# CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

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# CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

## 3.1 INTRODUCTION

This chapter details the market and technology assessment that the U.S. Department of Energy (DOE) conducted in support of its energy conservation standards rulemaking for small electric motors. The small electric motors rulemaking was initiated under the Energy Policy and Conservation Act (EPCA), Public Law 94–163, as amended, by the Energy Policy Act of 1992 (EPACT 1992), Public Law 102–486. The statute requires that, if DOE were to adopt energy conservation standards for small electric motors, they would become effective to small electric motors manufactured five years after the publication date of the final rule.[a]

This chapter consists of two major sections, the market assessment and the technology assessment. The goal of the market assessment is to develop a qualitative and quantitative characterization of the small electric motors industry. This assessment characterizes the market structure based on publicly available information as well as data supplied by manufacturers and other interested parties. Issues include manufacturer characteristics and market shares, existing regulatory and non-regulatory efficiency improvement programs, product classes, and trends in market and equipment characteristics. The goal of the technology assessment is to develop a list of technology options that manufacturers can use to improve the efficiency of small electric motors.

## 3.2 MARKET ASSESSMENT

This section addresses the scope of the rulemaking, identifies potential product classes, estimates national shipments of small electric motors, and the market shares of small electric motor manufacturers. This section also addresses typical equipment lifetimes and market performance data, and discusses regulatory and non-regulatory programs that apply to small electric motors.

### 3.2.1 Small Electric Motor Definition

One of the key documents that relates to the scope of coverage for small electric motors is the National Electrical Manufacturers Association (NEMA) Standards Publication MG1 for Motors and Generators. NEMA drafted and maintains the MG1 document, most recently revised in November 2007 as MG1–2006 with Revision 1. MG1 assists users in the correct selection and application of electric motors and generators. MG1 provides practical information to small

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[a] A Final Rule for Small Electric Motors is scheduled to be published by February 28, 2010. Under section 346(b)(3), any standard for small electric motors "shall apply to small electric motors manufactured 60 months after the date such rule is published or, in the case of small electric motors which require listing or certification by a nationally recognized test laboratory, 84 months after such date." (42 U.S.C. 6317(b)(3)) Thus, if DOE does adopt energy conservation standards for small electric motors, it is anticipated that these standards would apply to small electric motors manufactured after February 28, 2015 and February 28, 2017, respectively.

electric motor manufacturers and users concerning the construction, testing, performance, and safety of alternating current (AC) and direct current (DC) motors and generators.

The term "small electric motor" is defined in the statute, and thus, the scope of coverage for this rulemaking is determined by this statutory definition. Section 340(13)(G) of EPCA defines the term "small electric motor" to mean "a NEMA general-purpose alternating current[b] single-speed induction motor,[c] built in a two-digit frame number series[d] in accordance with NEMA Standards Publication MG1–1987." (42 U.S.C. 6311(13)(G)) Such motors include single-phase, capacitor-start induction-run (CSIR), capacitor-start capacitor-run (CSCR), and polyphase motors. DOE addresses the scope of small electric motors covered in the sections that follow, noting that today's scope is slightly narrower than what DOE considered for the determination analysis. See http://www1.eere.energy.gov/buildings/appliance_standards/commercial/small_electric_motors.html.

Section 346(b)(3) of EPCA (42 U.S.C. 6317(b)(3)) requires that a standard prescribed for small electric motors shall not apply to any small electric motor that is a component of a covered product under section 322(a) of EPCA (42 U.S.C. 6292(a)) or of covered equipment under section 340 of EPCA. (42 U.S.C. 6311) Such products and equipment include, for example, residential air conditioners and heat pumps, furnaces, refrigerators and freezers, clothes washers and dryers, commercial packaged air-conditioning and heating equipment, and commercial refrigeration equipment. Accordingly, the analysis does not include small electric motors incorporated into residential and commercial products either covered or specifically excluded by statute.

On July 10, 2006, DOE published in the *Federal Register* its determination that energy conservation standards for small electric motors appear to be technologically feasible and economically justified, and would result in significant energy savings. 71 FR 38807. A key issue that arose early in the analytical process was interpretation of the EPCA definition of a small electric motor and precisely which motors are covered. The EPCA definition identifies several key terms that are defined in NEMA MG1–1987, such as general purpose, alternating-current and two-digit frame series. Thus, EPCA's definition of a small electric motor is tied to NEMA MG1–1987 terminology and performance requirements established for (1) general-purpose alternating-current motors, (2) various categories of induction motors, and (3) the

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[b] "General-purpose alternating current" is a term that NEMA uses for alternating-current motors that are not designed with a specific application in mind.
[c] An induction motor converts electrical power into rotational mechanical power. It depends on electromagnetic induction for its operation and has one or more component members capable of rotary movement.
[d] The terms "two-digit frame number series" and "frame series" refer to a motor's standard system of numbers in combination with letters for designating the size and mounting dimensions of a motor, according to NEMA Standards Publication MG1, "Motors and Generators." In the case of small motors, frame series is the "D" dimension in inches multiplied by 16. The "D" dimension is measured from the centerline of the shaft to the bottom of the mounting feet. For example, a 48-frame motor would have a "D" dimension of 3.00 inches (16 x 3.00 = 48). Such standard dimensions are essential to fitting a motor to the equipment it drives and for interchangeability among motors.

definition of two-digit frame number series. In the following subsections, DOE addresses elements of the definition of "small electric motor" that need clarification.

### 3.2.1.1 General-Purpose Alternating-Current Motor

One element in the statutory definition of small electric motors that derives from NEMA MG1–1987, is "general-purpose, alternating-current." Paragraph MG1–1.05 sets forth the definition:

> A general-purpose alternating-current motor is an induction motor, rated 200 horsepower and less, which incorporates all of the following: (1) open construction[e], (2) rated continuous duty, (3) service factor in accordance with MG1-12.47, and (4) Class A insulation system with a temperature rise as specified in MG1-12.42 for small electric motors or Class B insulation system with a temperature rise as specified in MG1-12.43 for medium motors. It is designed in standard ratings with standard operating characteristics and mechanical construction for use under usual service conditions without restriction to a particular application or type of application.

The four criteria that NEMA used in MG1-1987 to define a general-purpose alternating-current motor are open construction, continuous duty, service factor, and a Class A insulation system.

Open construction refers to the type of enclosure that houses the motor. An open construction enclosure allows outside air to pass through and cool the motor when it is operating. Electric motors are also manufactured with closed construction housings, which do not circulate external air for cooling.

A motor rated for continuous duty can operate a driven machine indefinitely at the rated load, speed, and temperature without injury to the motor. The statutory language directs DOE to cover and evaluate general-purpose alternating-current motors, which are rated for continuous duty (as opposed to intermittent duty). Therefore, in this rulemaking, DOE covers only those motors rated for continuous duty.

MG1–1987 defines general-purpose alternating-current motors as having a service factor in accordance with MG1–12.47. The service factor is a measure of the overload capacity at which a motor can operate without damage, while operating normally within the correct voltage tolerances. The rated horsepower (hp) multiplied by the service factor gives that overload capacity. For example, a 1-horsepower motor with a 1.25 service factor can operate at 1.25 horsepower (1 horsepower x 1.25 service factor). NEMA MG1–1987 requires that the service factor for general-purpose alternating-current motors be in accordance with MG1–12.47. (See

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[e] NEMA MG1–1987 defines each of the following motors, in part, as "an open machine": drip-proof, splash-proof, semi-guarded, guarded, dripproof guarded, open externally ventilated, open pipe-ventilated, and weather-protected (Type I and Type II).

Table 3.1.) Therefore, in this rulemaking, DOE covers only those small electric motors that meet the NEMA service factor requirements.

**Table 3.1. National Electrical Manufacturers Association Standard MG1–1987 Service Factor Requirements of Small Electric Motors**

| **Horsepower** | **Required Service Factors by Synchronous Speed (rpm)** | | |
|---|---|---|---|
| | **3,600** | **1,800** | **1,200** |
| **1/4** | 1.35 | 1.35 | 1.35 |
| **1/3** | 1.35 | 1.35 | 1.35 |
| **1/2** | 1.25 | 1.25 | 1.25 |
| **3/4** | 1.25 | 1.25 | - |
| **1** | 1.25 | - | - |

The MG1–1987 definition of "general-purpose alternating-current motor," in part identifies a small electric motor as one that incorporates a Class A insulation system with a temperature rise as specified in MG1–12.42. This paragraph establishes the maximum temperature rise of the various parts of the motor, over a 40°C ambient temperature. For example, the temperature rise of the windings of a small electric motor with open construction and a Class A insulation system shall not exceed 60°C; if the motor's service factor is greater than 1.15, it shall not exceed 70°C. However, MG1-1987 also defines Class B, F, and H insulation systems. DOE believes that, because any of these insulations systems also meets the specification of a Class A system and they are regularly used in small electric motors, they are covered. Additionally, DOE notes that NEMA MG1-1987 does not require small motors to meet the temperature rise for a Class A insulation system. Rather, it only requires that the motor incorporates an insulation system that meets Class A requirements, which DOE has determined could be Class A, B, F, or H. Therefore, DOE also believes that motors incorporating these insulation class systems are covered under this final rule regardless of their associated temperature rise.

Lastly, MG1–1987 requires that a general-purpose alternating-current motor be designed in standard ratings with standard operating characteristics and mechanical construction for use under usual service conditions without restriction to a particular application or type of application. This provision is consistent with the definition of "general-purpose motor" under section 431.12 of Title 10 of the Code of Federal Regulations, Part 431 (10 CFR Part 431). Essentially, both MG1–1.05 and 10 CFR 431.12 require general-purpose motors to meet "standard ratings," which are generally understood to mean any performance or physical characteristics established as a rule or model by authority, custom, or general consent. The NEMA Standard MG1 is based on general consent, meaning that NEMA members who manufacture motors and generators covered in MG1 can vote to approve the document.

For small electric motors, examples of standard ratings include minimum breakdown torque, minimum locked-rotor torque, and minimum locked-rotor current. Such requirements limit the scope of covered small electric motors. For example, the breakdown torques of many shaded-pole and permanent-split capacitor motors (which are single-phase motors) do not fall within the breakdown torque ranges of MG1-1987. Table 3.2 below presents the performance requirements that NEMA MG1-1987 provides for small electric motors.

**Table 3.2 NEMA MG1-1987 Performance Requirements Relevant to General Purpose Small Motors**

| | Single Phase | Polyphase |
|---|---|---|
| Breakdown Torque | 12.32.1 | 12.37 |
| Locked Rotor Current | 12.33.2 | None* |
| Locked Rotor Torque | 12.32.2 | None |

* Because NEMA MG1-1987 section 12.35 is labeled as applying to only medium motors, DOE does not believe there are polyphase locked rotor current requirements for small motors.

These requirements are only applicable to a subset of the horsepower and pole configuration combinations covered in today's rulemaking because of the way that NEMA divides its requirements for "small" and "medium" motors. NEMA MG1-1987 illustrates a dividing line and motors below 1½ horsepower for two-pole motors, 1 horsepower for four-pole motors, and ¾ horsepower for six-pole motors are considered small and only performance tables of requirements for small motors are applicable to two-digit frame size motors. However, DOE does not believe this precludes certain higher horsepower ratings built in a two-digit NEMA frame form coverage. When determining scope, DOE examined not only NEMA MG1-1987, but also manufacturer catalogs and comments received in response to earlier stages of the rulemaking. Upon review of NEMA manufacturer product catalogs, DOE noted that two-digit frame size motors of higher horsepower ratings are commonly marketed as general purpose. In addition, DOE also considered NEMA shipment data provided to DOE for the determination analysis. DOE found that when NEMA surveyed its members, requesting shipments of general purpose motors built in a two-digit frame number series, the manufacturers provided shipments data in horsepower ratings exceeding those listed in the discussion above. Thus, DOE believes that even though NEMA MG1 does not provide standard ratings for higher horsepower small electric motors, many of these motors are considered NEMA general purpose motors and should be included in the scope of this rulemaking. Therefore, DOE is covering motors of higher horsepower ratings and for those combinations of horsepower rating and pole configuration that do not have performance requirements for two-digit frame sizes, DOE has no performance requirements. Instead, DOE will cover only those motors widely considered general purpose and marketed as such in manufacturer catalogs.

Of the motors satisfying the frame-size requirement of the EPCA definition of "small electric motor" and "built in a two-digit frame number series in accordance with NEMA Standards Publication MG1–1987," only a subset incorporates the other performance requirements of a general-purpose motor under NEMA MG1–1987, paragraph 1.05. Among single-phase motors with a two-digit frame series, DOE found that only capacitor-start motors–including capacitor-start induction-run, and capacitor-start capacitor-run motors–can meet the torque requirements for NEMA general-purpose motors. Among three-phase small electric motors, only non-servo motors can meet the NEMA performance requirements for general-purpose motors. Hence, DOE's analysis only covers the capacitor-start categories of single-phase motors and three-phase small electric motors.

### 3.2.1.2 Categories of Induction Motors

The statutory definition also requires that a small electric motor be a single-speed induction motor" built in accordance with NEMA MG1–1987. DOE identified six categories of alternating current single-speed induction motors: split-phase,[f] shaded-pole,[g] capacitor-start (both CSIR[h] and CSCR[i]), permanent-split capacitor (PSC),[j] and polyphase.[k] In the discussion that follows, DOE explains its review of these six induction motor categories and its conclusion that the CSIR, CSCR, and polyphase motors are the only three categories which are covered under EPCA.

DOE eliminated split-phase, PSC, and shaded-pole motors from consideration because they are not designed as and do not meet the performance requirements of general-purpose motors. Split-phase motors are designed for specific purposes and applications, and generally for applications that are short-time rated. Also, split-phase motors do not meet the breakdown torque requirements or the locked-rotor torque requirements while simultaneously maintaining the locked-rotor current requirements that have been established in NEMA for general-purpose motors. In some cases, split-phase motors are components of products covered under EPCA sections 322(a) and 340, 42 U.S.C. 6292(a) and 6311, respectively and are otherwise excluded from coverage by statute. (42 U.S.C. 6317(b)(3)) Similarly, PSC motors used in fans, business machines, and hermetic motor compressors do not meet the torque requirements for NEMA general-purpose motors. Shaded-pole motors that are generally intended for intermittent operation in applications such as rotisseries, fans, humidifiers, small business machines, advertising machines, copiers, vending machines and advertising displays also do not meet the performance requirements. These shaded-pole motors tend to have low efficiency ratings (*i.e.*, less than 50 percent) and are sold in high volume. However, DOE believes that because PSC and shaded-pole motors do not meet the performance characteristics for NEMA general-purpose motors, which are required under EPCA section 340(13)(G), 42 U.S.C. 6311(13)(G), and identified in NEMA MG1–1.05, and therefore are not covered categories of induction motors.

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[f] A split-phase motor is a single-phase induction motor equipped with an auxiliary winding displaced in magnetic position from, and connected parallel to, the main winding. Unless otherwise specified, DOE assumed that the auxiliary circuit is open when the motor attains a predetermined speed. The term "split-phase motor" describes a motor to be used without impedance other than that offered by the motor windings themselves.
[g] A shaded-pole motor is a single-phase induction motor provided with an auxiliary short-circuited winding or windings displaced in magnetic position from the main winding.
[h] A capacitor-start, induction-run motor is a single-phase motor with a main winding arranged for direct connection to a source of power and an auxiliary winding connected in series with a capacitor. The motor has a capacitor phase, which is in the circuit only during the starting period.
[i] A capacitor-start, capacitor-run motor is a single-phase motor with different values of effective capacitance for the starting and running conditions.
[j] A permanent-split capacitor motor is another category of single-phase motor that has the same value of capacitance for both starting and running conditions.
[k] A polyphase motor is an electric motor that uses the phase changes of the electrical supply to induce a rotational magnetic field and thereby supply torque to the rotor.

The remaining categories of small electric motors include CSIR, CSCR, and polyphase. In view of its July 2006 determination (71 FR 38799), DOE re-examined the standard performance characteristics, construction specifications, and ratings for these three motor categories. DOE concluded that they meet the EPCA requirements for small electric motors. Furthermore, CSIR, CSCR, and polyphase small electric motors are manufactured in two-digit frame series, can be rated for continuous-duty applications, and can meet other performance requirements for general-purpose motors, including the torque requirements under NEMA MG1–1987, paragraph 12.32 for single-phase motors. Therefore, DOE will address three categories of small electric motors in today's rulemaking: single-phase CSIR, single-phase CSCR, and polyphase.

#### 3.2.1.3 Frame Series and Metric Equivalents

Another element in the statutory definition is that a small electric motor is "built in a two-digit frame number series in accordance with NEMA Standards Publication MG1–1987." NEMA MG1–1987 establishes a system of numbers and letters for designating motor frames. The frame number for a small electric motor is determined by measuring the distance in inches between the centerline of the shaft to the bottom of the mounting feet multiplied by 16. The two-digit frame series encompasses NEMA frame series 42, 48, and 56. Two-digit NEMA frames have standard dimensions and tolerances specified in NEMA Standard MG1-1987 paragraphs 11.31 and 11.34, which are necessary for mounting and interchangeability among general-purpose applications.

DOE understands that manufacturers produce other two-digit frame series, namely a 66 frame series. The 66 frame series is used for definite-purpose or special-purpose motors and not used in general-purpose applications and therefore not covered under the EPCA definition of "small electric motor." At this time, DOE is unaware of any other motors with frame series that are built in accordance with NEMA MG1-1987, but should such frame series appear, DOE will evaluate whether or not they are included equipment at that time.

DOE is concerned about metric equivalents for the two-digit NEMA frame series, the uncertainty about cross-references, and the potential issues with imports of small electric motors, whether manufactured alone or as a component of another piece of equipment.

EPCA section 340(13)(F), as amended by EPCA 1992, 42 U.S.C. 6311(13)(F), defines small electric motors in terms of "NEMA Standards Publication MG1–1987," whose construction and rating system uses English units of measurement and output ratings in horsepower.[1] In contrast, general-purpose electric motors manufactured outside the United States and Canada are defined and described with reference to the International Electrotechnical Commission (IEC) Standard 60034–1 series, "Rotating electrical machines," which use different terminology and criteria than EPCA. The performance attributes of these IEC motors are rated pursuant to IEC Standard 60034–1, "Rating and performance," which uses metric units of

[1] The Energy Independence and Security Act of 2007 (EISA 2007), renumbered EPCA section 340(13)(F) (42 U.S.C. 6311(13)(F)) to be section 340(13)(G) (42 U.S.C. 6311(13)(G)). There was no change in the language.

measurement, a different construction and rating system than NEMA MG1–1987, and output ratings in kilowatts instead of output ratings in horsepower. Standards exist, such as the Institute of Electrical and Electronics Engineers Standard 112, which define the relationship between horsepower and watts or kilowatts. Further, 10 CFR 431.12 (2008) defines “electric motor” in terms of NEMA and IEC equivalents, and 10 CFR 431.25 provides a table of horsepower and kilowatt equivalent ratings, which DOE views as a precedent for similar treatment of small electric motors.

Although the statutory definition of small electric motor does not address metric or kilowatt-rated motors, DOE believes that EPCA covers any motor that is equivalent to or can be used as a substitute for a covered small electric motor. Generally, IEC metric or kilowatt-equivalent motors can perform the identical functions of small electric motors and provide comparable rotational mechanical power to the same machines or equipment. In other words, IEC metric or kilowatt-equivalent motors can be interchanged with small electric motors as defined by NEMA standards. A given commercial central air conditioner, for example, could operate with either an IEC motor or NEMA motor with little or no effect on performance. Therefore, DOE interprets EPCA to mean that a “small electric motor” is any motor that is identical or equivalent to a motor constructed and rated in accordance with NEMA MG1 and covered by the statute. Otherwise, placing energy efficiency requirements on NEMA small electric motors, but not on equivalent IEC or kilowatt-rated small electric motors, could give preferential treatment to the latter, should DOE establish minimum energy conservation standards for the NEMA small electric motors, but not the IEC equivalent motors.

#### 3.2.1.4 Motor Enclosure

DOE examined the definition of “general-purpose, alternating-current” motor as it appears in NEMA Standard MG1–1987. It explicitly states that a general-purpose, alternating-current motor incorporates an “open construction.” Later versions of NEMA Standard MG1 revised the definition and expanded it to incorporate open or enclosed construction. However, this is not the case with the EPCA-directed definition. DOE considered this and believes that the reference MG1-1987 applies to all facets of the statutory definition of a small electric motor. The language of the statute specifies that the requirements of MG1-1987 apply in determining what constitutes a small electric motor. DOE's application of that definition is consistent with that language. Similarly, because the statute specifically mentions MG1-1987 as the version of MG1 on which DOE should relay, the 1987 version is the only applicable version of NEMA MG1. Accordingly, consistent with MG1-1987, only CSIR, CSCR, and polyphase motors with open construction meet the statutory definition.

DOE considered poly- and single-phase motors, including non-servo three-phase motors; capacitor-start, induction-run motors; and capacitor-start, capacitor-run motors. Only those motors that are built with an open construction are applicable. Horsepower ranges and pole configurations are also important characteristics of covered motors. Table 3.3 through Table 3.5 present the 62 product classes (PC) for polyphase, CSIR and CSCR motors, broken down by number of poles and horsepower/standard kilowatt equivalent ratings. Upon reexamining manufacturer catalogs DOE found that motors did not exist for some horsepower ratings/pole configuration combinations included in the NOPR. Specifically, DOE found that no open construction, two-digit frame size motors have horsepower ratings greater than 3-horsepower. In addition, DOE found no small electric polyphase motors built with a 2- or 3-horsepower rating and a six-pole configuration. DOE also found that small electric single-phase motors (CSIR and CSCR) do not exist with a 1½ -horsepower rating or higher for six-poles or a 3-horsepower rating for four-poles. As there is no evidence that these motors, if manufactured, would be considered general purpose motors, and because DOE lacks data on which to base energy conservation standards for these motors, DOE is not including them in the scope of this rulemaking. For DOE's minimum energy conservation standards for small electric motors, each "PC" cell in the following table is replaced by the applicable average full-load efficiency value.

**Table 3.3. Polyphase Small Electric Motor Product classes**

| Horsepower/Standard Kilowatt Equivalent | Six Poles | Four Poles | Two Poles |
|---|---|---|---|
| 1/4 hp/0.18 kW | PC # 1 | PC # 2 | PC # 3 |
| 1/3 hp/0.25 kW | PC # 4 | PC # 5 | PC # 6 |
| 1/2 hp/0.37 kW | PC # 7 | PC # 8 | PC # 9 |
| 3/4 hp/0.55 kW | PC # 10 | PC # 11 | PC # 12 |
| 1 hp/0.75 kW | PC # 13 | PC # 14 | PC # 15 |
| 1½ hp/1.1 kW | PC # 16 | PC # 17 | PC # 18 |
| 2 hp/1.5 kW | - | PC # 19 | PC # 20 |
| ≥ 3 hp/2.2 kW | - | PC # 21 | PC # 22 |

**Table 3.4. Capacitor-Start, Induction-Run Small Electric Motor Product classes**

| Horsepower/Standard Kilowatt Equivalent | Six Poles | Four Poles | Two Poles |
|---|---|---|---|
| 1/4 hp/0.18 kW | PC #23 | PC # 24 | PC # 25 |
| 1/3 hp/0.25 kW | PC #26 | PC #27 | PC #28 |
| 1/2 hp/0.37 kW | PC #29 | PC # 30 | PC # 31 |
| 3/4 hp/0.55 kW | PC #32 | PC # 33 | PC # 34 |
| 1 hp/0.75 kW | PC #35 | PC # 36 | PC # 37 |
| 1½ hp/1.1 kW | - | PC #38 | PC # 39 |
| 2 hp/1.5 kW | - | PC #40 | PC # 41 |
| ≥ 3 hp/2.2 kW | - | - | PC #42 |

**Table 3.5. Capacitor-Start, Capacitor-Run Small Electric Motor Product classes**

| Horsepower/Standard Kilowatt Equivalent | Six Poles | Four Poles | Two Poles |
|---|---|---|---|
| 1/4 hp/0.18 kW | PC #43 | PC #44 | PC #45 |
| 1/3 hp/0.25 kW | PC #46 | PC #47 | PC #48 |
| 1/2 hp/0.37 kW | PC #49 | PC #50 | PC #51 |
| 3/4 hp/0.55 kW | PC #52 | PC #53 | PC #54 |
| 1 hp/0.75 kW | PC #55 | PC #56 | PC #57 |
| 1½ hp/1.1 kW | - | PC #58 | PC #59 |
| 2 hp/1.5 kW | - | PC #60 | PC #61 |
| ≥ 3 hp/2.2 kW | - | - | PC #62 |

### 3.2.2 Small Electric Motor Nameplates and Terminology

The National Fire Protection Association (NFPA) Standard 70, "National Electrical Code," article 430.7, and NEMA MG1 paragraph 10.39 prescribe a consistent set of required information that is reported on all motor nameplates. This information enables a motor user to purchase and install a motor that is appropriate for a particular application. NFPA Standard 70 and MG1 each require that an electric motor nameplate be marked with information that includes, but is not limited to:

- manufacturer's name;
- frame designation;
- rated voltage;
- rated full-load current;
- rated frequency;
- number of phases;

- rated full-load speed;
- rated temperature rise or the insulation system class and rated ambient temperature;
- rated horsepower;
- time rating;
- code letter for locked-rotor amperes; and
- thermal protection.

In the following table, DOE provides a brief description of each of the fields that NFPA 70 or NEMA Standard MG1 require on the motor nameplate.

**Table 3.6. Required Small Electric Motor Nameplate Information**

| | |
|---|---|
| Frame Designation | Frame series numbers represent standardized designations for size and dimensions. For small electric motors, the frame series are two digits, determined by the shaft height of the motor from the bottom of the base in sixteenths of an inch. For example, a 56-frame motor would have a shaft height (“D” dimension) of 56/16 of an inch, or 3.5 inches. For metric motors, the frame series is also the shaft height of the motor from the bottom of the base, but the height is noted in millimeters rather than sixteenths of an inch. |
| Rated Voltage | Rated voltage is the design voltage at which an electric motor will yield optimal performance. In general, motors should be capable of operating within a 20% band of the rated voltage, 10% above to 10% below. |
| Rated Full-Load Amperage | The rated full-load amperage represents the amperage consumption when the motor reaches full-load torque. The value is determined by testing a sample of motors, and is usually rounded up to allow for slight variations in manufacturing that may increase the full-load amperes. The purpose of the full-load amperes is to enable appropriate sizing of power supply wiring and any overload protection devices. |
| Frequency | For the North American market, motors are designed to operate on alternating current at 60 Hertz (cycles per second). |
| Phase | Single-phase and three-phase motors are available in the United States. |
| Rated Full-Load Speed | The rated full-load speed is the approximate rotations per minute of the motor under full-load conditions at a specified voltage and frequency. The full-load speed is typically 95% to 99% of the no-load speed. |
| Insulation Class and Rated Ambient Temperature | Insulation class and allowable maximum ambient temperature denote the operating parameters of an electric motor, which directly relates to motor operating life. The maximum temperature (*i.e.*, hot spot) is a combination of motor design and ambient temperature. |
| Rated Horsepower | Rated horsepower is a measure of how much work a motor is expected to perform. Horsepower is based on full-load speed and torque rating, as follows:<br>Horsepower (hp) = [(Motor Speed) × (Torque (lb-ft))] ÷ 5,250. |
| Time Rating | Time rating states whether the motor is rated for continuous duty (24 hours per day / 7 days per week) or certain “short-time” requirements, ranging from 5 to 60 minutes. In this rulemaking, all small electric motors are rated for continuous duty. |
| Locked-Rotor Code Letter | Starting an AC motor creates an inrush current that is usually several times greater than the full-load current. The inrush current may be large enough to cause a voltage dip that affects other equipment. Manufacturers provide the inrush current in motor performance specification sheets (“locked-rotor current”) and as a coded letter on the nameplate. |
| Manufacturer's Name | The name of the motor’s manufacturer must appear on the nameplate. |

In addition to the above information, manufacturers of small electric motors may voluntarily include information, such as service factor, efficiency, and power factor. Manufacturers usually provide such information because it facilitates purchasing and allows maintenance personnel to quickly identify an appropriate replacement motor.

**Table 3.7. Optional Small Electric Motor Nameplate Information**

| | |
|---|---|
| Service Factor | This measure indicates how much overload a motor can withstand when operating normally within the correct voltage tolerances. The standard service factor for a 1 horsepower open motor with a rated full load speed of 1800 revolutions per minute is 1.15. This means that such a motor could provide 1.15 horsepower when operated at its service factor. Small electric motors are also designed with higher service factors, such as 1.25 or 1.35. |
| Full-Load Efficiency | Full-load efficiency is a measure of the motor's ability to effectively convert electrical power into mechanical power and is expressed as a percentage. |
| Power Factor | This value is represented by the ratio of the motor load in watts divided by voltage-amperes at full load. Power factor varies directly with loading, generally increasing with load percentage. |

### 3.2.3 Manufacturers and Market Share

Five large manufacturers dominate the small electric motor market for this rulemaking:

- A.O. Smith Electrical Products Company;
- Baldor Electric Company;
- Emerson Motor Technologies;
- Regal-Beloit Corporation; and
- WEG Electric Motors Corporation.

The five manufacturers identified above are all major manufacturers with diverse portfolios of product offerings, including small electric motors covered under EPCA. Over the past decade, there has been a consolidation of motor manufacturing in the United States and, in part, the limited number of small electric motor manufacturers is a result of mergers and acquisitions occurring over the last few decades.

DOE does not have empirical data on the market shares of particular manufacturers of small electric motors. Nevertheless, estimates of available cumulative data indicate that shipments of small electric motors from these five companies constitute over 50 percent of the total U.S. market.

#### 3.2.3.1 Small Businesses

The small electric motor market is predominantly supplied by large manufacturers, DOE examined those small businesses that manufacture small electric motors during the final rule stage of the rulemaking. In general, the Small Business Administration (SBA) defines a small business manufacturing enterprise for "motor and generator manufacturing" as one that has 1,000 or fewer employees. The number of employees in a small business is rolled up with the total employees of the parent company; it does not represent the division manufacturing small electric motors. SBA lists small business size standards for industries as they are described in the North American Industry Classification System (NAICS). For small electric motors, the size standard is matched to NAICS code 335312, Motor and Generator Manufacturing.[1]

DOE found that there are no small businesses that manufacture the type of small electric motors covered by this rulemaking. While many small businesses exist that produce small electric motors, none of these companies produce motors that meet the criteria to be covered by this rulemaking. For example, Sterling Electric manufactures a line of small electric motors that meet most criteria (open enclosure, general purpose, etc.), but the motors are not two-digit frame series, and therefore are not covered by this rulemaking.

### 3.2.4 Application and Performance of Existing Equipment

The general purpose CSIR, CSCR and polyphase small electric motors covered are used in a fairly wide range of applications, including the following:

- blowers
- compressors
- commercial clothes dryers
- conveyors
- fans
- food processing equipment
- heating, ventilation, and air-conditioning equipment
- medical equipment
- packing machinery
- pumps

### 3.2.5 Trade Associations

DOE is aware of two trade associations for manufacturers of small electric motors: the National Electrical Manufacturers Association (NEMA) and the Motors and Motion Association (SMMA).[m] All five major manufacturers discussed above are members of NEMA and SMMA.

#### 3.2.5.1 National Electrical Manufacturers Association

NEMA was established as a trade association in 1926, and has since been divided into four groups that provide different functions for its members:

- NEMA/TEC, Technical Services Department
- NEMA/GOV, Government Relations Department

[m] For more information about The Motors and Motion Association, visit www.smma.org. Likewise, for information about NEMA, visit www.nema.org.

- NEMA/PAC, Political Action Committee
- NEMA/BIS, Business Information Services

Through these groups, NEMA helps to standardize the performance, size, and functionality of electrical equipment for its members. An example of NEMA's role in standardization is the NEMA Standard MG1 document,[n] which is a reference document for motor and generator manufacturers and users. NEMA Standard MG1 provides guidance to motor manufacturers on performance and construction specifications for a broad range of electric motors. By standardizing around certain parameters, NEMA makes it easier for users to identify and purchase electric motors. NEMA Standard MG1 is a complete industry reference document for standardizing the motors offered in the market.[2]

In addition to MG1, NEMA established and promoted a high efficiency standard for electric motors through the "NEMA Premium®" label for qualifying motors.[o] NEMA motor manufacturers attach this label to motors that are built to prescribed high efficiency standards. These standards exceed the minimum requirements established by EPACT 92, which requires general-purpose motors from 1 to 200 horsepower to meet certain minimum efficiency levels. See section 3.2.7 for more discussion on these minimum efficiency levels.

#### 3.2.5.2 The Motors and Motion Association

SMMA is a trade association focused on electric motors and motion control products. SMMA has over 120 members, including manufacturers, suppliers, users, consultants, universities, and distributors. SMMA supports its members through programs and services, including annual conferences, in-house educational courses from the SMMA Motor and Motion College, the publication of industry market trend data, and small electric motor research activity.[p]

In 1995, SMMA founded the Electric Motor Education and Research Foundation (EMERF), whose mission is "to advance and promote the electric motor industry through education, pre-competition research, and facilitation of technology transfer within the industry and in cooperation with academic, private research and governmental organizations."[3] EMERF is important because it is a segment of the SMMA that promotes energy efficiency through teaching and providing information on new motor technologies.

### 3.2.6 Regulatory Programs

Under EPCA, as amended by EPACT 1992, each general-purpose three-phase induction motor, which is covered by definition and manufactured for distribution in commerce in the United States, is required to have a nominal full load efficiency that is not less than the efficiency in 10 CFR 431.25. The output ratings of these electric motors are from 1 to 200 horsepower and, as such, there appears to be some overlap with the 1 to 3 horsepower small electric motors

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[n] NEMA's MG1 document can be purchased online at www.nema.org/stds/MG1.cfm.
[o] NEMA's Premium® Motors program can be reviewed at www.nema.org/gov/energy/efficiency/premium.
[p] Information about the SMMA Motor and Motion College can be obtained at http://www.smma.org/MotorMotionCollege.htm.

covered in this rulemaking. However, the electric motors covered under the EPACT 1992 amendment are defined as "T-frame" and constructed according to NEMA standard three-digit frame series dimensions for mounting and interchangeability. The small electric motors covered in the analysis are, by definition, built in a "two-digit frame number series" for which the dimensions for mounting and interchangeability are fundamentally different from "T-frame" motors. This one element in the definition of "small electric motor," distinctly separates the identity of "small electric motors" from "electric motors" covered by EPCA. Therefore, DOE concludes that there is no overlap between these covered electric motors.

In general, EPCA, as amended by EISA 2007, covers certain categories of motors other than those already covered under the EPACT 1992 amendment and for some, it extends the upper limit of the output power range from 201 horsepower to 500 horsepower. For all of these motors, EISA 2007 prescribes nominal full load efficiency levels as defined in NEMA MG1–2006, Table 12–11. Further, for those electric motors already covered under the EPACT 1992 amendment, EISA 2007 prescribes nominal full load efficiency levels as defined in NEMA MG1–2006, Table 12–12. EISA 2007 does not however, address efficiency levels for small electric motors that are the subject of this analysis.

Nevertheless, EPACT 1992 amended EPCA to cover "small electric motors" and directed the Secretary of Energy to make a determination as to whether energy conservation standards for covered small electric motors would be technologically feasible, economically justified, and would result in significant energy savings. 42 U.S.C. 6317(b). Based on its analysis of available information, DOE determined that energy conservation standards for the defined small electric motors appear to meet these criteria. 71 FR 38807. As a result, DOE has undertaken a rulemaking process for small electric motors as directed by EPCA.

### 3.2.7 Non-Regulatory Programs

DOE reviewed voluntary programs that promote energy efficient electric motors in the United States, including the DOE Motor Challenge program, NEMA Premium energy efficient motors program, and Consortium for Energy Efficiency (CEE) Premium Efficiency motors program.

#### 3.2.7.1 Department of Energy Motor Challenge Program

In general, motor-driven equipment accounts for more than 70 percent of all electricity consumption by U.S. industries. In 1993, DOE launched its industry/government partnership, Motor Challenge Program with the goals of increasing the energy-efficiency of electric motor-driven systems in domestic industry and enhancing environmental quality. The program uses a market-driven approach to promote the design, purchase, installation, and management of energy-efficient electric motors and motor-driven systems and equipment, such as pumps, fans, and compressors. It was designed to help industry capture 5 billion kilowatt-hours per year of electricity savings and 1.2 million metric tons of carbon equivalent by the year 2000, with projections of much larger and longer-term national energy savings opportunities of over 100 billion kilowatt-hours per year by the year 2010.[q]

The Motor Challenge program encompasses three-phase 60 Hertz motors rated 1 horsepower and above. Its elements and offerings include: the DOE Energy Efficiency and Renewable Energy (EERE) Information Center, which provides up-to-date information about the practicality and profitability of electric motor system strategies; design decision tools, such as MotorMaster+ software; Showcase Demonstration projects; training; workshops; and conferences. In general, the response to the program from industry has been overwhelmingly favorable. The Motor Challenge program is no longer active; however, the EERE Information Center and the MotorMaster+ database of industrial motors remain viable.

The EERE Information Center answers questions on energy efficient products and services and refers callers to the most appropriate DOE/EERE resources. Industrial callers are eligible for an advanced level of service that includes engineering assistance, research, and software support for plant staff and industrial service providers working on industrial energy savings projects.[r]

MotorMaster+ is an energy-efficient motor selection and management tool, which includes a database of over 20,000 electric motors. It features motor inventory management tools, maintenance log tracking, efficiency analysis, savings evaluation, energy accounting, and environmental reporting capabilities.[s] Recently, MotorMaster+ has been expanded to include an International Electrotechnical Commission 50 Hertz database that contains 0.03, 0.04, 0.06, 0.09, 0.12, 0.15, 0.18, 0.25, 0.3, 0.37, 0.45,0.55, and 0.75 kW motors–the equivalent of polyphase small electric motors, but rated in kilowatts. Many manufacturers have supplied data to MotorMaster+ that was outside the scope of small electric motors, nevertheless, the database could be expanded in the future to include small electric motors.

#### 3.2.7.2 National Electrical Manufacturers Association Premium Efficiency Motor Program

On January 11, 1989, NEMA established voluntary energy efficiency levels for 1 through 200 horsepower, polyphase squirrel-cage induction motors. For an electric motor to be classified as "energy efficient," it was required to meet certain levels of efficiency in NEMA Standards Publication MG1–1987 (Revised March 1991). In 1992, the NEMA efficiency levels were incorporated into section 342(b) of EPACT 1992 and subsequently codified in 10 CFR 431.25. In 2001, the NEMA Premium Efficiency Motor Program was established to provide special recognition to electric motors that exceed the required efficiency levels established by EPACT 1992. NEMA Premium labeled motors help purchasers identify more efficient motors and optimize motor system efficiency commensurate with a particular application.[4] [t]

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[q] For more information about DOE "BestPractices," under the DOE Industrial Technologies Program, and Motor Challenge, visit http://www1.eere.energy.gov/industry/bestpractices/index.html.
[r] For more information about the EERE Information Center, visit https://www.eecbg.energy.gov/informationcenter/.
[s] For more information about MotorMaster+, visit www1.eere.energy.gov/industry/bestpractices/software.html#mm.
[t] For more information about the NEMA Premium Efficiency Motor Program, visit http://www.nema.org/gov/energy/efficiency/premium/.

Going a step beyond EPACT, NEMA Premium applies to single-speed, polyphase; 1 to 500 horsepower; 2-, 4-, and 6-pole; squirrel-cage; induction motors; NEMA Designs A or B; 600 volts or less; and rated for continuous duty operation. [5] Such electric motors are typically used in industrial applications operating more than 2000 hours per year. The NEMA Premium Efficiency Motor Program does not cover small electric motors as they are defined in EPCA. Nevertheless, some motor manufacturers offer polyphase, capacitor-start induction-run, and capacitor-start capacitor-run small electric motors at premium efficiency levels. As a result of the Energy Independence and Security Act (EISA) of 2007, these efficiency levels will become mandatory on December 19, 2010.

### 3.2.7.3 Consortium for Energy Efficiency

The Consortium for Energy Efficiency (CEE) is a nonprofit corporation that develops initiatives for its North American members to promote the manufacture and purchase of energy efficient products, including electric motors and services. Its members include utilities, statewide and regional market transformation administrators, environmental groups, research organizations and state energy offices in the U.S. and Canada. Also included in the CEE collaborative process are manufacturers, retailers, and government agencies.

In 1996, CEE began its Premium-Efficiency Motors Initiative to promote the production, distribution, and adoption of premium efficiency motors over motors meeting the minimum efficiency levels established under EPACT 1992 In 1999, CEE took a systems approach to energy savings and launched its Motor Systems Initiative that viewed the motor as a component of a larger system, where efficient motors, adjustable speed drives, and system-specific design strategies would provide the greatest opportunity for savings. Then, in 2001, CEE launched its Motor Decisions Matter to promote greater awareness of the benefits of motor systems efficiency. In June 2001, CEE and NEMA aligned to promote NEMA Premium motor efficiency levels that are higher than EPACT 1992 requirements.[6]

In May 2007, CEE published the Energy-Efficiency Incentive Programs – Premium-Efficiency Motors & Adjustable Speed Drives in the U.S and Canada, which provides information about the incentive-based programs in North America. These programs concentrate on 1 to 200 horsepower motors, but some include 201 to 500 horsepower motors. DOE reviewed the report and the CEE program descriptions it contains, but did not find any incentives that explicitly cover small electric motors. It appears that the programs cover commercial and industrial motors rated from 1 to 500 horsepower, although there is some potential for crossover to small polyphase electric motors in the 1 to 3 horsepower range.[u] There are a number of different programs broken down by region. For more information on these programs, download the report from CEE.[7]

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[u] For more information about CEE motor and motor systems programs, visit http://www.cee1.org/ind/mot-sys/mtr-ms-main.php3.

## 3.3 TECHNOLOGY ASSESSMENT

The small electric motors covered in this rulemaking are all AC induction motors. Induction motors have two core components: a stator and a rotor. The components work together to convert electrical energy into rotational mechanical energy. This is done by creating a rotating magnetic field in the stator, which induces a current flow in the rotor. This current flow creates an opposing magnetic field in the rotor, which creates rotational forces. Because of the orientation of these fields, the rotor field follows the stator field. The rotor is connected to a shaft that also rotates and provides the mechanical energy output.

The purpose of the technology assessment is to develop a preliminary list of technology options that could improve the efficiency of small electric motors. In the small electric motors covered in this rulemaking, energy efficiency losses are grouped into four main categories: $I^2R$ losses, core losses, friction and windage losses, and stray load losses. The technology options considered in this section are categorized by these four categories of losses.

### 3.3.1 Technology Options for $I^2R$ Losses

$I^2R$ losses stem from the current flow through the copper windings in the stator and conductor bars in the rotor. These conductor bars are usually made of aluminum, but some high efficiency motors that use copper are now available. $I^2R$ losses are reduced by decreasing resistance to current flow in the electrical components of a motor. These losses are manifested as waste heat, which can shorten the service life of a motor.

There are several ways that manufacturers work to minimize the losses created by resistance to current flow. Most of these efforts use the same principle of decreasing resistance, but there are different ways and areas of the motor where this can be done effectively. The resistance of a conductor is a function of both the resistivity and the geometric dimensions (*e.g.*, the cross-sectional area) of the material through which current flows. Resistivity is a physical characteristic that remains relatively constant for a given material, so changing the material type or manipulating the material's geometry (*e.g.*, copper wire diameter) are two approaches manufacturers employ to lower resistance. For single-phase CSCR motors, design engineers can also change the microfarad rating of the run-capacitor in combination with changing the copper wiring. The second capacitor reduces the current required to run the motor and in turn reduces the $I^2R$ losses.

Rotor conductor bars are areas where current flows. These bars are usually made of aluminum in small electric motors. One method of increasing the efficiency of the motor is to substitute copper bars for aluminum. Aluminum has a higher electrical resistivity ($2.65 \times 10^{-8}$ ohm-m) than copper ($1.68 \times 10^{-8}$ ohm-m). Copper is approximately 58 percent more conductive than aluminum, and changing from aluminum bars to copper would reduce associated $I^2R$ losses in the rotor.

Manipulation of the rotor's geometrical design is another approach to reduce $I^2R$ losses in the rotor. For the motors covered in this rulemaking, the rotors are called "squirrel-cage rotors" because without the core steel stack, the rotor conductor bars and end rings resemble the exercise wheels that domesticated squirrels would run in. The conductor bars of the rotor cage are not straight from one end ring to another; instead, they are twisted or slightly skewed. By skewing the rotor bars, motor designers can reduce harmonics that add cusps to the speed-torque characteristics of the motor. The cusps in the speed-torque curves mean that the acceleration of the motor will not be completely smooth. The degree of skew matters, because reducing the skew will help reduce the rotor resistance and reactance, thereby providing gains in efficiency. However, overly reducing the skew may have adverse impacts on the speed-torque characteristics.

Another change to the rotor bar geometry that can reduce resistance is increasing the cross-sectional area of the conductor bars. Resistance is inversely proportional to the cross-sectional area of the material (*i.e.*, aluminum or copper) through which current is flowing. By increasing the cross-sectional area, resistance will decrease and current flow will increase.

Another area of the rotor that manufacturers may alter to increase efficiency is the end ring. Current also flows through this area of the rotor. Increasing the size of the end ring can help decrease resistance and alleviate some of the $I^2R$ losses.

When rotor resistance is lowered, rotor bar current is increased, resulting in an increase in the electromagnetic forces. Depending on the magnitude of the gain in efficiency, this may actually have some adverse impacts on the electric motor. Also, when manufacturers increase the diameter of the rotor bars to lower rotor resistance, they remove steel from the lamination and thus the magnetic circuit. The reduction in steel will drive up magnetic saturation, which could counteract the efficiency gains. Furthermore, changing the conductor bar shape could induce harmonic content to the motor's operation. Odd harmonics, particularly the third harmonic, can create cusps in the speed-torque characteristics, which in turn disrupt motor acceleration. Larger rotor bars may also cause manufacturers to build new lamination tooling and add stack length because of magnetic saturation.

$I^2R$ losses are also prevalent in the stator. There are several design alterations that manufacturers may employ to decrease these losses. Most of the design options involve increasing the amount of copper winding in the slots. Manufacturers can accomplish this by using different gauges of copper wire, changing the slot sizes, and adjusting the length to diameter ratios. The use of larger (*i.e.*, numerically lower) wire gauges increases the efficiency of the motor because the larger cross-sectional area decreases the overall motor resistance. Increasing the stator's slot size may also allow manufacturers to increase the slot fill. Slot fill is the amount of copper wire inserted into a cross-sectional area relative to the total slot cross-sectional area. Depending on the number of poles in the motor, certain length-to-diameter ratios are better suited to balance the magnetic circuit.

Another way for manufacturers to reduce $I^2R$ losses is to reduce the air gap between the stator and rotor. A smaller air gap will decrease the magnetomotive force drop, which occurs across the air gap. The motor will then require less current to drive the load and thereby reduce $I^2R$ losses. The problem with this option is that smaller air gaps mean there are tighter tolerances on specifications when building a motor, which at some point become technically infeasible to manufacture. Based on discussion with manufacturers and small electric motor design engineers, DOE believes that the smallest air gap possible, without manufacturing problems, is 0.0125 inch.

### 3.3.2 Technology Options for Core Losses

Core losses are those losses created in the steel components of a motor. These losses, like $I^2R$ losses, manifest themselves as heat. Core losses are generated in the steel by two electromagnetic phenomena: hysteresis losses and eddy currents. Hysteresis losses are caused by magnetic domains resisting reorientation to the alternating magnetic field (*i.e.*, 60 times per second, or 60 hertz). Eddy currents are physical currents that are induced in the steel laminations by the magnetic flux of the windings.

Manufacturers have several techniques to help reduce the effects of hysteresis and eddy current losses in their motors. One of the first approaches is simply adding additional steel to the rotor and stator (*i.e.*, increasing the "stack" length). This is one of the least costly and least invasive changes a manufacturer can use to increase motor efficiency. The extra steel laminations and increased stack height decrease flux density. This reduces hysteresis losses, but also changes motor performance. Adding stack length increases motor impedance, which is then reduced by removing turns of wire in the stator. Monitored starting torque is also important because an increased stack may reduce torque, potentially rendering the motor unable to start in certain applications. Adding stack to the motor means the motor is also getting longer physically, therefore geometrical constraints can become an issue as well.

Another technique for reducing steel losses is using a higher quality, more efficient grain-oriented electrical steel in the core. Hysteresis losses are reduced because the magnetic permeability improves and grain size increases, reducing the magnetic domain resistance. Eddy currents are reduced because the resistivity of the laminations is higher, reducing the magnitude of the currents. In studying the techniques used to reduce steel losses, DOE considered two types of materials: conventional silicon steel and so-called "exotic" steels, which contain a relatively high percentage of boron or cobalt.

Conventional steels are commonly used in small electric motors manufactured today. There are three types of steel that DOE considers "conventional:" cold-rolled magnetic laminations (CRML), fully processed non-oriented electrical steel, and semi-processed non-oriented electrical steel. Each steel type is sold in a range of grades. Generally, as the grade number goes down, so does the amount of loss associated with the steel (*i.e.*, watts of loss per pound of steel). The induction level also drops, causing the need for increased stack length. Of these three types, CRML steels are the most commonly used, but also the least efficient. The fully processed steels do not require annealing after being punched and assembled, and are available in a range of steel grades from M56 through M15.[v] Semi-processed electrical steels are designed for annealing after punching and assembly, but they have more limited availability.[8]

The exotic steels generally are not manufactured for specific use in small electric motors. These steels include amorphous steel, vanadium permendur, and other alloyed steels containing a high percentage of boron or cobalt. These steels offer a lower loss level than the best electrical steels, but are more expensive per pound. From a manufacturing perspective, these steels also present problems because they come in non-standard thicknesses that are harder to manufacture.

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[v] Lower "M" grades of steel denote lower losses, thus M15 has fewer losses per pound of steel than M56.

Another method manufacturers use to reduce core losses is to use thinner laminations of steel. Using thinner laminations decreases the cross-sectional area through which the eddy currents are produced, reducing the magnitude of the eddy currents. This reduction in losses will reduce heat generation in the steel and improve efficiency. However, this design change does come with a penalty. As laminations become thinner, more laminations are needed for the same stack height, requiring more punching and assembly time.

Manufacturers may also reduce eddy currents by using improved insulating coatings between the steel laminations. Improved coatings increase the resistance between the steel laminations, which makes it more difficult for eddy currents to flow from lamination to lamination.

Annealing the core steel is another technique manufacturers use to reduce hysteresis losses. Annealing is a heating process that alters the grain structure of the steel and alleviates any stresses introduced during punching and assembly. After being annealed, the material becomes much easier to magnetize, which means the magnetic domains reorient more easily. Manufacturers will incur more cost if they do additional annealing to the steel because they are adding another step to the manufacturing process, which increases production time. The necessary annealing equipment also requires a large capital investment.

Table 3.8 presents the core steels used in manufacturing small electric motors, including some more efficient steels that are not as common, which DOE considered in its analysis. In addition to the steel grade name, the table presents nominal thickness and core losses at a fixed magnetic flux density.

**Table 3.8. Core Steel Grades, Thicknesses, and Associated Losses**

| Steel Grade | Nominal Thickness (inches) | Theoretical Core Loss at 60 Hz (Watts per Pound at Magnetic Flux Density) | Remarks |
|---|---|---|---|
| 24 M56* | 0.025 | 4.30 Watts/lb at 1.5 T[9] | Cold-rolled magnetic laminations (semi-processed) |
| 26 M47 | 0.019 | 2.80 Watts/lb at 1.5 T[8] | Non-oriented electrical steel (fully processed) |
| 24 M36 | 0.025 | 2.35 Watts/lb at 1.5 T[8] | Non-oriented electrical steel (fully processed) |
| 24 M19* | 0.025 | 2.00 Watts/lb at 1.5 T[8] | Non-oriented electrical steel (fully processed) |
| 29 M15* | 0.014 | 1.45 Watts/lb at 1.5 T[8] | Non-oriented electrical steel (fully processed) |
| Hiperco 50* | 0.006 | 1.00 Watts/lb at 1.5 T[10] | Iron-cobalt-vanadium soft magnetic alloy |

* Denotes a steel used in the engineering analysis.
†Watts of loss per pound of core steel are only comparable at the same magnetic flux density, measured in tesla. The tesla (symbol T) is the SI-derived unit of magnetic field, which is also known as "magnetic flux density," named in honor of inventor, scientist, and electrical engineer Nikola Tesla.

#### 3.3.2.1 Plastic Bonded Iron Powder

Recently, DOE became aware of a new technology that Lund University researchers in Sweden developed the production of magnetic components for electric motors from plastic bonded iron powder (PBIP). The technique has the potential to cut production costs by 50 percent while doubling motor output.

The method uses two main ingredients: metal powder and plastics. Combining the ingredients creates a material with low conductivity and high permeability. The metal particles are surrounded by an insulating plastic, which prevents electric current from developing in the material. This is critical because it essentially eliminates losses in the core due to eddy currents. Properties of PBIP can differ depending on the processing. If the metal particles are too closely compacted and begin to touch, the material will gain electrical conductivity, counteracting one of its most important features.

Another advantage of PBIP is a reduction in the number of production steps. The number of steps in manufacturing a rotor and stator is reduced from roughly 60 to just a few. A second way to increase savings is to build an inductor with PBIP. During processing, the plastic and metal are molded together using a centrifugal force. During this process, the inductor core consisting of PBIP and pre-wound windings are baked into the core. This inductor is then used as a filter for grid power application. The filter then reduces the use of cooling equipment in the motor design.[11]

### 3.3.3 Technology Options for Friction and Windage Losses

Bearing friction and an imperfect cooling fan system create what is called "friction and windage losses" in AC induction motors. These losses also add heat to the motor's system and decrease the motor's efficiency.

To decrease the losses caused by motor bearings, manufacturers can change the bearings or bearing lubricant. Less friction, and thus less heat, is produced when manufacturers use a better bearing structure or bearing lubricant, but manufacturers must also consider issues such as temperature rating and speed.

Another way to reduce heat in an induction motor is to use a better cooling system. Changing the fan or adding baffles to the current fan can help reduce heat and losses. Baffles help redirect airflow through the motor, creating better circulation and a cooler motor overall. With a well-designed cooling system, the motor should run more efficiently. However, some manufacturers choose to use one cooling system for a range of horsepower ratings. This means that the same cooling system may exceed spatial constraints for certain smaller motors, resulting in more losses than are necessary to cool the motor.

### 3.3.4 Technology Options for Stray Load Losses

Any losses that are otherwise unaccounted for and not attributed to $I^2R$ losses, steel losses, or frictional and windage losses are considered stray-load losses. DOE is not aware of any specific techniques manufacturers use to reduce stray-load losses. General process changes to the manufacturing of rotors and stators could somewhat reduce these losses.

### 3.3.5 Summary of the Technology Options Under Consideration

Table 3.9 summarizes the technology options discussed in this technology assessment, and those that DOE will now consider in the screening analysis (see chapter 4). The options that pass all four screening criteria are considered "design options" and are used in the engineering analysis (see chapter 5) as a means of improving the efficiency of small electric motors.

**Table 3.9. Summary of Technology Options for Improving Efficiency**

| Type of Loss to Reduce | Technology Option Applied |
|---|---|
| $I^2R$ Losses | Use copper die-cast rotor cage |
| | Remove skew on conductor cage |
| | Increase cross-sectional area of rotor conductor bars |
| | Increase end ring size |
| | Changing gauges of copper wire in stator |
| | Manipulate stator slot size |
| | Decrease the radial air gap |
| | Change run-capacitor rating |
| Core Losses | Improve grades of electrical steel |
| | Use thinner steel laminations |
| | Anneal steel laminations |
| | Add stack height (*i.e.*, length, add electrical steel laminations) |
| | Use high-efficiency lamination materials |
| | Use plastic bonded iron powder |
| Friction and Windage Losses | Use better bearings and lubricant |
| | Install a more efficient cooling system |

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