# ENGINEERING LETTER | 22

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## INTEGRAL MOTORS FOR CENTRIFUGAL FANS

### INTRODUCTION

The most common power source for fans is the electric motor. A motor's service life is largely dependent upon proper selection and installation. Since the motor and its control circuitry represent a substantial portion of the cost of many fan systems, they deserve careful consideration. This Letter introduces some of the more important matters for consideration.

### SELECTION CRITERIA

The selection of the proper motor is based on numerous criteria. Included are horsepower, service factor, enclosure, ambient temperature, phase and voltage, speed, and efficiency.

**Horsepower.** If all air-handling systems had exactly the same volume/pressure relationship the designer anticipated, all motors could be selected merely to cover the fan brake horse-power (BHP) calculated. However, system design usually involves some estimating, and systems are not always installed exactly as intended by their designers.

With all centrifugal fans, the fan speed must be increased to handle the desired volume when the system resistance is higher than anticipated, creating a substantially higher fan BHP requirement. For radial and forward-curved wheels, if the system resistance is lower than anticipated, fan BHP will increase with the greater volume of air being handled. Refer to Figure 1.

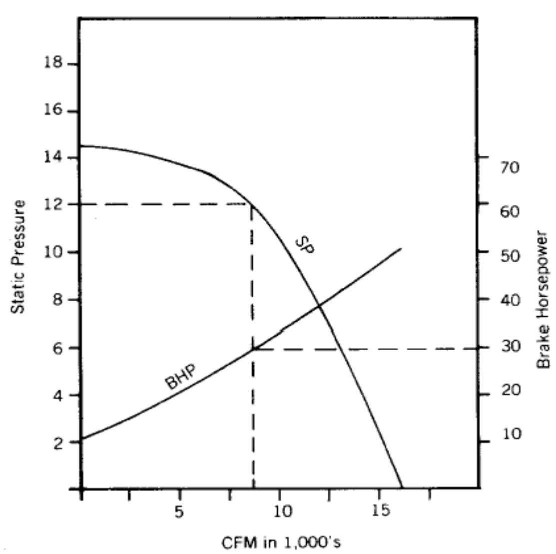


**Figure 1 - At 12" WG, the fan delivers 8750 CFM with 30 BHP. At 6" WG, the fan handles 13,000 CFM at approximately 44 BHP.**

The major difference in the BHP curve for backwardly-inclined fans is its "non-overloading" characteristic. Figure 2 illustrates a BHP curve that reaches a peak and then drops off as the volume continues to increase. This makes it possible to select a motor for the maximum BHP at a given speed without fear of overload despite any variance in the volume/pressure relationship of the installed system. Since BHP varies with changes in fan speed, the non-overloading characteristic only applies to a given fixed speed.

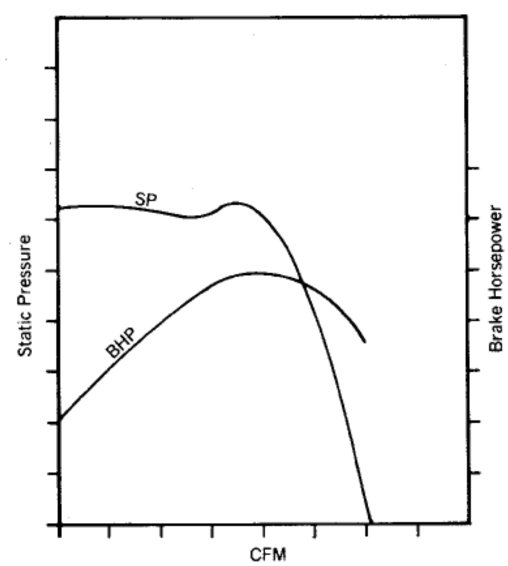


**Figure 2 - "Non-overloading" BHP characteristic inherent in backwardly-inclined wheel designs.**

The fan capacity table (Figure 3) shows the fan BHP for a given volume/pressure relationship. However, it is not uncommon to size the motor for a static pressure 5% to 10% higher than design to allow for variances in the installed system. The system designer should also be prepared to reduce fan speed if resistance is lower than anticipated.

Motors should be selected so that the fan BHP rating for the required volume and pressure is less than the rated motor horsepower. The rated motor horsepower is the mechanical power available at the motor shaft at full-load speed without exceeding the motor's maximum temperature rise.

| CFM | OV | 4" SP | | 4 1/2" SP | | 5" SP | | 5 1/2" SP | |
|---|---|---|---|---|---|---|---|---|---|
| | | RPM | BHP | RPM | BHP | RPM | BHP | RPM | BHP |
| 10856 | 2100 | 1140 | 9.29 | 1194 | 10.4 | 1248 | 11.6 | 1300 | 12.8 |
| 11373 | 2200 | 1154 | 9.79 | 1205 | 10.9 | 1257 | 12.1 | 1308 | 13.3 |
| 11890 | 2300 | 1167 | 10.2 | 1218 | 11.4 | 1269 | 12.7 | 1318 | 13.9 |
| 12607 | 2400 | 1183 | 10.8 | 1232 | 12.0 | 1282 | 13.3 | 1330 | 14.6 |
| 12924 | 2500 | 1200 | 11.4 | 1248 | 12.6 | 1296 | **13.9** | 1342 | **15.2** |
| 13441 | 2600 | 1217 | 12.0 | 1263 | 13.3 | 1310 | 14.5 | 1355 | 15.9 |

**Figure 3 - At 12,924 CFM and 5" SP, the BHP required is 13.9. With an additional 10% system resistance margin (5 1/2" SP), the BHP required is 15.2.**

**Service Factor.** Integral open-dripproof and totally enclosed motors usually have a service factor of 1.15, while explosion-proof motors usually have a 1.0 service factor. When the motor nameplate voltage and frequency are maintained, the motor can be run up to the capacity obtained by multiplying the rated horsepower by the safety factor shown on the motor nameplate.

For example, a fan in a given system might require 5.0 BHP according to original estimates, but minor system changes could increase the demand to 5.25 BHP. In this case, a 5 HP open motor rated with a 1.15 service factor could still be used (5 HP x 1.15 = 5.75 HP) without detrimental overheating.

**Enclosure.** The selection of a motor enclosure depends upon ambient conditions. Electric motors are air-cooled machines and their service life depends greatly upon protecting the motor from contaminated surroundings. Basically, all motor enclosures can be divided into two categories: open and totally enclosed.

OPEN MOTORS - This type is recommended for relatively clean environments since the ventilating openings permit passage of external cooling air over and around the motor windings. Open motors are usually less expensive than other enclosures.

DRIPPROOF MOTORS - These are open motors with ventilating openings so constructed and positioned that operation is not hampered when drops of liquid or solid particles strike the enclosure at any angle from 0° to 15° downward from the vertical axis. The standard insulation is Class B with a 1.15 service factor rating.

WPI AND WPII MOTORS - These are essentially open motors with vacuum-pressure impregnation (VPI) winding treatment for moisture resistance and weather protection. WPI motors are equipped with space heaters. WPII motors have ventilating openings arranged so that high-velocity air and/or airborne contaminants blown into the motor during storms or high winds can be discharged without entering the internal electrical parts of the motor. Generally, the weather protected motors are only available in frame sizes larger than NEMA standard and they are less expensive than totally enclosed motors in those cases.

TOTALLY ENCLOSED - This type is recommended for any installation where dirt or contaminants can collect in or around the motor. They are constructed in a manner that prevents the free exchange of air between the inside and outside of the motor case, but they are not airtight.

TOTALLY ENCLOSED FAN-COOLED MOTORS - These are totally enclosed motors equipped with a cooling fan, or fans, integral with the motor assembly but external to the enclosed parts. These motors should be installed so that the intake of the cooling fan is not blocked or impeded. The standard insulation is Class F with a 1.15 service factor rating.

TOTALLY ENCLOSED AIR-OVER MOTORS - These special-purpose totally enclosed motors are intended for use in fan applications where the fan provides sufficient cooling airflow over the surface of the motor. However, they are not self-cooling, so they should only be used when airflow is present at or above the velocities necessary for continuous operation within the rated motor temperature rise.

TEFC SEVERE DUTY MOTORS - These special purpose TEFC motors are intended for use in contaminated environments such as in the paper, metal, or chemical industries. Special features include cast-iron frame, end brackets, conduit box and fan cover, plated hardware, and stainless steel nameplates. They are also rated with 1.15 service factors and Class F insulation. Some trade names include "Mill and Chemical," "Dirty Duty," "Extra Tough," and "Chemical Duty."

TOTALLY ENCLOSED NON-VENTILATED MOTORS - These are basically totally enclosed motors with larger frames to dissipate heat, but no cooling fan. Typically offered in the smaller fractional horsepowers, these motors should only be used in open, well-ventilated areas.

EXPLOSION-PROOF MOTORS - These special-purpose totally enclosed motors are designed to withstand internal explosions of gases or vapors, and to prevent the ignition of gases or vapors surrounding the motor. Refer to Engineering Letter 23, Electric Motor Codes and Standards, for details.

**Insulation.** Various motor insulation systems are available. The rated temperature for a given insulation classification is the maximum temperature for sustained operation. Three common insulation classes are shown in Figure 4.

**INSULATION**

| NEMA Class | Ambient Temperature* | Hot-Spot Temperature |
|---|---|---|
| B | 40°C. | 130°C (266°F.) |
| F | 41° - 65°C. | 155°C. (311°F.) |
| H | 66° - 90°C. | 180°C. (356°F.) |

*Note that these ratings apply to 1.0 service factor only.

**Figure 4**

Not all parts of the motor windings operate at the same temperature. The temperature at the center of the coil is the hottest, and is commonly referred to as "hot-spot temperature." This hot-spot temperature is used to establish the rating of an insulation class. The actual temperature is the sum of all the heat-producing factors including the ambient temperature, motor induced temperature rise, and the hot-spot allowance.

**Ambient temperatures.** Whenever possible it is best to select a motor with the appropriate insulation for the specific ambient conditions. For example, a TEFC motor with Class F insulation is suitable for ambient temperatures of 40°C. (104°F.) with 1.15 service factor or 65°C. (149°F.) with 1.0 service factor. If this same motor is used in an ambient of 75°C. (167°F.)

continuously, the life of the motor will be greatly reduced.

**Phase and voltage.** Although these 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 in order to achieve the most economical equipment and installation costs. Single phase motors typically cost more than polyphase because of the need for capacitors, centrifugal switches, etc. Higher voltage ratings can reduce installation costs by reducing the required electrical line size.

In most U.S. and Canadian industrial sites, the power supply typically found for the average polyphase motor is 230 or 460 volts (U.S.) and 575 volts (Canada) at 60 Hertz (cycles per second) generation. In many large cities where 120/208 volt networks are employed, commercial and small industrial loads require motors rated for 200 volts.

Motors for 2300 volts can be furnished in motor frames 445T and larger. Because of the cost of starting equipment for this higher voltage, 2300 volt motors are not generally available below 200 HP.

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.

The standard motor frequencies are 60 and 50 cycles per second, or “Hertz.” The prevailing frequency in the United States and Canada is 60 Hertz. Most of Europe, the Middle East, and the Pacific Rim have 50 Hertz service. Many motors specified for 50 Hertz will require 380 volts, 440 volts, or 220/380 volts . . . all of which are considered standard by motor manufacturers.

Although motors built for 50 Hertz are becoming more readily available in this country, consideration should be given to the accepted practice of derating 60 Hertz motor speed and horsepower. Ratings can be derated by a factor of .833 (50/60) to determine the operating characteristics in 50 Hertz service.

For example:

60 Hertz - 10 HP, 1800 RPM, 3/60/230/460

50 Hertz* - 8.3 HP, 1500 RPM, 3/50/190-380

* Note: This does not apply to single phase or explosion-proof motors. RPM and Voltage rounded to standard nomenclature.

NEMA standards state that motors must be capable of delivering their rated horsepower at a variance of nameplate voltage of ± 10% voltage, although not necessarily at the standard rated temperature rise. One exception is a motor nameplated as 208-230/460 volts. The ± 10% voltage only applies to 230 or 460, and thus requires very good voltage regulation for operation in a 208 volt network. Another exception is 60 Hertz motors derated for 50 Hertz operation.

A 208 volt network requires a 200 or 200/208 volt motor. Note that the 200/208 does not mean dual voltage, (as with a standard 23 0/460 rating), but is simply a 200 volt motor rated and recommended for 208 volt service.

The NEMA standard 230/460 volt rating is not generally recommended for 208 volt service unless authorized by the motor manufacturer. Motors for use in a 208 volt network should be ordered with a 200 volt rating, with windings and nameplate so designed and stamped.

**Speed.** The general rule of thumb is to select the highest practical motor speed to reduce the size, weight, and cost of the motor. However, belt-drive fan applications are usually limited to 1800 RPM motors when the horsepower requirements are 25 and up. Generally, TS (short shaft) frames are used on larger 3600 RPM motors, and these are not well-suited to belt-drive arrangements. Although T frame motors are available for larger horsepower 3600 RPM motors, they are not standard, so long procurement lead times and cost can be prohibitive.

The majority of electric motors used in fan applications are single speed. However, multispeed motors are available in either single phase or three phase.

The motor synchronous speed is expressed as:

$$\text{Synchronous RPM} = \frac{120 \times F}{P}$$

where: F = supply frequency in Hertz
P = number of poles in motor winding

The actual full load RPM (nominal speed) will be somewhat below the synchronous speed. The percentage in speed is known as the *percent slip*. Thus, an 1800 RPM (4 pole) motor with a 2.8% slip will have a full load nominal speed of 1750 RPM (1800 - 50 = 1750).

The exact slip percentage will vary from one motor size and type to another. Slip is also somewhat dependent upon load. A partially loaded motor will run slightly faster than a fully loaded motor. Since calculating the precise nominal speed for each application would be impractical, the Air Movement and Control Association (AMCA) has established nominal speeds to be used uniformly to determine fan performance. See Figure 5.

**NOMINAL SPEEDS FOR 60 HERTZ MOTORS**

| Number of Poles | Synchronous Speed (RPM) | Nominal Speed (RPM) |
|---|---|---|
| 2-pole: | 3600 | |
| thru 1 HP | | 3450 |
| 1 1/2 thru 25 HP | | 3500 |
| 30 HP and up | | 3550 |
| 4-pole: | 1800 | |
| thru 3/4 HP | | 1725 |
| 1 thru 20 HP | | 1750 |
| 25 HP and up | | 1770 |
| 6-pole: | 1200 | |
| thru 3 HP | | 1150 |
| 5 HPand up | | 1175 |
| 8-pole: | 900 | |
| thru 1/8 HP | | 850 |
| 1/2 HP and up | | 875 |

Note: 50 Hz motor speeds can be determined by multiplying the above ratings by .833 (50/60).

**Figure 5**

**Motor Efficiency.** The continued increase in energy costs and emergence of energy savings programs have heightened concern for electrical usage and motor efficiency. Good system design necessitates the selection of the most efficient motor for a given application.

Motor manufacturers are able to improve motor efficiency by altering any number of design factors. The use of thinner steel laminations in the stator and rotor core, using better grades of steel, more copper in the stator, and more efficient, smaller cooling fans are just a few examples.

In an effort to distinguish one manufacturer's motor from another, motor manufacturers use a number of names, such as standard, high, premium, etc., to qualify published efficiency values. The generally accepted basis for comparison of efficiency values is the "guaranteed minimum efficiency" based on NEMA recommendations. Motor efficiency can be calculated by the following formula:

$$\text{Motor Efficiency} = \frac{746 \text{ x HP output}}{\text{Watts Input}}$$

When comparing motor efficiencies, the power factor must also be considered. At a given efficiency, a higher power factor results in a lower current demand. The power factor is the ratio of real current (current required to run the motor) to the total current (real current plus the reactive current that creates the magnetic field). The power factor for a given motor should be obtained from the specific motor manufacturer, but it can be calculated by the following formula:

$$\text{Power Factor} = \frac{\text{Watts Input}}{\text{Volts x Amps x 1.73*}}$$

* For 3-phase motors only.

## SPECIAL CONSIDERATIONS

In addition to the previous selection criteria, there are several other special considerations that affect proper motor selection. These include high or low voltage, starting times, minimum sheave diameters, heavy cycling, and excessive loading.

**High or low voltage.** Motor service life can be shortened considerably if the motor is operated outside the ± 10% voltage variance range.

With low voltage, motor torque decreases. The motor is therefore forced to slow down to develop the required torque. This causes increased current draw which creates additional heat in the motor winding. In addition, at the slower speed ventilation is reduced and heat will not be dissipated as rapidly.

High voltage will cause an increase in magnetizing current in the motor. This causes additional heating in the motor windings. Particularly with older motors, increased voltage can break down the motor insulation by breaching its insulating capability.

**Starting times.** Whenever an electric motor is used to drive a centrifugal fan, both the fan's maximum power demand and the motor starting torque characteristics must be considered. Where larger centrifugal fans are to be driven by relatively small motors, it is possible that the motor will not be capable of overcoming the fan's inertia to bring it up to the required speed in a reasonable time. Excessive starting time, generally greater than 10 to 15 seconds, will raise the temperature of the motor windings to a point where circuit breakers can trip out, or the motor itself can be damaged. The user must be aware of this problem when selecting the fan and motor combination.

The two main factors to be considered are the fan wheel inertia ($WR^2$ or $WK^2$) and the starting torque characteristics of the motor. Exact curves of the motor starting torque, as a percentage of full load torque at a given speed, are available from the motor manufacturer.

Many fan applications require a fan speed other than a nominal motor speed, so a belt-drive configuration is used. In these cases, the $WR^2$ must be corrected to include the effects of the fan shaft and fan sheave.

It is best to consult the fan manufacturer for confirmation of questionable fan/motor combinations, i.e. large fans with small motors. If the combination has an unacceptable starting time, the solution could be to use a larger motor, damper the fan for reduced load starting, or in some cases consider clutching systems so the fan can be brought up to speed without tripping electrical breakers or damaging the motor.

**Minimum Sheave Diameters.** Special consideration should be given to the diameter of drive sheaves used on motors. As belt tension must increase to avoid slippage with small diameter sheaves, the radial load imposed on the motor bearing becomes significant. The motor manufacturer can provide specific recommendations for minimum sheave diameters. Some general recommendations are shown in Engineering Letter 23 - Electric Motor Codes and Standards.

**Heavy Cycling.** When a motor is started and stopped frequently, heat build-up from the heavy starting current cannot be adequately dissipated. Heat will build up on successive starts and the temperature will rise even after the motor is stopped because air movement is not present for heat dissipation. This type of operation poses unusual problems in the selection of proper protective devices. Thermal protectors located in the motor starter will cool more rapidly than the motor windings, so protection is compromised. Internal temperature sensors, known as thermal overload detectors, can be embedded in the motor windings to provide the best form of protection for motors subjected to heavy cycling.

Generally, standard integral motors are designed for continuous operation. Cyclic service of any fan/motor combination demands special consideration. Such situations should be explained and carefully reviewed with the fan and motor manufacturers.

**Excessive Loading.** When too much is demanded of a motor, it will attempt to compensate by drawing more current. Heat build-up is proportional to the square of the increase in current. Proper overload protection will guard against excessive heat build-up; however, it is unwise to use overcurrent protectors with automatic resets because the motor can cycle until enough heat builds up to damage the windings.

The potential problems of excessive loading are often dealt with by using backwardly inclined fan designs. As explained previously, it is possible to select a motor for a backwardly inclined fan that will not overload at a fixed speed, regardless of any changes in system resistance.

## CONCLUSION

The New York Blower Company frequently supplies the entire fan, drive, and motor package. However, because motor selection is dependent upon the actual location, environment, and intended service, and since only the system designer or end user can be fully aware of these variables, **nyb** cannot be expected to select or recommend motor specifications.

The information contained in this Letter provides the system designer or user with fundamental information to aid in the selection and application of motors. Further information can be obtained by contacting motor manufacturers directly.