course, higher RPM could also increase overall operating efficiency by allowing a piece of machinery to finish its job more quickly. So, as always, the results will vary with the application. Some designs that concentrate only on efficiency can exhibit some unusual characteristics. One example is high locked rotor amps, which could affect wiring and starters, especially in the “next generation” of motor efficiency.

To understand the issues behind these “next generation” motors, you must first understand that EPACT-efficiency motors are essentially efficiency optimizations of standard NEMA Design B motors. They must meet standard Design B performance in areas other than efficiency. These include such key requirements as locked rotor amp draw, torque and so forth. These requirements limit how much design factors can be employed to improve efficiency. Therefore, to avoid going to “exotic” means to boost efficiency still further, some of these requirements must be relaxed. To address this future trend, NEMA created a new motor type, Design E. (See Design E efficiency table on

ANNUAL ENERGY COST WORKSHEET

To determine the annual energy cost to operate an electric motor, you'll need this information:

Motor Horsepower:
(from nameplate)

Motor Loading:
(actual or see Note A below; express as decimal — example: for 75%, write .75)

Annual Operating Hours:
(Actual or see Note B below)

Full Load Efficiency:
(from nameplate; express as decimal — example: for 92%, write .92)

Electric Rate per kWh:
(from local utility; express as decimal — example: for 5 cent per kWh, write .05)

Now, plug the information into this formula:

Converts HP to kW

$$\frac{\text{Horsepower} \times .746 \times \text{Loading} \times \text{Annual Hours} \times \text{Electric Rate}}{\text{Efficiency}}$$

The result is your annual operating cost.

For example, a 40 HP motor, loaded to 75%, operating 6,000 hours per year, with an electric rate of 5 cents per kWh, and 92% efficiency would use $7,298 per year in electricity...

$$\frac{40 \times .746 \times .75 \times 6{,}000 \times .05}{.92} = \$7{,}298$$

Note A: If you know your motor loading, use that number. Otherwise, assume it is loaded to 75%.

Note B: Use actual annual operating hours if you know them. If not, use these guideline numbers:
4 shifts = 8,000; 3 shifts = 6,000; 2 shifts = 4,000; 1 shift = 2,000.

page 17.) Design E standards allow a great deal higher locked rotor amps (as much as 50% or more above Design B) as a tradeoff for notching efficiency up a step further by reducing rotor resistance. Design E's higher amperage will probably require a whole new range of motor starters, or at least a change in how starters are selected, plus changes in wiring, circuit and surge protection and all the modifications to the National Electric Code that this could entail. With lower rotor resistance also comes lower starting torque, which may make Design E machines unsuitable for some hard-to-start loads. Plus, the motor speed will be stepped up a bit further, due to less slip, again having an impact particularly on centrifugal loads.

Another possible disadvantage to higher-efficiency motors, of whatever design, could be a greater cost to repair, because they require more carefully controlled service procedures, plus more and costlier rewind materials. And, in those cases where mounting space is tight, high-efficiency motors, because most have a longer stack, could be a tight squeeze.

Now, a word on the durability of high-efficiency motors. In general, it should be enhanced compared with standard efficiency designs because of improved materials, less heat generated and a somewhat larger core size, which will tend to fend off the extra heat stress of peak loads or start/stop operation. Still, this durability difference could be difficult to measure given the reliability and long life of virtually all industrial-duty AC polyphase motors. The best statement might be this: Rest assured that high efficiency motors, like their standard-efficiency counterparts, will be among the most reliable pieces of industrial machinery you'll ever own.

Now That EPACT Is Here, What Other Changes Might We Expect?

We've already discussed what, if any, additional types or sizes of motors might be added to EPACT as time goes on. Those include small motors (under 1 HP), possibly single phase, perhaps also motors larger than 200 HP. These may be under consideration at some point, though it seems unlikely that much action will be taken for several years. Similarly, the complete range of Design E "super-high-efficiency" motors appears to be some time off, though some manufacturers are beginning to offer these "next generation" motors on a limited basis.

Of more immediate interest is the future of utility rebates. Certainly, the proliferation of such utility programs has focused attention on the value of stepping up motor efficiency. Rebates may also have helped utilities avoid the hassles and cost of some new power plant construction — though overall efficiency gains by industry probably played a greater role than motors themselves.

But now, given the fact that the majority of new industrial motors will now be high-efficiency by requirement, of what value are the rebates? Put another way: With the force of law behind the motor efficiency movement, what further incentive could be necessary?

The answer, it seems, is that while rebates will not apply to mandated-efficiency motors, they may apply to motors that "go the next step" to an even higher efficiency. It's likely that motor manufacturers will continue to build premium-efficiency lines of motors, over and above their mandated-efficiency lines — whether these are further optimizations of current designs, or the new Design E motors explained earlier. And it's likely that in some areas of the country where generating capacity is nearly fully utilized, rebates for the new premium-efficiency motors will continue to make sense. This comprises basically the "industrial heartland," plus the Northeast, Northwest and California. As an example, at least one industrial state, Wisconsin, already has two tiers of rebates — the lower tier

Motor Efficiency and Rebate Levels

	Tier 1	Totally Enclosed Fan-Cooled and Explosion-Proof Motors Minimum Efficiencies			Open Drip-Proof Motors Minimum Efficiencies			Tier 2	Totally Enclosed Fan-Cooled and Explosion-Proof Motors Minimum Efficiencies			Open Drip-Proof Motors Minimum Efficiencies		
Motor HP	Rebate Per Motor	RPM 3600	RPM 1800	RPM 1200	RPM 3600	RPM 1800	RPM 1200	Rebate Per Motor	RPM 3600	RPM 1800	RPM 1200	RPM 3600	RPM 1800	RPM 1200
2	$40	84.0	84.0	86.5	84.0	84.0	85.5	$75	86.5	86.5	88.5	86.5	86.5	87.5
3	$40	85.5	87.5	87.5	84.0	86.5	86.5	$75	87.5	89.5	89.5	86.5	88.5	88.5
5	$50	87.5	87.5	87.5	85.5	87.5	87.5	$95	89.5	89.5	89.5	87.5	89.5	89.5
7.5	$80	88.5	89.5	89.5	87.5	88.5	88.5	$120	91.0	91.7	91.7	90.2	91.0	91.7
10	$90	89.5	89.5	89.5	88.5	89.5	90.2	$140	91.7	91.7	91.7	91.0	91.7	92.4
15	$120	90.2	91.0	90.2	89.5	91.0	90.2	$140	92.4	93.0	92.4	91.7	93.0	92.4

Example of two-tier utility rebate program.

linked to NEMA 12-10 (or EPACT '92) levels, the upper tier even higher — and could easily adapt to a single-tier system based on the upper tier once mandates take effect. (See chart on next page.)

Still, even where motor-only rebates might continue, the emphasis by utilities will be more and more on a systems approach to saving energy. Canada provides an example. In Canada, which began its provincial and federal efforts to boost motor efficiency years before the United States, utilities now offer no efficiency rebates at all, feeling that their objective to boost the population of energy-efficiency motors has been achieved over the past several years. The market share of high-efficiency motors in now reported to be above 50% in most provinces, and as high as 75% in British Columbia, which has been under EPACT-level efficiency mandates since the beginning of 1995.

The point is, Canadian utilities have demonstrated in a very practical fashion that rebates and focused motor-efficiency efforts are clearly the first step, to be followed by programs addressing inefficiencies throughout a motor-driven system. It's easy to see the value of such an approach. While motor efficiencies, taken alone, continue to push into the mid 90% area, overall system efficiencies may well be as low as 50% — the result of oversized, mismatched or inefficient machinery, or poor operating and maintenance procedures. Simply put, the remaining few percentage points of inefficiency that might be wrung from a motor, at considerable additional effort and cost, are dwarfed by the dozens of percentage points of gain possible through a comprehensive systems approach. This is especially true when the system is relatively high horsepower and operates all or most of the time, such as many fans, blowers or pumps.

Very often, the systems approach in such cases is equated to the use of adjustable speed drives to modulate output, rather than simply using single-speed motors and throttling techniques such as valves or dampers. In reality, that is only one important tool in the solution that involves an overall effort to match system performance more closely to process requirements—an effort that the Department of Energy says could save 10 times more energy than motor optimization alone. Already, programs to encourage such “process optimization” through financial assistance have taken root under the auspices of utilities and other groups, not only in Canada, but also in the U.S. Midwest. Plus, the Department of Energy, through its Motor Challenge program, continues to showcase the advantages of managing all parts of a motor-driven system. And this overall systems approach, we believe, will quite appropriately represent the efficiency trend of the future.

Full-Load Efficiencies of Design E Motors

	Open Motors		
	2 POLE	**4 POLE**	**6 POLE**
HP	**Nominal Efficiency**	**Nominal Efficiency**	**Nominal Efficiency**
0.75	—	—	82.5 —
1.0	—	86.5 (82.5)	84.0 (80.0)
1.5	86.5 (82.5)	87.5 (84.0)	87.5 (84.0)
2.0	87.5 (84.0)	87.5 (84.0)	88.5 (85.0)
3.0	87.5 (84.0)	89.5 (86.5)	89.5 (86.5)
5.0	88.5 (85.5)	90.2 (87.5)	90.2 (87.5)
7.5	90.2 (87.5)	91.0 (88.5)	91.0 (88.5)
10.0	91.0 (88.5)	91.7 (89.5)	92.4 (90.2)
15.0	91.0 (89.5)	92.4 (91.0)	92.4 (90.2)
20.0	92.4 (90.2)	93.0 (91.0)	92.4 (91.0)
25.0	93.0 (91.0)	93.6 (91.7)	93.6 (91.7)
30.0	93.0 (91.0)	94.1 (92.4)	93.6 (92.4)
40.0	93.6 (91.7)	94.5 (93.0)	94.5 (93.0)
50.0	93.6 (92.4)	95.4 (93.0)	94.5 (93.0)
60.0	93.6 (93.0)	95.4 (93.6)	95.0 (93.6)
75.0	94.5 (93.0)	95.4 (94.1)	95.4 (93.6)
100.0	95.0 (93.0)	95.4 (94.1)	95.4 (94.1)
125.0	95.4 (93.6)	95.4 (94.5)	95.4 (94.1)
150.0	95.8 (93.6)	95.8 (95.0)	95.8 (94.5)
200.0	95.8 (94.5)	95.8 (95.0)	95.8 (94.5)
250.0	95.8 (94.5)	96.2 (95.4)	96.2 (95.4)
300.0	96.2 (95.0)	96.2 (95.4)	96.2 (95.4)
350.0	96.2 (95.0)	96.5 (95.4)	96.5 (95.4)
400.0	96.5 (95.4)	96.5 (95.4)	—
450.0	96.5 (95.8)	96.8 (95.8)	—
500.0	96.8 (95.8)	96.8 (95.8)	—
	Enclosed Motors		
0.75	—	—	82.5 —
1.0	— (75.5)	86.5 (82.5)	84.0 (80.0)
1.5	86.5 (82.5)	87.5 (84.0)	86.5 (85.5)
2.0	87.5 (84.0)	87.5 (84.0)	88.5 (86.5)
3.0	88.5 (85.5)	88.5 (87.5)	89.5 (87.5)
5.0	90.2 (87.5)	89.5 (87.5)	90.2 (87.5)
7.5	91.0 (88.5)	90.2 (89.5)	91.7 (89.5)
10.0	91.0 (89.5)	91.0 (89.5)	92.4 (89.5)
15.0	91.7 (90.2)	92.4 (91.0)	92.4 (90.2)
20.0	92.4 (90.2)	93.0 (91.0)	92.4 (90.2)
25.0	93.0 (91.0)	93.6 (92.4)	93.6 (91.7)
30.0	93.6 (91.0)	94.1 (92.4)	93.6 (91.7)
40.0	94.1 (91.7)	94.5 (93.0)	94.1 (93.0)
50.0	94.5 (92.4)	95.0 (93.0)	94.1 (93.0)
60.0	94.5 (93.0)	95.0 (93.6)	95.0 (93.6)
75.0	94.5 (93.0)	95.4 (94.1)	95.0 (93.6)
100.0	95.0 (93.6)	95.4 (94.5)	95.4 (94.1)
125.0	95.4 (94.5)	95.8 (94.5)	95.4 (94.1)
150.0	95.8 (94.5)	95.8 (95.0)	95.8 (95.0)
200.0	96.2 (95.0)	96.2 (95.0)	96.2 (95.0)
250.0	96.2 (95.4)	96.2 (95.0)	96.2 (95.0)
300.0	96.2 (95.4)	96.2 (95.4)	96.2 (95.0)
350.0	96.5 (95.4)	96.5 (95.4)	96.5 (95.0)
400.0	96.5 (95.4)	96.5 (95.4)	—
450.0	96.5 (95.4)	96.8 (95.4)	—
500.0	96.8 (95.4)	96.8 (95.8)	—

Design E standards for the "next generation" of motor efficiency. NEMA 12-10 values are shown in parentheses. Through 200 HP, NEMA 12-10 efficiencies are the basis for the EPACT mandates, which are to take effect in October 1997.

Appendix A

Department of Energy
Washington, DC 20585

SEP 17 1997

Policy Statement for Electric Motors Covered Under the Energy Policy and Conservation Act

The enclosed policy statement provides guidance concerning compliance with provisions of the Energy Policy and Conservation Act, as amended, (EPCA) which establish energy efficiency standards and test procedures for certain commercial and industrial electric motors.

Section 340(13)(A) of EPCA defines the term "electric motor," and a rule proposed by the Department of Energy (Department) at 61 FR 60440, November 27, 1996, clarifies this definition. Notwithstanding the definition in EPCA and the proposed clarification, motor manufacturers have expressed residual uncertainty as to whether motors with certain modifications are "electric motors" covered under the statute. Consequently, motor manufacturers have requested that the Department provide guidance as to which types of motors are covered under EPCA. Motor manufacturers have also expressed concern about their ability to comply with the statute by October 25, 1997, for some such covered motors, and the impact of compliance on manufacturers of some equipment that incorporates electric motors. Hence, they have requested that the Department delay enforcement of EPCA as to certain motors.

The policy statement that follows addresses these concerns. It is based upon recommendations from motor manufacturers, original equipment manufacturers, energy efficiency advocates, trade associations, testing laboratories, and other government officials, and provides such guidance.

Sincerely,

Joseph J. Romm
Acting Assistant Secretary
Energy Efficiency and Renewable Energy

Enclosure

U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy:
Policy Statement for Electric Motors Covered Under the Energy Policy and Conservation Act

I. Introduction

The Energy Policy and Conservation Act (EPACT), 42 U.S.C. 6311, et seq., establishes energy efficiency standards and test procedures for certain commercial and industrial electric motors manufactured (alone or as a component of another piece of equipment) after October 24, 1997, or, in the case of an electric motor which requires listing or certification by a nationally recognized safety testing laboratory, after October 24, 1999.[1] EPACT also directs the Department of Energy (DOE or Department) to implement the statutory test procedures prescribed for motors, and to require efficiency labeling of motors and certification that covered motors comply with the standards.

Section 340(13)(A) of EPACT defines the term “electric motor” based essentially on the construction and rating system in the National Electrical Manufacturers Association (NEMA) Standards Publication MG1. Sections 340(13)(B) and (C) of EPACT define the terms “definite purpose motor” and “special purpose motor,” respectively, for which the statute prescribes no efficiency standards.

In its proposed rule to implement the EPACT provisions that apply to motors (61 FR 60440, November 27, 1996), DOE has proposed to clarify the statutory definition of “electric motor,” to mean a machine which converts electrical power into rotational mechanical power and which: 1) is a general purpose motor, including motors with explosion-proof construction[2]; 2) is a single speed, induction motor; 3) is rated for continuous duty operation, or is rated duty type S-1 (IEC)[3]; 4) contains a squirrel-cage or cage (IEC) rotor; 5) has foot-mounting, including foot-mounting with flanges or detachable feet; 6) is built in accordance with NEMA T-frame dimensions, or IEC metric equivalents (IEC); 7) has performance in accordance with NEMA Design A or B characteristics, or equivalent designs such as IEC Design N (IEC); and 8) operates on polyphase alternating current 60-Hertz sinusoidal power, and is (i) rated 230 volts or 460 volts, or both, including any motor that is rated at multi-voltages that include 230 volts or 460 volts, or (ii) can be operated on 230 volts or 460 volts, or both.

[1] The term “manufacture” means “to manufacture, produce, assemble or import.” EPACT ß321(10). Thus, the standards apply to motors produced, assembled, imported or manufactured after these statutory deadlines.

[2] Section 342(b)(1) of EPACT recognizes that EPCA’s efficiency standards cover “motors which require listing or certification by a nationally recognized safety testing laboratory.” This applies, for example, to explosion-proof motors which are otherwise general purpose motors.

[3] Terms followed by the parenthetical “IEC” are referred to in the International Electrotechnical Commission (IEC) Standard 34-1. Such terms are included in DOE’s proposed definition of “electric motor” because DOE believes EPCA’s efficiency requirements apply to metric system motors that conform to IEC Standard 34, and that are identical or equivalent to motors constructed in accordance with NEMA MG1 and covered by the statute.

Notwithstanding the clarification provided in the proposed rule, there still appears to be uncertainty as to which motors EPACT covers. It is widely understood that the statute covers "general purpose" motors that are manufactured for a variety of applications, and that meet EPCA's definition of "electric motor." Many modifications, however, can be made to such generic motors. Motor manufacturers have expressed concern as to precisely which motors with such modifications are covered under the statute, and as to whether manufacturers will be able to comply with the statute by October 25, 1997 with respect to all of these covered motors. Consequently, motor manufacturers have requested that the Department provide additional guidance as to which types of motors are "electric motors," "definite purpose motors," and "special purpose motors" under EPACT. The policy statement that follows is based upon input from motor manufacturers and energy efficiency advocates, and provides such guidance.

II. Guidelines for Determining Whether a Motor is Covered by EPACT

A. General

EPACT specifies minimum nominal full-load energy efficiency standards for 1 to 200 horsepower electric motors, and, to measure compliance with those standards, prescribes use of the test procedures in NEMA Standard MG1 and Institute of Electrical and Electronics Engineers (IEEE) Standard 112. In DOE's view, as stated in Assistant Secretary Ervin's letter of May 9, 1996, to NEMA's Malcolm O'Hagan, until DOE's regulations become effective, manufacturers can establish compliance with these EPACT requirements through use of competent and reliable procedures or methods that give reasonable assurance of such compliance. So long as these criteria are met, manufacturers may conduct required testing in their own laboratories or in independent laboratories, and may employ alternative correlation methods (in lieu of actual testing) for some motors. Manufacturers may also establish their compliance with EPACT standards and test procedures through use of third party certification or verification programs such as those recognized by Natural Resources Canada. Labeling and certification requirements will become effective only after DOE has promulgated a final rule prescribing such requirements.

Motors with features or characteristics that do not meet the statutory definition of "electric motor" are not covered, and therefore are not required to meet EPACT requirements. Examples include motors without feet and without provisions for feet, and variable speed motors operated on a variable frequency power supply. Similarly, multispeed motors and variable speed motors, such as inverter duty motors, are not covered equipment, based on their intrinsic design for use at variable speeds. However, NEMA Design A or B motors that are single speed, meet all other criteria under the definitions in EPACT for covered equipment, and can be used with an inverter in variable speed applications as an additional feature, are covered equipment under EPACT. In other words, being suitable for use on an inverter by itself does not exempt a motor from EPACT requirements.

Section 340(13)(F) of EPACT, defines a "small electric motor" as "a NEMA general purpose alternating current single-speed induction motor, built in a two-digit frame number series in accordance with NEMA Standards Publication MG 1-1987." Section 346 of EPACT requires DOE to prescribe testing requirements and efficiency standards only for those small electric motors for which the Secretary determines that standards are warranted. The Department has not yet made such a determination.

B. Electrical Features

As noted above, the Department's proposed definition of "electric motor" provides in part that it is a motor that "operates on polyphase alternating current 60-Hertz sinusoidal power, and...can be operated on 230 volts or 460 volts, or both." In DOE's view, "can be operated" implicitly means that the motor can be operated successfully. According to NEMA Standards Publication MG1-1993, section 12.44, "Variations from Rated Voltage and Rated Frequency," alternating-current motors must operate successfully under running conditions at rated load with a variation in the voltage or the frequency up to the following: plus or minus 10 percent of rated voltage, with rated frequency for induction motors;4 plus or minus 5 percent of rated frequency, with rated voltage; and a combined variation in voltage and frequency of 10 percent (sum of absolute values) of the rated values, provided the frequency variation does not exceed plus or minus 5 percent of rated frequency. DOE believes that, for purposes of determining whether a motor meets EPCA's definition of "electric motor," these criteria should be used to determine when a motor that is not rated at 230 or 460 volts or 60 Hertz can be operated at such voltage and frequency.5

NEMA Standards Publication MG1 categorizes electrical modifications to motors according to performance characteristics that include locked rotor torque, breakdown torque, pull-up torque, locked rotor current, and slip at rated load, and assigns design letters, such as Design A, B, C, D, or E, to identify various combinations of such electrical performance characteristics. Under section 340(13)(A) of EPACT, electric motors subject to EPACT efficiency requirements include only motors that fall within NEMA "Design A and B...as defined in [NEMA] Standards Publication MG1-1987." As to locked rotor torque, for example, MG1 specifies a minimum performance value for a Design A or B motor of a given speed and horsepower, and somewhat higher minimum values for Design C and D motors of the same speed and horsepower. The Department understands that, under MG1, the industry classifies a motor as Design A or B if it has a locked rotor torque at or above the minimum for A and B but below the minimum for Design C, so long as it otherwise meets the criteria for Design A or B. Therefore, in the Department's view, such a motor is covered by EPCA's requirements for electric motors.

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4 For example, a motor that is rated at 220 volts should operate successfully on 230 volts, since 220 + .10(220) = 242 volts. A 208 volt motor, however, would not be expected to operate successfully on 230 volts, since 208 + .10(208) = 228.8 volts.

5 The Department understands that a motor that can operate at such voltage and frequency, based on variations defined for successful operation, will not necessarily perform in accordance with the industry standards established for operation at the motor's rated voltage and frequency. In addition, under the test procedures prescribed by EPACT, motors are to be tested at their rated values. Therefore, in DOE's view a motor that is not rated for 230 or 460 volts, or 60 Hertz, but that can be successfully operated at these levels, must meet the energy efficiency requirements at its rated voltage(s) and frequency. DOE also notes that when a motor is rated to include a wider voltage range that includes 230/460 volts, the motor should meet the energy efficiency requirements at 230 volts or 460 volts.

By contrast a motor that meets or exceeds the minimum locked rotor torque for Design C or D is not covered by EPACT. In sum, if a motor has electrical modifications that meet Design A or B performance requirements it is covered by EPACT, and if its characteristics meet Design C, D or E it is not covered.

C. Size

Motors designed for use on a particular type of application which are in a frame size that is one or more frame series larger than the frame size assigned to that rating by sections 1.2 and 1.3 of NEMA Standards Publication MG 13-1984 (R1990), "Frame Assignments for Alternating Current Integral-Horsepower Induction Motors," are not, in the Department's view, usable in most general purpose applications. This is due to the physical size increase associated with a frame series change. A frame series is defined as the first two digits of the frame size designation. For example, 324T and 326T are both in the same frame series, while 364T is in the next larger frame series. Hence, in the Department's view, a motor that is of a larger frame series than normally assigned to that standard rating of motor is not covered by EPACT. A physically larger motor within the same frame series would be covered, however, because it would be usable in most general purpose applications.

Motors built in a T-frame series or a T-frame size smaller than that assigned by MG 13-1984 (R1990) are also considered usable in most general purpose applications. This is because simple modifications can generally be made to fit a smaller motor in place of a motor with a larger frame size assigned in conformity with NEMA MG 13. Therefore, DOE believes that such smaller motors are covered by EPACT.

D. Motors with Seals

Some electric motors have seals to prevent ingress of water, dust, oil, and other foreign materials into the motor. DOE understands that, typically, a manufacturer will add seals to a motor that it manufactures, so that it will sell two motors that are identical except that one has seals and the other does not. In such a situation, if the motor without seals is "general purpose" and covered by EPCA's efficiency requirements, then the motor with seals will also be covered because it can still be used in most general purpose applications. DOE understands, however, that manufacturers previously believed motors with seals were not covered under EPACT, in part because IEEE Standard 112, "Test Procedure for Polyphase Induction Motors and Generators," prescribed by EPACT, does not address how to test a motor with seals installed.

The efficiency rating of such a motor, if determined with seals installed and when the motor is new, apparently would significantly understate the efficiency of the motor as operated. New seals are stiff, and provide friction that is absent after their initial break-in period. DOE understands that, after this initial period, the efficiency ratings determined for the same motor with and without seals would be virtually identical. To construe EPACT, therefore, as requiring such separate efficiency determinations would impose an unnecessary burden on manufacturers.

In light of the foregoing, the Department believes that EPACT generally permits the efficiency of a motor with seals to be determined without the seals installed. Furthermore, notwithstanding the prior belief that such motors are not covered by EPACT, use of this approach to determining efficiency will enable manufacturers to meet EPCA's standards with respect to covered motors with seals by the date the standards go into effect on October 25, 1997.

III. Discussion of How DOE Would Apply EPACT Definitions, Using the Foregoing Guidelines

Using the foregoing guidelines, the attached matrix provides DOE's view as to which motors with common features are covered by EPACT. Because manufacturers produce many basic models that have many modifications of generic general purpose motors, the Department does not represent that the matrix is all-inclusive. Rather it is a set of examples demonstrating how DOE would apply EPACT definitions, as construed by the above guidelines, to various motor types. By extension of these examples, most motors currently in production, or to be designed in the future, could probably be classified. The matrix classifies motors into five categories, which are discussed in the following passages.

Category I - For "electric motors" (manufactured alone or as a component of another piece of equipment) in Category I, DOE will enforce EPACT efficiency standards and test procedures beginning on October 25, 1997.

The Department understands that some motors essentially are relatively simple modifications of generic general purpose motors. Modifications could consist, for example, of minor changes such as the addition of temperature sensors or a heater, the addition of a shaft extension and a brake disk from a kit, or changes in exterior features such as the motor housing. Such motors can still be used for most general purpose applications, and the modifications have little or no effect on motor performance. Nor do the modifications affect energy efficiency.

Category II - For certain motors that are "definite purpose" according to present industry practice, but that can be used in most general purpose applications, DOE will generally enforce EPACT efficiency standards and test procedures beginning no later than October 25, 1999.

<u>General Statement</u>
EPACT does not prescribe standards and test procedures for "definite purpose motors." Section 340(13)(B) of EPACT defines the term "definite purpose motor" as "any motor designed in standard ratings with standard operating characteristics or standard mechanical construction for use under service conditions other than usual or for use on a particular type of application and which cannot be used in most general purpose applications." [Emphasis added.] Except, significantly, for exclusion of the italicized language, the industry definition of "definite purpose motor," set forth in NEMA MG1, is identical to the foregoing.

Category II consists of electric motors with horsepower ratings that fall between the horsepower ratings in section 342(b)(1) of EPACT, thermally protected motors, and motors with roller bearings. As with motors in Category I, these motors are essentially modifications of generic general purpose motors. Generally, however, the modifications contained in these motors are more extensive and complex than the modifications in Category I motors. These Category II motors have been considered "definite purpose" in common industry parlance, but are covered equipment under EPACT because they can be used in most general purpose applications.

According to statements provided during the January 15, 1997, Public Hearing, Tr. pgs. 238-239, Category II motors were, until recently, viewed by most manufacturers as definite purpose motors, consistent with the industry definition that did not contain the clause "which cannot be used in most general purpose applications." Hence, DOE understands that many manufacturers assumed these motors were not subject to EPCA's efficiency standards. During the period prior and subsequent to the hearing, discussions among manufacturers resulted in a new understanding that such motors are general purpose under EPACT, since they can be used in most general purpose applications. Thus, the industry only recently recognized that such motors are covered under EPACT. Although the statutory definition adopted in 1992 contained the above-quoted definition of "definite purpose," the delay in issuing regulations which embody this definition may have contributed to industry's delay in recognizing that these motors are covered.

The Department understands that redesign and testing these motors in order to meet the efficiency standards in the statute may require a substantial amount of time. Given the recent recognition that they are covered, it is not realistic to expect these motors will be able to comply by October 25, 1997. A substantial period beyond that will be required. Moreover, the Department believes different manufacturers will need to take different approaches to achieving compliance with respect to these motors, and that, for a particular type of motor, some manufacturers will be able to comply sooner than others. Thus, the Department intends to refrain from taking enforcement action for two years, until October 25, 1999, with respect to motors with horsepower ratings that fall between the horsepower ratings in section 342(b)(1) of EPACT, thermally protected motors, and motors with roller bearings. Manufacturers are encouraged, however, to manufacture these motors in compliance with EPACT at the earliest possible date.

The following sets forth in greater detail, for each of these types of motors, the basis for the Department's policy to refrain from enforcement for two years. Also set forth is additional explanation of the Department's understanding as to why manufacturers previously believed intermediate horsepower motors were not covered by EPACT.

Intermediate Horsepower Ratings

Section 342(b)(1) of EPACT specifies efficiency standards for electric motors with 19 specific horsepower ratings, ranging from one through 200 horsepower. Each is a preferred or standardized horsepower rating as reflected in the table in NEMA Standards Publication MG1-1993, paragraph 10.32.4, Polyphase Medium Induction Motors.

However, an “electric motor,” as defined by EPACT, can be built at other horsepower ratings, such as 6 horsepower, 65 horsepower, or 175 horsepower. Such motors, rated at horsepower levels between any two adjacent horsepower ratings identified in section 342(b)(1) of EPACT will be referred to as “intermediate horsepower motors.” In the Department’s view, efficiency standards apply to every motor that has a rating from one through 200 horsepower (or kilowatt equivalents), and that otherwise meets the criteria for an “electric motor” under EPACT, including an electric motor with an intermediate horsepower (or kw) rating.

To date, these motors have typically been designed in conjunction with and supplied to a specific customer to fulfill certain performance and design requirements of a particular application, as for example to run a certain type of equipment. See the discussion in Section IV below on “original equipment” and “original equipment manufacturers.” In large part for these reasons, manufacturers believed intermediate horsepower motors to be “definite purpose motors “that were not covered by EPACT. Despite their specific uses, however, these motors are electric motors under EPACT when they are capable of being used in most general purpose applications.

Features of a motor that are directly related to its horsepower rating include its physical size, and the ratings of its controller and protective devices. These aspects of a 175 horsepower motor, for example, which is an intermediate horsepower motor, must be appropriate to that horsepower, and would generally differ from the same aspects of 150 and 200 horsepower motors, the two standard horsepower ratings closest to 175. To re-design an existing intermediate horsepower electric motor so that it complies with EPACT could involve all of these elements of a motor’s design. For example, the addition of material necessary to achieve EPCA’s prescribed level of efficiency could cause the size of the motor to increase. The addition of magnetic material would invite higher inrush current that could cause an incorrectly sized motor controller to malfunction, or the circuit breaker with a standard rating to trip unnecessarily, or both. The Department believes motor manufacturers will require a substantial amount of time to redesign and retest each intermediate horsepower electric motor they manufacture.

To the extent such intermediate horsepower electric motors become unavailable because motor manufacturers have recognized only recently that they are covered by EPACT, equipment in which they are incorporated would temporarily become unavailable also. Moreover, re-design of such a motor to comply with EPACT could cause changes in the motor that require re-design of the equipment in which the motor is used. For example, if an intermediate horsepower electric motor becomes larger, it might no longer fit in the equipment for which it was designed. In such instances, the equipment would have to be re-designed. Because these motors were previously thought not to be covered, equipment manufacturers may not have had sufficient lead time to make the necessary changes to the equipment without interrupting its production.

With respect to intermediate horsepower motors, the Department intends to refrain from enforcing EPACT for a period of 24 months only as to such motor designs that were being manufactured prior to the date this Policy Statement was issued. The Department is concerned that small adjustments could be made to the horsepower rating of an existing electric motor, in an effort to delay compliance with EPACT, if it delayed enforcement as to all intermediate horsepower motors produced during the 24 month period. For example, a 50 horsepower motor that has a service factor of 1.15 could be renameplated as a 57Ω horsepower motor that has a 1.0 service factor. By making this delay in enforcement applicable only to pre-existing designs of intermediate horsepower motors, the Department believes it has made adequate provision for the manufacture of bona fide intermediate horsepower motor designs that cannot be changed to be in compliance with EPACT by October 25, 1997.

<u>Thermally Protected Motors</u>

The Department understands that in order to redesign a thermally protected motor to improve its efficiency so that it complies with EPACT, various changes in the windings must be made which will require the thermal protector to be re-selected. Such devices sense the inrush and running current of the motor, as well as the operating temperature. Any changes to a motor that affect these characteristics will prevent the protector from operating correctly. When a new protector is selected, the motor must be tested to verify proper operation of the device in the motor. The motor manufacturer would test the locked rotor and overload conditions, which could take several days, and the results may dictate that a second selection is needed with additional testing. When the manufacturer has finished testing, typically the manufacturer will have a third party conduct additional testing. This testing may include cycling the motor in a locked-rotor condition to verify that the protector functions properly. This testing may take days or even weeks to perform for a particular model of motor.

Since it was only recently recognized by industry that these motors are covered by EPACT, in the Department’s view the total testing program makes it impossible for manufacturers to comply with the EPACT efficiency levels in thermally protected motors by October 25, 1997, especially since each different motor winding must be tested and motor winding/thermal protector combinations number in the thousands.

<u>Motors with Roller Bearings</u>

Motors with roller bearings fit within the definition of electric motor under the statute. However, because the IEEE Standard 112 Test Method B does not provide measures to test motors with roller bearings installed, manufacturers mistakenly believed such motors were not covered. Under IEEE 112, a motor with roller bearings could only be tested for efficiency with the roller bearings removed and standard ball bearings installed as temporary substitutes. Then on the basis of the energy efficiency information gained from that test, the manufacturer may need to redesign the motor in order to comply with the statute. In this situation, the Department understands that testing, redesigning, and retesting lines of motors with roller bearings, to establish compliance, would be difficult and time consuming.

Categories III, IV and V - Motors not within EPCA’s definition of “electric

motor," and not covered by EPACT.

Close-coupled Pump Motors

NEMA Standards Publication MG1-1993, with revisions one through three, Part 18, "Definite-Purpose Machines," defines "a face-mounting close-coupled pump motor" as "a medium alternating-current squirrel-cage induction open or totally enclosed motor, with or without feet, having a shaft suitable for mounting an impeller and sealing device." Paragraphs MG1 18.601-18.614 specify its performance, face and shaft mounting dimensions, and frame assignments that replace the suffix letters T and TS with the suffix letters JM and JP.

The Department understands that such motors are designed in standard ratings with standard operating characteristics for use in certain close-coupled pumps and pumping applications, but cannot be used in non-pumping applications, such as, for example, conveyors. Consequently, the Department believes close-coupled pump motors are definite-purpose motors not covered by EPACT. However, a motor that meets EPCA's definition of "electric motor," and which can be coupled to a pump, for example by means of a C-face or D-flange endshield, as depicted in NEMA Standards Publication MG1, Part 4, "Dimensions, Tolerances, and Mounting," is covered.

Totally-enclosed Non-ventilated (TENV) and Totally-enclosed Air-over (TEAO) Motors

A motor designated in NEMA MG1-1993, paragraph MG1-1.26.1, as "totally-enclosed non-ventilated (IP54, IC410)"6 is "not equipped for cooling by means external to the enclosing parts." This means that the motor, when properly applied, does not require the use of any additional means of cooling installed external to the motor enclosure. The TENV motor is cooled by natural conduction and natural convection of the motor heat into the surrounding environment. As stated in NEMA MG1-1993, Suggested Standard for Future Design, paragraph MG1-1.26.1a, a TENV motor "is only equipped for cooling by free convection." The general requirement for the installation of the TENV motor is that it not be placed in a restricted space that would inhibit this natural dissipation of the motor heat. Most general purpose applications use motors which include a means for forcing air flow through or around the motor and usually through the enclosed space and, therefore, can be used in spaces that are more restrictive than those required for TENV motors. Placing a TENV motor in such common restricted areas is likely to cause the motor to overheat. The TENV motor may also be larger than the motors used in most general purpose applications, and would take up more of the available space, thus reducing the size of the open area surrounding the motor. Installation of a TENV motor might require, therefore, an additional means of ventilation to continually exchange the ambient around the motor.

A motor designated in NEMA MG1-1993 as "totally-enclosed air-over (IP54, IC417)" is intended to be cooled by ventilation means external to (i.e., separate and independent from) the motor, such as a fan. The motor must be provided with the additional ventilation to prevent it from overheating.

Consequently, neither the TENV motor nor the TEAO motor would be suitable for most general purpose applications, and, DOE believes they are definite-purpose motors not covered by EPACT.

Integral Gearmotors

An “integral gearmotor” is an assembly of a motor and a specific gear drive or assembly of gears, such as a gear reducer, as a unified package. The motor portion of an integral gearmotor is not necessarily a complete motor, since the end bracket or mounting flange of the motor portion is also part of the gear assembly and cannot be operated when separated from the complete gear assembly. Typically, an integral gearmotor is not manufactured to standard T-frame dimensions specified in NEMA MG1. Moreover, neither the motor portion, not the entire integral gearmotor, are capable of being used in most general purpose applications without significant modifications. An integral gearmotor is also designed for a specific purpose and can have unique performance characteristics, physical dimensions, and casing, flange and shafting configurations. Consequently, integral gearmotors are outside the scope of the EPACT definition of “electric motor” and are not covered under EPACT.

However, an “electric motor,” as defined by EPACT, which is connected to a stand alone mechanical gear drive or an assembly of gears, such as a gear reducer connected by direct coupling, belts, bolts, a kit, or other means, is covered equipment under EPACT.

IV. Electric Motors that are Components in Certain Equipment

The primary function of an electric motor is to convert electrical energy to mechanical energy which then directly drives machinery such as pumps, fans, or compressors. Thus, an electric motor is always connected to a driven machine or apparatus. Typically the motor is incorporated into a finished product such as an air conditioner, a refrigerator, a machine tool, food processing equipment, or other commercial or industrial machinery. These products are commonly known as “original equipment” or “end-use equipment,” and are manufactured by firms known as “original equipment manufacturers” (OEM).

Many types of motors used in original equipment are covered under EPACT. As noted above, EPACT prescribes efficiency standards to be met by all covered electric motors manufactured after October 24, 1997, except that covered motors which require listing or certification by a nationally recognized safety testing laboratory need not meet the standards until after October 24, 1999. Thus, for motors that must comply after October 24, 1997, once inventories of motors manufactured before the deadline have been exhausted, only complying motors would be available for purchase and use by OEMs in manufacturing original equipment. Any non-complying motors previously included in such equipment would no longer be available.

The physical, and sometimes operational, characteristics of motors that meet EPACT

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[6] IP refers to the IEC Standard 34-5: Classification of degrees of protection provided by enclosures for rotating machines. IC refers to the IEC Standard 34-6: Methods of rotating machinery. The IP and IC codes are referenced in the NEMA designations for TENV and TEAO motors in MG1-1993 Part 1, “Classification According to Environmental Protection and Methods of Cooling,”as a Suggested Standard for Future Design, since the TENV and TEAO motors conform to IEC Standards. Details of protection (IP) and methods of cooling (IC) are defined in MG1 Part 5 and Part 6, respectively.

efficiency standards normally differ from the characteristics of comparable existing motors that do not meet those standards. In part because of such differences, the Department is aware of two types of situations where strict application of the October 24, 1997 deadline could temporarily prevent the manufacture of, and remove from the marketplace, currently available original equipment.

One such situation is where an original equipment manufacturer uses an electric motor as a component in end-use equipment that requires listing or certification by a nationally recognized safety testing laboratory, even though the motor itself does not require listing or certification. In some of these instances, the file for listing or certification specifies the particular motor to be used. No substitution could be made for the motor without review and approval of the new motor and the entire system by the safety testing laboratory. Consequently, a specified motor that does not meet EPACT standards could not be replaced by a complying motor without such review and approval.

This re-listing or re-certification process is subject to substantial variation from one piece of original equipment to the next. For some equipment, it could be a simple paperwork transaction between the safety listing or certification organization and the OEM, taking approximately four to eight weeks to complete. But the process could raise more complex system issues involving redesign of the motor or piece of equipment, or both, and actual testing to assure that safety and performance criteria are met, and could take several months to complete. The completion time could also vary depending on the response time of the particular safety approval agency. Moreover, in the period immediately after October 24, the Department believes wholesale changes could occur in equipment lines when OEMs must begin using motors that comply with EPACT. These changes are likely to be concentrated in the period immediately after EPACT goes into effect on October 24, and if many OEMs seek to re-list or re-certify equipment at the same time, substantial delays in the review and approval process at the safety approval agencies could occur. For these reasons, the Department is concerned that certain end-user equipment that requires safety listing or certification could become unavailable in the marketplace, because an electric motor specifically identified in a listing or certification is covered by EPACT and will become unavailable, and the steps have not been completed to obtain safety approval of the equipment when manufactured with a complying motor.

Second, a situation could exist where an electric motor covered by EPACT is constructed in a T-frame series or T-frame size that is smaller (but still standard) than that assigned by NEMA Standards Publication MG 13-1984 (R1990), sections 1.2 and 1.3, in order to fit into a restricted mounting space that is within certain end-use equipment. (Motors in IEC metric frame sizes and kilowatt ratings could also be involved in this type of situation.) In such cases, the manufacturer of the end-use equipment might need to redesign the equipment containing the mounting space to accommodate a larger motor that complies with EPACT. These circumstances as well could result in certain currently available equipment becoming temporarily unavailable in the market, since the smaller size motor would become unavailable before the original equipment had been re-designed to accommodate the larger, complying motor.

The Department understands that many motor manufacturers and OEMs became aware only recently that the electric motors addressed in the preceding paragraphs were covered by EPACT. This is largely for the same reasons, discussed above, that EPACT coverage of Category II motors was only recently recognized. In addition, the Department understands that some motor manufacturers and original equipment manufacturers confused motors that themselves require safety listing or certification, which need not comply until October 25, 1999, with motors that, while not subject to such requirements, are included in original equipment that requires safety listing or certification. Consequently, motor manufacturers and original equipment manufacturers took insufficient action to assure that appropriate complying motors would be available for the original equipment involved, and that the equipment could accommodate such motors. OEMs involved in such situations may often be unable to switch to motors that meet EPACT standards in the period immediately following October 24. To mitigate any hardship to purchasers of the original equipment, the Department intends to refrain from enforcing EPACT in certain limited circumstances, under the conditions described below.

Where a particular electric motor is specified in an approved safety listing or certification for a piece of original equipment, and the motor does not meet the applicable efficiency standard in EPACT, the Department’s policy will be as follows: For the period of time necessary for the OEM to obtain a revised safety listing or certification for that piece of equipment, with a motor specified that complies with EPACT, but in no event beyond October 24, 1999, the Department would refrain from taking enforcement action under EPACT with respect to manufacture of the motor for installation in such original equipment. This policy would apply only where the motor has been manufactured and specified in the approved safety listing or certification prior to October 25, 1997.

Where a particular electric motor is used in a piece of original equipment and manufactured in a smaller than assigned frame size or series, and the motor does not meet the applicable efficiency standard in EPACT, the Department’s policy will be as follows: For the period of time necessary for the OEM to re-design the piece of equipment to accommodate a motor that complies with EPACT, but in no event beyond October 24, 1999, the Department would refrain from enforcing the standard with respect to manufacture of the motor for installation in such original equipment. This policy would apply only to a model of motor that has been manufactured and included in the original equipment prior to October 25, 1997.

To allow the Department to monitor application of the policy set forth in the prior two paragraphs, the Department needs to be informed as to the motors being manufactured under the policy. Therefore, each motor manufacturer and OEM should jointly notify the Department as to each motor they will be manufacturing and using, respectively, after October 24, 1997, in the belief that it is covered by the policy. The notification should set forth: 1) the name of the motor manufacturer, and a description of the motor by type, model number, and date of design or production; 2) the name of the original equipment manufacturer, and a description of the application where the motor is to be used; 3) the safety listing or safety certification organization and the existing listing or certification file or document number for which re-listing or re-certification will be requested, if applicable; 4) the reason and amount of time required for continued production of the motor, with a statement that a substitute electric motor that complies with EPACT could not be obtained by an earlier date; and 5) the name, address, and telephone number of the person to contact for further information. The joint request should be signed by a responsible official of each requesting company, and sent to: U.S. Department of Energy, Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Codes and Standards, EE-43, Forrestal Building, 1000 Independence Avenue, SW, Room 1J-018, Washington, DC 20585-0121. The Department does not intend to apply this policy to any motor for which it does not receive such a notification. Moreover, the Department may use the notification, and make further inquiries, to be sure motors listed in the notification meet the criteria for application of the policy.

This part of the Policy Statement will not apply to a motor in Category II, discussed above in section III. Because up to 24 months is contemplated for compliance by Category II motors, the Department believes any issues that might warrant a delay of enforcement for such motors can be addressed during that time period.

V. Further Information

The Department intends to incorporate this Policy Statement into an appendix to its final rule to implement the EPACT provisions that apply to motors. Any comments or suggestions with respect to this Policy Statement, as well as requests for further information, should be addressed to the Director, Office of Codes and Standards, EE-43, U.S. Department of Energy, 1000 Independence Avenue, SW, Washington, DC 20585-0121.

DOE Guidelines – 9/17/97 Draft

Electrical Modifications		**Explanation**
Altitude	I	GP (up to frame series change larger).
Ambient	I	GP (up to frame series change larger).
Multi-Speed	V	EPACT applies to single-speed only.
Special Leads	I	
Special Insulation	I	
Encapsulation	IV	Due to special construction.
High Service Factor	I	GP (up to frame series change larger.)
Space Heaters	I	
Wye Delta Start	I	
Part Winding Start	I	
Temperature Rise	I	GP (up to frame series change larger).
Thermally Protected	II	Requires retesting and 3rd party approval.
Thermostat/Thermistor	I	
Special Voltages	V	EPACT applies to 230/460 VAC.
Intermediate Horsepowers	II	Round HP per 10 CFR 431.42 for efficiency.
Frequency	V	EPACT applies to 60 Hz.
Fungus/Tropical Insulation	I	
Mechanical Modifications		**Explanation**
Special Balance	I	
Bearing Temp. Detector	I	
Special Base/Feet	V	Does not meet definition of T frame.
Special Conduit Box	I	
Auxiliary Conduit Box	I	
Special Paint/Coating	I	
Drains	I	
Drip Cover	I	
Ground Lug/Hole	I	
Screens on ODP Enclosure	I	
F1, F2; W1-4; C1, C2	I	Foot-mounting, rigid base and resilient base.

I. General-purpose motor. Covered 10/24/97.
II. Definite-purpose motor that can be used as general-purpose. Covered 10/24/97.
III. Definite-purpose motor. Not covered.
IV. Special-purpose motor. Not covered.
V. Outside scope of “electric motor” definition. Not covered.

DOE Guidelines – 9/17/97 Draft

Bearings		**Explanation**
Bearing Caps	I	
Roller Bearings	II	Test with a standard bearing.
Shielded Bearings	I	
Sealed Bearings	I	Test with a standard bearing.
Thrust Bearings	IV	Special mechanical construction.
Clamped Bearings	I	
Sleeve Bearings	IV	Special mechanical construction.
Special Endshields		**Explanation**
C Face	I	Covered if with base. Round body exempt.
D Flange	I	Covered if with base. Round body exempt.
Customer Defined	IV	Special design for particular application.
Seals		**Explanation**
Contact Seals	I	Lip and taconite – test w/o seal.
Non-Contact Seal	I	Labyrinth and slinger – test w/seal.
Shafts		**Explanation**
Standard shafts/NEMA MB-1	I	Single, double, cylindrical, tapered, short.
Non-Standard Material	I	
Fans		**Explanation**
Special Material	I	
Quiet Design	I	
Other Motors		**Explanation**
Washdown	I	Test with seals removed.
Close-Coupled Pump	III	JM and JP frame assignments.
Integral Gearmotor	V	Motor, box inseparable, work as system.
Vertical-Normal Thrust	V	EPACT covers horizontal, foot-mounting.
Saw Arbor	IV	Special electrical/mechanical design.
TENV	III	Totally encl., non-vent., no cooling.
TEAO/OAO	III	Requires air flow from external source.
Fire Pump	I	Safety certification not required
Non-Continuous	V	EPACT covers continuous duty ratings.
IEC-Equivalent	I	IEC Stnd. 72-1. Preferred rated outputs.
Brake	IV	Not readily adaptable to GP applications.

I. General-purpose motor. Covered 10/24/97.
II. Definite-purpose motor that can be used as general-purpose. Covered 10/24/97.
III. Definite-purpose motor. Not covered.
IV. Special-purpose motor. Not covered.
V. Outside scope of “electric motor” definition. Not covered.

Appendix B

Understanding IEEE 112 Method B (or CSA C390)

The goal of all of EPACT (Energy Policy Act) legislation is, of course, energy savings. This is to be accomplished by improving energy efficiency or using less energy to perform the same task. To demonstrate or prove a product's energy efficiency, in this case an electric motor, obviously requires a method of testing. And to compare one product to another requires that this method of testing be standardized, preferably to some recognized national or international standard. Discussions about how EPACT applies to electric motors, presently three phase industrial motors, therefore have always included mention of test standard IEEE 112B, or the Canadian Standards Association's C390, which can be considered equivalent. But what are these standards and what do they mean to the average user?

To understand this we must first realize that there are a number of ways to determine an electric motor's efficiency. The most obvious way, or so it would seem, is to connect the motor to a known load and measure the electrical power into the motor. Assuming we now know both the power (or work) output and power going in, the ratio of these is efficiency. A mathematical way of stating this is shown below.

Most of these losses produce the heat given off by the motor during operation. This energy is therefore not available to perform work.

$$\text{efficiency} = \frac{\text{output}}{\text{input}} = \frac{\text{output}}{\text{output + losses}}$$

$$= \frac{\text{input-losses}}{\text{output + losses}} \quad \text{= fraction of the total input power that produces work or output}$$

Motor Losses

Induction motor losses are normally broken into these categories.

- Iron or steel losses: energy lost in the magnetizing of the steel laminations, and to keep them magnetized.
- Stator copper losses: heat generated due to the resistance of the wire as the current flows through it.
- Rotor copper losses: heat generated due to the resistance in the rotor conductors or bars and end rings as current also flows through them.
- Friction and windage losses: energy lost in bearing friction, energy needed to turn the cooling fans and windage of other rotating parts

- Stray losses: other energy lost that does not directly fall into one of the above categories. These are related to the construction of the motor, parts that don't produce output power in or near the magnetic fields in the motor, and interaction of magnetic fields in the motor.

Motor Testing

So why not simply test the motor, as mentioned, to determine the efficiency and total losses? First consider that the efficiency of an electric motor changes as the grease "breaks in" (warms and flows), as the motor materials heat up, and so on. Therefore, a procedure must be established to define which efficiency measurement will be considered the "real" or "steady state" efficiency. Secondly, there is the accuracy of the measurements to consider. The output and input power are relatively large numbers that differ by as much as 15% but as little as 4 to 5%. For lower efficiency motors, a slight error in measurement would have a relatively smaller effect on the efficiency. However, with higher efficiency motors (those for EPACT, higher horsepower motors, etc.) where cost decisions are based on only a few tenths of a percent difference in efficiency, great accuracy is critical. Accuracy is another issue that must be addressed in a standard way to get consistent results. Third, a rotating motor and load constitute a "dynamic" system. Readings of speed, torque, volts, amperes, watts, and temperature are not steady or constant values. There are fluctuations, though small, that must be dealt with during testing in order to be consistent. Basing motor efficiency on essentially one reading could be misleading.

To address all these concerns and more, IEEE (the Institute of Electrical and Electronics Engineers) set out to write standards to define how best to test electric motors. In IEEE standard 112, several methods are described. Efficiency determination is only part of this standard, although it is an important one. Some of the key (there are a total of 10) test methods for efficiency are:

- Method A: simple input-output
- Method B: input-output with loss segregation (or separation)
- Method F: equivalent circuit (model) calculation

The other methods, C, E, E1, F1, C/F, E/F and E1/F1 are variations of these. Very early discussions about efficiency testing concluded that simple input-output was not accurate enough. Method F, using an equivalent circuit approach was considered an indirect determination rather than a direct measurement. There was also a need, by motor design engineers, to know how the total losses were distributed among the various types or categories. This information would allow them to determine how best to improve efficiency and where to focus their efforts.

Of all the methods outlined, only one, Method B, measures input and output and attempts to determine and separate each type of loss. Because of this IEEE 112 Method B became a popular tool and is commonly used in the U.S. motor industry (and in Canada by way of standard C390). Further work has improved the accuracy and repeatability of this method over the years. Experience with the method and this additional work have led to its adoption as the standard and most accurate method for determining motor efficiency.

How Does Method B Relate to the "Real World"?

Testing for efficiency to IEEE 112 Method B is broken down into sections or types of testing. These are no load testing, temperature testing, and testing under load.

During no load testing the motor is connected to rated voltage and frequency and allowed to run without a connected load until the input watt readings stabilize. This can take from over one to perhaps four hours to occur. Once the motor has "loosened up," or stabilized, testing proceeds by adjusting the motor voltage and taking a series of readings from approximately 125% of rated voltage down to a minimum voltage where motor current no longer continues to drop with voltage. Using these readings — combined with winding and ambient temperatures and winding resistance — two of the motor losses, iron loss and friction loss, can be determined. The iron loss will vary with voltage while the friction loss will stay relatively constant because motor speed is constant (within a few RPM). The process involves first subtracting out the stator copper loss that can be calculated from the current and resistance (we are not interested in these at this time) and plotting (or mathematically curve-fitting) the remainder. By extrapolating the low voltage data to zero, the constant loss (friction) can be determined. Subtracting this out of the higher voltage readings will allow the iron loss to be calculated for exactly rated voltage.

The temperature testing (or full load heat run) simply involves testing the motor under rated load conditions at rated voltage and frequency and monitoring temperature. The specifications define how precise the load and input voltage must be held. This test must continue until the motor temperature is stable (thermal equilibrium). This is defined as when the motor temperature rise does not change more than 1°C over a period of 30 minutes

Testing under load is done by maintaining rated voltage and frequency while applying six different loads to the motor in one-fourth rated load increments from approximately a quarter load to 1.5 times rated load. Readings such as current, torque, RPM, and temperature will provide information about how the motor performs under load. At this point motor testing is complete and analysis begins.

Known or directly calculated losses are determined by tabulating the readings, making any adjustments to these readings so they are at the correct operating temperature (from the temperature test), and determining each individual loss for each of the six load readings mentioned previously. The iron loss and friction losses were determined in the no-load test. These are held constant for all load points. The winding resistance, corrected for temperature, and measured current will yield the stator copper loss. Knowing the motor speed (and therefore slip), power input, and other losses at each load will allow the rotor copper loss to be calculated. All of these losses are therefore directly determined or calculated from measured values. However, there is one remaining loss category that has not been addressed, that being stray loss.

Stray loss cannot be calculated directly from an equation based on input or output readings. It is actually the sum of several smaller losses that are dependent primarily on motor (or part) geometry and variation. For the purposes of this test method, stray loss is determined indirectly by subtracting the directly calculated losses and output power from the input power. Because all power (or energy) must be accounted for, this difference is considered to be the stray loss. (There are special tests designed to "measure" or isolate stray loss, but the added time and complexity of testing would not improve the accuracy of this method.) The value of stray loss is typically in the 1% range of motor output power. Even with very accurate measurements, the calculated value of stray loss can vary significantly from reading to reading. This is compounded by the fact that this loss being "what's left" will include small errors or inaccuracies in the measurements or calculation of other losses. This presents a problem.

This entire test method is based on the premise that all losses follow some smooth function of motor load, with other parameters held constant. This potential variation or error often will not allow the stray values to fall on a smooth curve. To address this, the standard outlines a "smoothing" calculation where these remainder values (stray losses) are fit to an agreed upon equation form based on theory. The equation must go through zero, have a positive slope, and the value of stray loss is to vary by the value of torque squared. This smoothing is also intended to "improve" accuracy under the assumption that the true value of stray loss should be closer to values calculated from this smooth equation than the actual test difference values. Therefore, the values calculated must "closely" fit this curve. Specifically, to determine if the readings are correct and/or the test is valid, the values of stray loss must fit this type of curve with a correlation coefficient of 0.9 (90%) or better. If not, there is an allowance provided that a maximum of one point can be ignored if necessary to bring the correlation coefficient up to this level (thus allowing for the possibility of one bad test point). But if this still does not improve the correlation coefficient enough, the test must be taken over.

The calculation of efficiency is done by applying the equation we started with. The efficiency value is determined by first subtracting the losses, now corrected to the operating temperature and smoothed in the case of stray loss, from the known input power to get the corrected output power. Then this corrected output power divided by input power is efficiency as defined by IEEE 112B.

Testing Time, Accuracy, Comparison with Other Methods

The first thing one may notice from this discussion is that these methods require much time, very accurate measurements, as well as patience and experience. Including the preparation of the motor (adding thermocouples to measure temperature, mounting it to a dynamometer of some sort for loading, and hooking up leads and meters), taking readings, waiting for temperatures to stabilize, and performing calculations these tests easily take eight hours or more. The standard defines the accuracy of all measurement equipment to the point of also including a dynamometer correction calculation (not discussed here) to check and account for small errors in output measurement resulting from friction in the dynamometer or other factors. Even so, one can see that there are a relatively large number of measurement calculations which do result in some "calculation error." This includes round off, slight errors in temperature corrections, stray smoothing, and simply error compounding as measurement values are multiplied, squared, and so on. And, one cannot ignore the "human" or procedural errors and limitations in measuring a dynamic system.

NEMA, IEEE, and CSA have worked to address these issues over time with updates to the standard. The latest improvements dealt with tightening up the equipment accuracy and more clearly defining the procedure of testing to minimize "human error." But even with these improvements, variation does exist. A report, published by NEMA, on a "round robin" test program involving several different motors, shows that the variation in total losses on the same motor tested at different facilities, all with proper equipment and using the best practices is still about 10%. Even without a study you can show that with ± 0.2% instruments and ± 1 RPM speed measurements (both as required by the latest standard) the resulting change in losses can be 4-25% and the range in efficiency calculated for any single load point is almost 1% (0.8-0.9%). See chart above for an example.

It should be noted that one of the original considerations in the development of IEEE 112 Method B was to reduce errors due to measurement limitations that existed in older test equipment. Today, with more accurate equipment available, some question if this method is still the best for efficiency determination. But, in spite of the apparent shortcomings, most feel that it is still the best method of testing and determining efficiency for 3 phase AC motors. It is certainly standardized, widely used in the North America for motor engineering purposes, and perhaps studied the most. It also segregates individual losses. And, if followed properly, the method will be a fair comparison of one motor to another. So it is not likely we will see a change any time soon.

It does NOT, however, allow for easy verification by the average user. And, one must understand that the tested efficiency is NOT an exact single static number. Although the efficiency calculated from a single rated load input-output reading should come close to the IEEE 112B value, it will seldom be the same. True verification will require a full test. And as we just found out, that too has some variability.

FOR MORE INFORMATION CONTACT:

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