PRODUCT APPLICATION

A technical bulletin for engineers, contractors and students in the air movement and control industry

Motor Application Guide for Ventilation Products

The evaluation of a fan's motor is a time-consuming part of the design of air-handling equipment. This article will aid in the selection of the correct motor type from an electrical and mechanical standpoint for a given application and fan type, and help you understand, identify, and eliminate application problems before they are encountered.

When selecting a motor, the fan and application must be in sync with each other. For example, money is wasted when putting an expensive, special-duty motor costing hundreds (or sometimes thousands) of dollars extra on a fan used in normal clean air applications. The overall benefit is not having to deal with special design requests that result in unnecessary extra expense and longer lead times.

Most often fan manufacturers will recommend the proper standard motor for the application. If your application requires special consideration, an outline of the factors to consider in evaluating fan motor performance is included for reference.

Motor Applications

When selecting the proper motor for the application, the two most commonly overlooked considerations are:



Physical Size: Space available for motor mounting may limit selections. Higher-efficiency National Electrical Manufacturers Association (NEMA) versus International Electrotechnical Commission (IEC) motor frames and explosion-resistant motors may not fit in a fan that was not originally designed for such applications, especially those selected for low CFM.

Belt drive versus direct drive fans: The selection of belt-driven versus direct-driven fans should involve consideration of fan sound levels, motor cost, energy efficiency, and maintenance. The belt-driven fan has pulleys, shafts, bearings, and belt(s) which contribute to the initial cost and periodic maintenance. However, lower-cost, higher-speed motors are generally used. Belt-driven fans are typically less efficient due to belt and bearing losses. The selection of larger, slower-moving belt-driven fans will generate less noise for a given application. Smaller direct drive fans will have a faster rotating wheel for the same air delivery and be more efficient, however, generate more noise.

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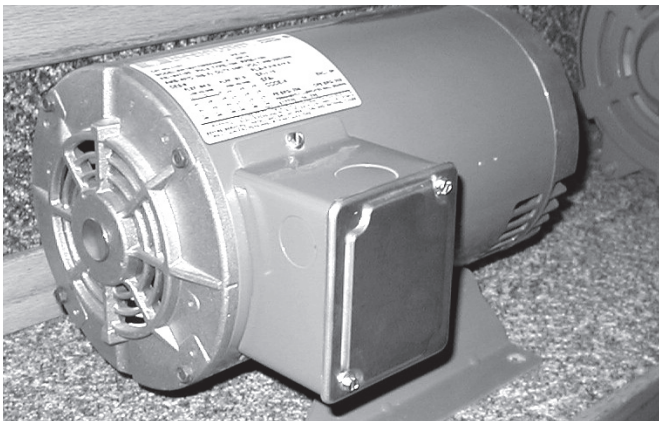
Belt-driven fans and very large or heavy direct-driven fans require high starting torque of split-phase, capacitor-start, or three-phase motors. Direct-driven motors work great where access to bearings and belts is difficult. Motors for belt-driven fans are typically 1725 rpm (60 cycle), while direct drive fans have specific motor RPMs available to accommodate for no pulley adjustment. Typically, when motors are lower than 1725 rpm, they cost more, are physically larger, have longer lead times, and have fewer motor options available. Direct drive fans utilizing motors with Variable Frequency Drives (VFDs) or Electronically Commutated (EC) motors offer integral motor/fan speed control for airflow balancing, variable volume airflow control, and superior energy efficiency.

Motor Enclosures

Many types of motor enclosures are available for all conditions from open to explosion resistant. The most common motor enclosures used with fans are open and totally enclosed. There are several different types within each enclosure. In most cases, it is best to let the fan manufacturer select within the subcategory of enclosures.

Open: Has ventilation openings that permit passage of external cooling air over and around the windings of the motor. The term “open” designates having no restriction to ventilation other than that necessitated by mechanical construction. An open drip-proof (ODP) motor is where ventilating openings are constructed such that operation is not interfered with when drops of liquid or solid particles strike or enter the enclosure at any angle from 0 to 15 degrees downward from vertical. The motor must be mounted in the proper orientation for the open drip-proof enclosure to function as designed.

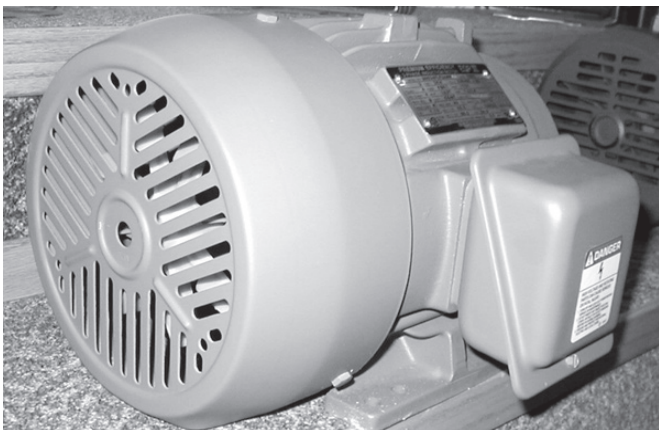
Totally Enclosed: Prevents free exchange of air between the inside and outside of the case, but not sufficiently enclosed to be termed airtight. Totally enclosed motors are best suited for use in humid environments or dusty, contaminated atmospheres. Some totally enclosed motors are also available for more severe applications.



Open drip-proof motor

Application: Suitable for indoor use and in relatively clean atmospheres that are fairly dry and well-ventilated. They do not resist airborne dust or chemical vapor. Typically used on small centrifugal roof fans with the motor out of the airstream where the air is clean and dry.

Totally enclosed fan-cooled (TEFC): A totally enclosed fan-cooled motor that is equipped for exterior cooling utilizing a fan integral to the motor but external to the enclosed parts.



Totally enclosed fan-cooled motor

Application: Used when protection from dust, moisture, rain, and non-explosive atmospheres is required and inadequate airflow over the motor is provided by the device it drives. These motors are typically used on belt-driven inline or duct fans.

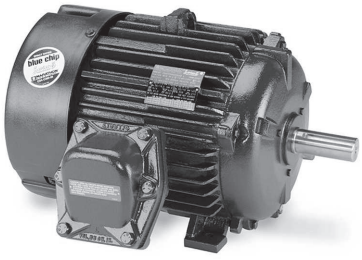
Totally enclosed air over (TEAO): A totally enclosed air over the motor is not self-ventilated and must be cooled by means external to the motor. The motor is typically installed in the airstream, with a fan that blows cooling air over the motor.

Application: These motors are used when protection is required from dust, moisture, rain, and non-explosive atmospheres. These motors are not self-cooling, so they are typically used where the driven device is a fan or blower that provides the necessary air movement over the motor for cooling. It is important that the airflow over the motor is of high enough velocity to equal or exceed the cooling offered by an integral fan. These motors are typically used on sidewall propeller fans, direct drive axial fans, and vane axial fans.

Totally enclosed special duty: Severe-duty motors are always totally enclosed, three-phase, cast iron casing with Class F insulation. They are designed for use in extremely moist or chemical environments but not for hazardous locations. These are typically called marine duty or chemical duty. Severe-duty Division 2 motor applications require clarification of the hazardous location to provide the correct motor and frame size for the application.

A washdown duty motor is totally enclosed and built to handle high-pressure washdowns. These motors are used in wet environments and where motors are subject to repeated washdowns.

Explosion-resistant (EXP): A totally enclosed motor is designed and constructed to withstand an internal explosion of specified gases or vapors, and not allow the internal flame or explosion to escape.



Explosion-resistant motor

When explosion-resistant motors are required, there is a lot to consider, which is why there are numerous classes, divisions, and groups.

The classification of the hazard requires considerable skill and judgment, particularly to the extent of the hazardous area.

Generally, **these conditions are defined by a Safety Engineer or by the insurance company**. Motors designed for one hazardous location are not necessarily suitable for use in another. It is necessary to obtain specifics on the hazardous-duty location to provide the proper motor. In many cases, explosion-resistant motors will not fit on the originally selected fan due to the increased frame size.

The following are definitions of the various classes and divisions of explosive atmospheres. The containment aspects are defined by “divisions” according to the likely concentration of the hazard. Division I applies to routine or periodic exposure. Division 2 refers to a hazard that is normally confined within a system or container and which would only escape in the event of some abnormal circumstance or equipment failure.

Class I locations: These are hazardous because of the presence of flammable gases or vapors in quantities to produce explosive or ignitable mixtures.

Class I Division I locations exist where ignitable concentrations of flammable gases or vapors exist under normal conditions, where ignitable concentrations of such gas or vapor may exist frequently, or where a breakdown might release ignitable concentrations and may cause simultaneous electrical equipment failure.

Class I, Division 2 locations exist where flammable liquids or flammable gases are normally confined within closed containers or systems from which they can escape only in the event of an accidental breakdown or abnormal operations.

Class II locations: These are hazardous because of the presence of combustible dust.

Class II, Division 1 locations exist where combustible dust is in the air in concentrations sufficient to produce explosives or ignitable mixtures, where equipment or machinery failure might cause the concentration to be produced, or where the concentration might be electrically conductive.

Class II, Division 2 locations exist where combustible dust is not in sufficient concentration to produce explosive or ignitable mixtures, dust is in suspension in the air as a result of processing or infrequent malfunctioning of equipment, and dust concentration may be ignitable by abnormal occurrences.

Class III locations: These are hazardous locations due to ignitable fibers or combustible flyings that are not in suspension in enough concentration to produce ignitable mixtures.

Class III, Division 1 locations exist where easily ignitable fibers or materials producing combustible flyings are being processed or used.

Class III, Division 2 locations exist where easily ignitable fibers are stored or handled.

Groups (Hazard degrees) The National Electrical Code (NEC) categorizes hazardous atmospheres and locations. Because the type and degree of hazard vary widely according to the materials encountered and their probable presence in hazardous quantities, the following methods of identification are used. Materials are "classed" as flammable vapors or gases (Class I), or as combustible dusts (Class II). Additionally, materials are “grouped" according to their relative degree of hazard with Groups C and D applicable to vapors or gases, and Groups E through G applicable to combustible dust.

Class I, Group A: Atmospheres containing acetylene.

Class I, Group B: Atmospheres containing hydrogen or gases or vapors of equivalent hazards such as manufactured gas.

Class I, Group C: Atmospheres containing ethyl ether vapors, ethylene, or cyclopropane.

Class I, Group D: Atmospheres containing gasoline, hexane, naphtha, benzene, butane, alcohol, acetone, benzyl, lacquer solvent vapors, or natural gas.

Class II, Group E: Atmospheres containing metal dust, including aluminum, magnesium, and their commercial alloys, and other metals of similarly hazardous characteristics.

Class II, Group F: Atmospheres containing carbon black, coal, or coke dust.

Class II, Group G: Atmospheres containing flour, starch, or grain dust.

Explosion-resistant equipment is not generally available for Class I, Groups A and B locations and it is necessary to isolate motors from the hazardous area.

A common misconception is that just because the class and group exist there should be suitable products (motors and other equipment) to operate in the defined environment. In the case of Class I Groups A and B, the market is limited and designs are so difficult that most manufacturers do not make them.

Fan Construction for Hazardous Locations

As previously mentioned, fan applications suitable for explosion-resistant motors may involve the handling of potentially explosive or flammable particles, fumes, or vapors. Such applications require explosion-resistant motors and careful consideration of all system components to ensure the safe handling of such gas streams. The Air Movement and Control Association International, Inc. (AMCA) Standard 99 “Classification for Spark Resistant Construction” deals with common explosion-resistant fan construction requirements. The Standard contains guidelines that are to be used by both the manufacturer and user as a means of establishing general methods of construction. The exact method of construction and choice of alloys is the responsibility of the manufacturer; however, the customer must accept both the type and design with full recognition of the potential hazard and the degree of protection required.

Motor Types

Fan and blower applications for use on AC power employ shaded-pole, permanent-split capacitor, split phase, capacitor start, three-phase induction, Synchronous Reluctance, Electronically Commutated, Switched Reluctance, and Ferrite-Assisted Synchronous Reluctance motor types. Each type has electrical characteristics and efficiencies which adapt it to specific load requirements or unit limits and controllability. Motor costs vary due to construction features and accessories. A squirrel cage induction motor is the most common motor. It is both rugged and simple in design, making it both economical and reliable.

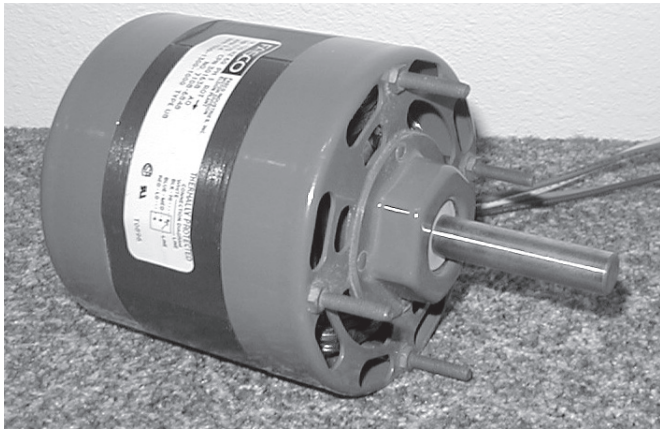
Single-Phase Induction Motors

Single-phase power does not naturally create a rotating magnetic field. Motors operating on single-phase power must include additional means to start the rotor moving. Once moving, the rotor induces a rotating magnetic field that sustains operation.

Therefore, in some single-phase motors, the starting circuit is "opened" after the rotor reaches a predetermined speed. In other types, the start circuit remains engaged. How single-phase motors are started, and the effect this has on torque, is often the factor that determines which single-phase motor type best fits the application. The fan manufacturer normally chooses the correct motor type for the application. The following explains single-phase motor types.

Shaded pole: These motors have only one main winding and no start winding. Starting is accomplished through a design that uses a copper ring around a small portion of each motor pole. This "shades" that portion of the pole, causing the magnetic field in the ringed area to lag the field in the non-ringed portion. The reaction of the two fields initiates rotation.

Since it lacks a start winding, starting switch, or capacitor, the shaded pole motor is electrically very simple and inexpensive. Speed can be controlled by varying the voltage. These motors offer poor starting torque, typically 25 to 75 percent of rated load, and very low efficiency. These motors typically are up to ¼ horsepower and have sleeve bearings.



Shaded pole motor

Application: With low initial cost, low-torque, and small horsepower applications such as small blowers, ceiling exhaust fans, and small appliances, these motors are commonly used with speed controllers.

Permanent split capacitor (PSC): These motors do not have a starting switch or a capacitor strictly for starting. Instead, these motors have a run-type capacitor that is permanently connected in series with the start winding. This makes the start winding an auxiliary winding after the motor reaches running speed. Maintenance is low due to the lack of a starting switch. (A capacitor is a device that stores electrical energy. It is used to change the timing of the current flow in the start windings, which helps to establish a rotating magnetic field.)

The run capacitor must be designed for continuous use, it cannot provide the short-term boost of a starting capacitor. Therefore, the starting torque of a PSC motor is low, ranging from 30 to 150 percent of the rated load, which makes the motors unsuitable for hard-to-start loads.

These motors have several advantages. With no starting mechanism, they can be designed for easy reversing. They are the most reliable single-phase motor, primarily because a starting switch is not required. These motors typically are available up to 1 horsepower and have ball bearings.

Advantages: These motors have a wide variety of applications. Examples include direct drive fans, blowers with low starting torque requirements and intermittent cycling applications, and for use with speed controls.

Split phase: Also called induction-start/induction-run motor is perhaps the simplest kind of single-phase motor. The stator has two types of coils; one is called the running winding and the other is the starting winding.

The start winding is made with a smaller gauge wire than the run winding and has much higher resistance. This results in different currents and magnetic fields in the two windings. These two magnetic fields, displaced from each other, form a rotating field that causes the rotor to turn.

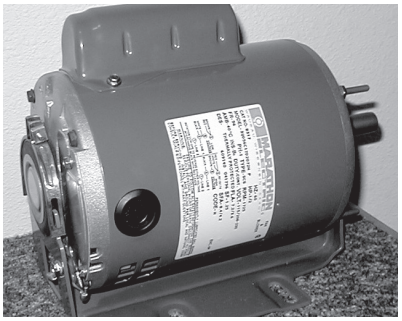
The split-phase motor's simple design is typically less expensive than other single-phase motor types. However, the simplicity limits performance. Starting torque is low; 100 to 175 percent of the rated load. In addition, the split-phase motor develops a high starting current relative to motor horsepower, also called locked rotor current, and has unreliable thermal protection due to the high locked rotor current relative to the running current. Also, these motors usually are designed for single voltage, limiting application flexibility. These motors typically are up to ¾ horsepower and have ball bearings.

Application: Good applications for split-phase motors include small fans, blowers, and other low-starting torque applications with low horsepower requirements. Primarily uses split-phase motors on direct drive units like small props and small centrifugal units.

Capacitor start/Induction run: This design results in a wide range of applications for industrial use. It is similar to a split-phase motor but has a much heavier start winding with a capacitor placed in the path of the electrical current to the starting winding to provide a starting boost. A capacitor motor can usually be recognized by the capacitor can or housing mounted on the stator.

These motors have several advantages over split-phase motors. Since the capacitor is in series with the start circuit, it creates more starting torque. Typical starting torque ranges from 200 to 400 percent of rated load. Plus, the starting current is much lower than the split phase due to the larger wire in the start circuit. This allows higher cycle rates and reliable thermal protection.

This motor is more expensive than a split-phase design because of the additional cost of the start capacity. However, the application range is much wider because of higher starting torque and lower starting current relative to motor horsepower. These motors typically are used up to 2 horsepower but are available in larger horsepower. With anything larger than 2 horsepower, there may be fit problems. These motors typically have ball bearings.



Capacitor start motor

Application: Ideal for a wide range of belt-driven applications like medium-sized blowers and many direct drive applications. Primarily used on larger belt-driven propeller fans and large centrifugal units.

Electronically Commutated (EC): EC motors or ECMs are an electronically commutated (EC) synchronous motor that uses internal electronics to convert and control the flow of direct current (DC) to the motor windings. The motor's electronics switches the DC current to the motor windings and adjusts the current pulses to control the motor's speed and torque. A permanent magnet rotor follows the magnetic fields created by the current pulses.



Vari-Green® EC Motor

Advantages: EC motors are efficient, with high power output per size, have a long service life and low operating costs, are quiet and don't generate much heat, and are easily controlled to vary speed.

Three-Phase Induction Motors (IM)

Three-phase power naturally creates a rotating magnetic field, no additional windings or switches are needed within the motor for starting. The simplicity of a three-phase induction motor can be attributed to the three-phase power supplied to the stator windings. Three-phase power can be thought of as three different single-phase power supplies.

Motor Types Summary Chart *Displays various motor types and their key differences*						
Motor Type	Cost	Nominal Efficiency	Starting Torque	Speed Control	Reversible	Typical Applications
Shaded Pole	Lowest	Lowest	Lowest	Yes	No	• Designed for specific fans • Used on small direct drive fans only • Can be used with speed controllers
PSC	Low	Low	Low	Yes	Yes	• Constant torque • Used on small direct drive fans only • Can be used with speed controllers
Split Phase	Average	Good	Medium	No	Yes	• Separate start windings to control starting amps • Used on medium sized fans
Capacitor Start	Average	56% @ ¼ hp 74% @ 3 hp High	High	No	Yes	• Used for higher starting torque requirements • Used on medium and large fans • Most common
Three Phase	Average	68% @ ¼ hp 87% @ 10 hp High	High	No	Yes	• Efficient electromechanical device • Used on large fans • Wide range of available motor options • Available for use with VFDs

Three identical sets of running windings are mounted in the stator, and each set of windings is connected to a different phase of the power sources. The increase and decrease or rise and fall of the current in each phase produces the rotating magnetic field. In turn, the rotation of the magnetic field produces a twisting motion in the motor shaft. These motors have the highest efficiencies and typically have ball bearings.

The industry has almost universally adopted the polyphase or three-phase induction motor as the most practical electric motor. These motors are available in a range from ½ hp to hundreds of horsepower. Their characteristics can be adapted to suit any type of load and to serve practically every industrial need. The summary chart on this page shows the major differences between each motor type.

Three-phase motors cannot be used with speed controls like single-phase motors, but three-phase inverter duty motors can be used with variable frequency drives (VFDs). VFDs not only vary the voltage like a speed controller, but they change the frequency with the voltage. Inverter duty motors require heavier insulation on the internal wires, due to the extra heat generated when used with a VFD.

Applications: These motors are typically used on large fans and are recommended when the horsepower is greater than ½ hp and when additional motor features are required. These can be available for use with VFDs where the speed of the fan or pump needs to change.

Synchronous Reluctance Motors (SynRM)

A synchronous reluctance motor differs from a standard induction motor as the rotor has no field-inducing winding. Additionally, they do not use permanent magnets in their rotor. They rely on the principle of magnetic reluctance, using a specially shaped rotor to generate torque. The rotor's design creates a difference in magnetic reluctance along different axes, allowing it to align with the rotating magnetic field generated by the stator, thus producing torque. Instead, the rotor utilizes laminated steel plates that rotate when the stator winding magnetic field is induced. This results in a more efficient motor than a traditional AC induction motor.

The main characteristics of a synchronous reluctance motor are high efficiency at synchronous speed without using rare earth permanent magnets.

Synchronous reluctance motors can be used with variable frequency drives (VFDs) to achieve optimal performance.

Ferrite-Assisted Synchronous Reluctance Motors (FASynRM)

Ferrite-assisted synchronous reluctance motors are a type of electric motor that combines the advantages of synchronous reluctance motors and permanent magnet motors, using ferrite magnets to enhance motor performance.

Ferrite magnets are embedded in the rotor structure to augment the reluctance torque. These magnets improve the motor's performance, particularly in terms of torque density and efficiency.

FASynRMs can achieve higher efficiency compared to traditional synchronous reluctance motors, particularly at lower speeds and higher torque requirements, and can be used with variable frequency drives (VFDs) to achieve optimal performance.

Motor Speed

The number of poles determines the speed of the motor. The number of poles is related to the number of coil centers. Sixty cycle (Hz) power cycles 60 times each second, or 3600 times each minute. When the stator is wound in the form of two poles, they change their polarity 3600 times each minute. The rotating magnetic field induces the rotor conductors to follow. All alternating current induction motors "slip". They cannot keep up with the speed of the pole changes within the stator. The speed of the magnetic field within the stator is called the synchronous speed of the motor. A two-pole motor has a synchronous speed of 3600 rpm on 60 cycle (Hz) alternating current. However, slip accounts for an actual speed of 3450 rpm.

This simple formula will help determine the synchronous speed (no load) of an electric motor:

$$\frac{\textit{Frequency (Hertz) x 120}}{\textit{Number of Poles}} = \textit{Synchronous RPM}$$

The chart below shows the actual speed, synchronous speed, and number of poles on an AC motor.

Actual Speed	Synchronous Speed	Number of Poles
3450	3600	2
1725	1800	4
1140	1200	6
850	900	8

Voltage and Phase

Voltage and phase are limited to the power supply available at the installation site. The general rule of thumb is to use polyphase (three-phase) motors of the highest available voltage to achieve the greatest efficiency. Single-phase motors of similar horsepower often cost more than polyphase because of the need for capacitors, centrifugal switches, etc.

In most industrial sites, the power supply typically used for the average polyphase motor is 230 or 460 volts at 60 Hertz. Single-phase motors are available for service on 115/230 volts for 3 hp and smaller. Motors up to 10 hp are available for 230-volt service in single-phase but are not very common.

The key to determining what motor voltage and phase to select is understanding the motor manufacturer's original design. Most motors operate successfully within 10% of nameplate voltage with the exception of the tri-voltage 208-230/460-volt rating. (The 230/460-volt rating is not generally recommended for 208-volt service unless authorized by the motor manufacturer.)

Motor service life can be shortened considerably if the motors are operated outside the +/- 10% variance range.

Service Factor

The service factor is a measure of continuous overload capacity at which a motor can operate without damage, provided the other design parameters such as rated voltage, frequency, and ambient temperature are within norms. Example: A ¾ hp motor with a 1.15 service factor can operate at .86 hp (.75 hp x 1.15 = .862 hp) without overheating or otherwise damaging the motor if rated voltage and frequency are supplied at the motor's leads. Some motors have higher service factors than the National Electrical Manufacturers Association (NEMA) standard.

General-purpose open motors usually have a service factor greater than 1.0 and totally enclosed motors usually have a service factor not exceeding 1.0. When the motor nameplate voltage and frequency are maintained, the motor can be run up to the capacity as shown on the motor nameplate.

For easy reference, standard NEMA service factors for various horsepower motors and motor speeds are shown in the table below.

NEMA service factor at synchronous speed (rpm) (for drip-proof motors)				
HP	3600	1800	1200	900
1/6, 1/4, 1/3	1.35	1.35	1.35	1.35
1/2	1.25	1.25	1.25	1.25
3/4	1.25	1.25	1.15	1.15
1	1.25	1.15	1.15	1.15
1-1/2 Up	1.15	1.15	1.15	1.15

Standard motors are rated under the assumption they will be operated at sea level in an ambient atmosphere of 40°C.

Ambient temperature is defined as the temperature that the motor will have in the surrounding air as an expected maximum.

It is assumed there is no difference in cooling between sea level and 3,300 feet. The air at higher altitudes is thinner and can't remove as much motor heat. As a result, the motor runs hotter. When running a motor above 3,300 feet, the following alternatives are available to keep a motor operating within the limits the insulation class allows. All options are dependent upon the actual temperature rise at sea level.

Do not run the motor into the service factor. For example, a motor rated at 1.15 service factor will operate successfully at 9,000 feet at a 1.0 service factor.

If a motor is operated at a lower ambient temperature, it may not need to be modified for altitude. For example, a 40°C ambient motor in a 20°C ambient condition could be operated at an altitude of up to 9,900 feet without a reduction in service factor.

Utilizing a higher efficiency motor will result in more flexibility due to lower losses and lower temperature rise at sea level.

Note: The service factor for motors operated with a VFD should be 1.0.

Efficiency

Motors are converters of energy. Their job is to convert electrical energy into mechanical energy. Efficiency ratings tell how well they do their job. Efficiency is the ratio of output power (mechanical) to input power (electrical). Single-phase AC induction squirrel cage peak motor efficiencies range from as low as 30% to as high as 65%, depending on the motor type and design. Motor efficiencies also depend on the actual motor load versus the rated load.

The best motor for the job is often designated by the nature of the load. Motor efficiency usually is greatest at the full load rating and falls off rapidly for under and overloaded conditions. It is a misconception that a motor running well below its maximum load rating will run cooler and more efficiently. Oversizing AC motors reduces efficiency by a substantial amount, causing a larger part of the input energy to be dissipated as heat. On the other end of the scale, overloading of motors is a much better-understood concept because there are signs that indicate poor motor selection (reduced speed, high amperage draw, tripped motor overloads).

From an efficiency standpoint, it is typically best to run an AC single-phase, squirrel cage motor at no less than 75% full load and no greater than 125% full load. Motor efficiency is greatest near its full load rating.

Driven by the interest to reduce motor energy consumption, the National Electrical Manufacturers Association (NEMA) motor efficiency designations (traditionally used in the United States) now have competition by European motor efficiency designations (such as IEC standards). Each is based on its classification systems, efficiency levels, and regulatory frameworks.

NEMA motor efficiency designations are typically based on Energy Efficiency Classes for motors. These are defined under NEMA MG 1 and are aligned with the Institute of Electrical Engineers (IEE) standards. The NEMA Class designations include Standard Efficiency (SE), High Efficiency (HE), Premium Efficiency (PE), and Super Efficiency (SE) motors. For example, motors may be rated as NEMA Premium Efficiency (PE), which corresponds to a high level of energy savings.

International Electrotechnical Commission (IEC) European motor efficiency designations are based on the standard IEC 60034-30-2 standard and specify the motor efficiency classification through a series of IE (International Efficiency) classes. The IEC class designations include Standard Efficiency (IE1), High Efficiency (IE2), Premium Efficiency (IE3), Super Premium Efficiency (IE4), and Ultra-Premium Efficiency (IE5).

A regional practical consideration to note in the case of motor replacement and availability is that **NEMA motor frame sizes and European frame sizes are not directly interchangeable (which can be a maintenance replacement headache).** This is due to differences in the way their dimensions are defined and standardized. While both standard systems provide a set of frame sizes for electric motors, the specific dimensions, tolerances, and mounting configurations can vary significantly.

Motor Efficiency Legislation in the US: The Energy Policy Act of 1992 (EPAct) gave the US Department of Energy (DOE) the authority to set minimum efficiency standards for electric motors.

In August 2001, the National Electrical Manufacturers Association (NEMA) introduced a Premium Energy-Efficiency motor standard. The efficiencies for NEMA Premium Efficiency motors (1-500 hp) are listed in NEMA Standard MG-1, Table 12-12, and apply to single-speed, polyphase, squirrel cage induction motors with a horsepower rating of 1–500 hp.

In 2012, the Energy Independence and Security Act (EISA) required all general-purpose three-phase motors from 1 hp up to 200 hp to meet NEMA Premium efficiency (PE) standards.

In 2023, the Medium Electric Motors (MEMs) rule scheduled to take effect in 2027 states all three-phase motors 1 to less than 100 hp meet Premium (PE) Level efficiency and 100-250 hp meet Super Premium (SP) level efficiency.

The table below compares the efficiency designations between NEMA and IEC motor types.

Motor Type	Efficiency Designation	
	NEMA*	IEC
Shaded Pole	SE	IE1
PSC	SE	IE1
Split Phase	SE	IE1
Capacitor Start	SE	IE1
Three Phase Induction	PE	IE3
SynRM - Synchronous Reluctance	SP	IE4
EC - Electronically Commutated	SP	IE4 - IE5
FASR - Ferrite-Assisted Sync Reluctance	SP**	IE5+

*SE = Standard Efficiency *PE = Premium Efficiency
*SP = Super Premium **with Variable Frequency Drive

Insulation

Winding insulation temperature rating and motor operating temperature should be considered together when specifying motors. Ideally, a motor should have a relatively high insulation temperature rating and a relatively low operating temperature. This provides a thermal margin in the event of motor overload, severe starting duty, or severe running conditions. (A well-accepted rule of thumb is for every 10°C that the motor temperature exceeds its rated insulation temperature, the insulation life is reduced by half.)

Insulating materials or combinations of such materials are grouped into "temperature tolerance classes", and these materials have been found to give satisfactory service and long life when operated within these temperature limits.

NEMA specifies letter designations for motor insulation temperature ratings. These insulation temperature ratings are noted as Classes A, B, F, and H, and are rated at 105, 130, 155, and 180º Celsius, respectively.

NEMA also specifies allowable temperature rises for motors at full load (and at service factor if applicable). These allowable temperature rises are based upon a reference ambient temperature of 40°C and are determined by the "resistance method", in which the resistance of the windings is measured. The temperature of the winding is a function of the resistance of the winding.

NEMA allowable temperature rises (at full load) for a 1.0 service factor motor are 60, 80, 105, and 125º Celsius for classes A, B, F, and H insulation, respectively. NEMA allowable temperature rises (at service factor) for a 1.15 service factor motor are 70, 90, and 115°C for classes A, B, and F insulation, respectively.

Adding the NEMA allowable temperature rise of 105°C (for a Class F insulated, 1.0 service factor motor), to the reference ambient temperature of 40°C, results in a total operating temperature for the motor of (105 + 40) = 145°C. The 10°C temperature differential between the Class F insulation maximum temperature rating (155°C) and the allowable maximum temperature (145°C) provides an allowance for the "hot spot" temperature of the interior of the winding, which cannot be measured directly.

Classes	Motor Insulation Temperature Ratings	Allowable Temperature Rises (at full load) 1.0 service factor motor	Allowable Temperature Rises (at service) 1.15 service factor motor
A	105º C	60º C	70º C
B	130º C	80º C	90º C
F	155º C	105º C	115º C
H	180º C	125º C	not defined

The overall winding resistance is the sum of the resistance of the cooler end turns, and the warmer (hot spot) windings embedded in the stator slots.

Class B is the most common insulation class used on most 60-cycle US motors. Class F is the most common for international and 50-cycle motors.

In conclusion, in standard fan applications, insulation class is not very important. But with any unusual or high-temperature applications, insulation class is an important factor.

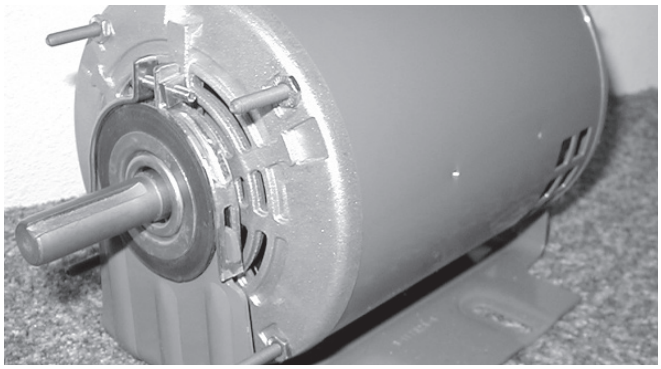
Mounting (Basic Types)

A motor can be mounted to the device its driving (fan) in several different ways. The fan manufacturer normally has the mounting type built into the construction of the fan.



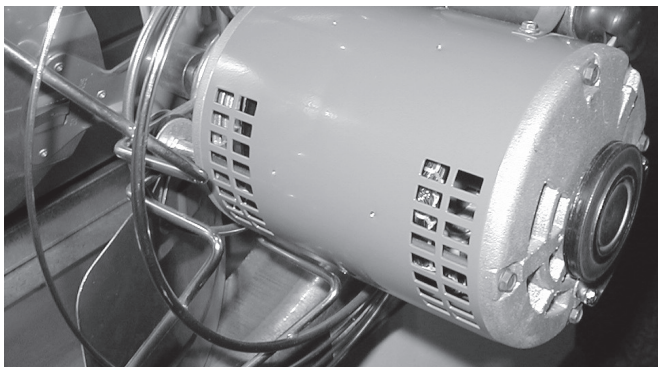
Rigid mount motor

Solid, rigid, or footed: Is solidly fastened to equipment through a metal base which is bolted, cast, or welded to the motor shell or frame.



Resilient mount motor

Resilient, cushion or rubber mount: Motor shell is isolated from the base by vibration absorbing rubber rings.



Thru bolt mounted motor

Extended thru bolts: Bolts extending from the front or rear. Used on small, direct drive fans and blowers.

Motor Protection (Thermal Overload)

A thermal protector, automatic or manual is mounted in the end frame or on a winding and is designed to prevent a motor from getting too hot, causing possible fire or damage to the motor. Protectors are generally current and temperature-sensitive. Some motors have no inherent protector, but they should have protection provided in the overall system's design for safety.

Basic types of overload protectors include:

- Automatic reset: After the motor cools, this line-interrupting protector automatically restores power. It should not be used where unexpected restarting would be hazardous.
- Manual reset: This line-interrupting protector has an external button that must be pushed to restore power to the motor. Use where unexpected restarting would be hazardous, as on saws, conveyors, compressors, and other machinery.
- Resistance temperature detectors: Precision-calibrated resistors are mounted in the motor and are used in conjunction with an instrument supplied by the customer to detect high temperatures.
- External to motor: Thermal overloads in starters or fuses in disconnects.

Underwriters Laboratory (UL) Listing

Motors are designed to meet safety specifications as set by an organization called Underwriters Laboratories, Inc. UL is an independent testing organization specializing in testing products, systems and materials with reference to life, fire and casualty hazards. Standards have been developed for motors and controls in cooperation with the manufacturers.

For fans to qualify for UL Listings, the manufacturer must furnish to UL a complete outline of all the motors to be used with that product. This outline of motors is specific to each fan model and fan manufacturer.

Motors must be UL-listed by the motor manufacturer, by manufacturer's model number, speed, horsepower, and enclosure type. UL Marks can only be applied to a specific fan model using a motor approved by UL.

What does this mean? It means that customers must accept specific motors when UL Listings are required. It may also limit a customer specifying motors of a given brand with special features.

Most motors and electrical components are UL-recognized. The fan manufacturer works with UL to get the UL-recognized motor tested with the fan to get the fan and motor combination UL Listed.

A reputable fan manufacturer requires a motor lab to test its suppliers' motors through extensive testing, which exceeds the requirements of UL standards. Tests must include starting current, input current, over/under voltage, high temp (overheating), speed control (when used), start/stop (cycle), motor noise, and reliability (shafts and bearings). Greenheck attempts to duplicate the field's worst-case scenario in its testing, which assures a safe, long-lasting product. These tests ensure that the motor's temperature is well below the manufacturer's recommended operating temperature of the insulation.

Additionally, final product testing prior to shipment assures a dependable product at start-up.

In today's environment, customers are demanding more from the products they place in their buildings. Testing is an important part of delivering a quality product. Stringent testing procedures during the product development cycle allow us to meet changing market needs while making products even more reliable. To certify and rate fan performance requires the most comprehensive testing facilities including AMCA-registered air testing chambers.

Summary

The information in this article is a guideline to help communicate a better overall understanding of motors and assorted motor specifications. Don't let your job get delayed by unnecessary special design requests caused by incorrect job specifications. The specifier should avoid writing one general motor specification to cover the range from general purpose to heavy-duty industrial purpose motors. This could force a general clean air motor application, where a commonly used motor is required, to a specification where a special motor is required. The end result is a general clean air application costing more time and money. The bottom line is to make sure the motor specification is correct for the application.

Fan manufacturer software programs can assist you with motor applications for fans and guide you in the selection of the suggested motor for an application with options. In the case of questions or unique applications, qualified experienced product application engineers work closely with motor vendors to ensure customers receive the highest quality products that meet the application requirements.

GLOSSARY

Ambient temperature - Temperature of the motor's surroundings. Usually 40°C (104°F).

AMCA Standard (99) on spark-resistant construction:

- Type A: All parts of the fan in contact with the air or gas being handled shall be made of nonferrous material (material less than 5% iron or any other material with demonstrated ability to be spark resistant). Steps must be taken to ensure that the impeller, bearings, and shaft are adequately attached and/or restrained to prevent a lateral or axial shift in these components.
- Type B: The fan shall have a nonferrous impeller and nonferrous ring around the opening through which the shaft passes. Ferrous hubs, shafts, and hardware are allowed provided construction is such that a shift of impeller or shaft will not permit two ferrous parts of the fan to rub or strike.
- Type C: The fan shall be so constructed that a shift of the impeller or shaft will not permit two ferrous parts of the fan to rub or strike.

Bearing life - Rating life, L10 (B10), is the life in hours or revolutions in which 90% of the bearings selected will obtain or exceed. Median life (average life), L50 (B50), is the life in hours or revolutions in which 50% of the bearings selected will obtain or exceed. Many of Greenheck's spun aluminum products have an L10 rating of 100,000 hours.

Breakdown torque - The maximum torque a motor will develop at rated voltage without a relatively abrupt drop or loss in speed.

Capacitor -A device that, when connected to an alternating current circuit, causes the current to lead the voltage in the time phase. The peak of the current wave is reached ahead of the peak of the voltage wave. This is the result of the successive storage and discharge of electric energy used in single-phase motors to start or in three-phase motors for power factor correction.

Capacitor start - The capacitor start single-phase motor is basically the same as the split phase start, except that it has a capacitor in series with the starting winding. The addition of the capacitor results in greater starting torque with much less power input. As in the case of the split-phase motor, this type can be reversed at rest, but not while running unless special starting and reversing switches are used. When properly equipped for reversing while running, the motor is much more suitable for this service than the split-phase start since it provides greater reversing ability at fewer watts of input.

Conduit box - Metal container usually on the side of the motor where the stator (winding) leads are attached to the power supply leads.

Constant hp (horsepower) - A designation for variable speed motors used for loads requiring the same amount of horsepower regardless of their motor speed during normal operation.

Constant torque - Refers to loads with horsepower requirements that change linearly at different speeds. Horsepower varies with the speed, i.e., 2/1 hp at 1800/900 rpm (seen on some two-speed motors). Applications include conveyors, some crushers, and constant-displacement pumps.

CSA - Canadian Standards Association like UL, sets specific standards for products used in Canada.

Current -The flow of an electrical charge through a conductor with the ability to overcome resistance and perform work. This time rate of flow of electrical charge is measured in amps (ampere).

Cycles per second (hertz) - One complete reverse of flow of alternating current per rate of time. (A measure of frequency.) 60 Hz (cycles per second) AC power is common throughout the US and 50 Hz is common in many foreign countries.

Dual torque - A dual-speed motor with torque values that vary with speed (as the speed changes the horsepower remains constant).

Dual voltage - Some motors can operate on two different voltages, depending on how the motor is built and connected.

Duty - Duty rating is determined by the enclosure, amount of cooling, and type of insulation used in the motor. This rating is the length of time that the motor may be operated without overheating or decreasing the normal life span of the motor. (Greenheck's motors are continuous duty).

Efficiency - The ratio or comparison of useful power output to the power input, expressed in the same units. Motors are converters of energy. Their job is to convert electrical energy into mechanical energy. Efficiency ratings indicate how well they do that job. By definition, efficiency is the ratio of output power (mechanical) to input power (electrical). Several terms are used to describe motor efficiency. These include "nominal", "minimum guaranteed", and "quoted" efficiencies. "Nominal" efficiency is the average efficiency of a large number of motors of a given rating, within the limits of the NEMA allowable 20% tolerance. "Minimum guaranteed" efficiency is, as the description implies, the minimum efficiency value that any motor of a given rating would ever produce under test. "Quoted" efficiency is the average efficiency value of a large number of motors of a given rating when tested to the tolerances of the CSA-C390 efficiency test method.

Electric motor - A device that transforms electrical energy into rotational mechanical energy.

Electrical unbalance - In a three-phase supply, where the voltages of the three different phases are not exactly the same; measured as a percent of unbalance.

Energy - The ability to do work. Energy cannot be created or destroyed, but it may be transferred among various bodies or changed from one form to another.

Explosion-resistant motors - Motors designed to safely operate in hazardous locations. There are various degrees of hazardous locations and the appropriate motor must be picked for each classification.

Frame - The supporting structure for the stator parts. In a direct-current motor, the frame usually forms a part of the magnetic circuit. It includes the poles only when they form an integral part of it. Motor frames may be of cast iron, rolled steel, or rolled aluminum. Cast iron is generally considered to be the most suitable frame material for industrial use, due to its high resistance to corrosion, extreme rigidity, etc.

Frame size - Refers to a set of physical dimensions of motors as established by NEMA. These dimensions include critical mounting dimensions. NEMA 48 and 56 frame motors are considered fractional horsepower sizes even though they can exceed one horsepower. NEMA 143T to 449T is considered integral horsepower AC motors and 5000 series and above are called large motors.

Frequency/Hertz (Hz) - Rated input frequency in cycles per second of the motor's power supply.

Full-load current - The current flowing through the line when the motor is operating at full-load torque and full-load speed with rated frequency and voltage applied to the motor terminals.

Full-load torque - The torque of a motor necessary to produce its rated horsepower at full-load speed, sometimes referred to as running torque.

Horsepower - As applied to an electric motor, the horsepower is an index of the amount of work the motor can produce in a period of time. For example, one horsepower equals 33,000 foot-pounds of work per minute. A one-horsepower motor, with suitable gearing and neglecting all losses, can lift 33,000 pounds one foot in a minute, or one pound 33,000 feet in a minute. Assuming 100% efficiency, 746 watts of electrical power will produce one horsepower.

IEC - The IEC (International Electrotechnical Commission) is a global, not-for-profit organization that develops and publishes international standards for all electrical, electronic, and related technologies.

Insulation class - Insulation class defines the maximum safe operating temperature of a motor; such ratings are A, B, F, and H. This maximum temperature is the sum of the maximum ambient and maximum rise temperatures.

Insulation life - Insulation life is defined as the time it takes for a material's tensile strength to be cut in half when operated at its full rated temperature. This is typically 20,000 hours.

Insulator - A material or combination of materials that effectively resists the passage of an electric current.

Inverter - An electronic device that converts fixed frequency and fixed voltages to variable frequency and voltage. Enables the user to electrically adjust the speed of an AC motor.

Inverter duty - Heavy duty motor with better thermal overload and insulation to protect against high voltage spikes. Designed to be used with a variable frequency drive (VFD) or inverter.

Locked rotor torque - The minimum torque that a motor will develop at rest for all angular positions of the rotor (with rated voltage applied at the rated frequency).

Laminations - Metal sheets (usually of a silicon alloy steel) stacked together and riveted or otherwise fastened to form the core of an electromagnet. The windings are placed in or around this core.

Motor protection - Devices that protect a motor from overloads, overheating, or short circuits.

Motor types -

- Shaded Pole - Lowest starting torque, low cost, low efficiency, no capacitors. No start switch, used on small direct drive fans and small gear motors.
- PSC (Permanent Split Capacitor) - Similar to shaded pole applications except for much higher efficiency, lower current, and higher horsepower capacity. Has run capacitor in the circuit at all times.
- Split Phase - Moderate to low starting torque, no capacitor, and has a starting switch. Used on easy start, belt drive fans and blowers, light start pump applications, and gear motors.
- Capacitor Start - Designed in both moderate and high starting torque types with both having moderate starting current and high breakdown torque. Uses include large fans, conveyors, and air compressors.
- Three-Phase - Generally, three-phase induction motors have a high starting torque, high power factor, high efficiency, and low current, and do not use a switch, capacitor, or relay. Suitable for use on larger commercial and industrial applications.

NEMA - National Electrical Manufacturers Association (NEMA) is a nonprofit U.S. organization consisting of members from the manufacturing sector. One of the stated purposes of NEMA is "to promote the standardization of electrical apparatus and supplies."

Overload protection - Relays that protect motors against overheating due to loads above their rated capacity.

Rating - The designated limit of operating characteristics of a motor, apparatus, or device based on definite conditions. Load, voltage, frequency, and other operating characteristics may be given in the rating.

Resilient mounting - A suspension system or cushioned mounting designed to reduce the transmission of normal motor noise and vibration to the mounting surface. This type of mounting is typically used in fractional horsepower motors for fans and blowers.

Rotor -The rotating part of most alternating current motors.

Service factor -The service factor is a measure of the overload capability of a motor. Essentially, it is a factor by which the motor horsepower may be multiplied to obtain the rating at which the motor can be operated continuously when supplied by rated voltage and frequency. A service factor of 1.15 is common for most NEMA frame ratings. A 1.15 service factor, 100 hp motor could deliver 115 hp continuously, without exceeding its design temperature rise, with rated voltage and frequency applied.

Slip - The difference between the speed of the rotating magnetic field (which is always synchronous) and the rotor in a non-synchronous induction motor is known as slip. It is expressed as a percentage of synchronous speed. Slip generally increases with an increase in torque.

Stator - That portion of an electrical motor that contains the stationary parts of the magnetic circuit with their associated windings.

Synchronous speed - The average speed of normal operation is exactly proportional to the frequency of the system to which it is connected.

Temperature Rise - The amount that a motor increases in temperature above ambient.

Thermal Overload - Consists of a heater element where motor current flows directly through. The heater element is in close proximity to a bi-metallic strip that bends and causes a contact to open when the current limit of the element is exceeded.

Torque - A force that produces or tends to produce rotation. Common units of measurement of torque are pound-feet, pound-inches, ounce-feet, and ounce-inches.

UL - Underwriter's Laboratories, an independent organization that sets safety standards for motors and other electrical equipment.

Volt - A unit of electrical potential or pressure.

Watt - A unit of electrical power, directly converted to work, the product of voltage and amperage. 746 watts are equal to one horsepower.

Winding insulation rating - Temperature rating of motor insulation.

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