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Engineers Newsletter

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Evaluating Efficiency In Air-Moving Systems

The energy efficiency of air movement in particular is driving a number of changes in the industry. Codes, standards, and equipment specifications have traditionally considered only the power measured at the fan shaft. However, the industry is beginning to realize that there are many opportunities to improve actual energy use by evaluating power at the input to the motor or motor speed controller. The latest advancements in fan and motor technology make this subject especially important.

This Engineers Newsletter will provide system designers with a better understanding of the energy required for air movement. This will help prepare designers for upcoming changes to codes and standards. It will conclude with a discussion on motorized impellers—compact direct-drive plenum fans with integrated speed control.

Why is Fan Efficiency Difficult to Evaluate?

The term "fan efficiency" can refer to efficiency at several different locations in what we'll call the fan system. For this article we'll define a fan system as the fan itself, mechanical drive components, electric motor, and motor controller. There is an efficiency associated with each of these components.

Another way to think about efficiency is that the air power produced by the fan system is less than the electrical power supplied to the fan system. Air power produced by the fan system is measured by the change in state of air entering the fan and leaving the fan. Electrical power supplied to the fan system is measured in kW input from the electrical system. Not all of the electrical input power ends up as air output power. Figure 1 (p.2) shows a typical fan system and the losses between electrical input power and air output power. You can think of each loss as reduction in electrical input power.

Variable-speed drives and motors

Many motors make use of power electronics either as a requirement of their design, or as an enhancement to allow better control. The implementation and methods used by these electronic controllers can vary, but to ease our conversation we will define the abstract term *variable-speed drive* (VSD) to refer to these controllers regardless of the details of their operation. The VSD could represent a variable-frequency drive (VFD) used with induction motors, or the electronically-commutated motor (ECM) controller for brushless DC motors and provides efficient, variable-speed control of the motor as well as over current protection.

Fan losses. Fan efficiency is a complicated topic as was described in an earlier EN (FANtastic!-A Closer Look At Fan Efficiency Metrics, Volume 43-1). For the sake of this discussion fan inefficiency generally includes the aerodynamic loss associated with fan blades moving air and the mechanical losses of the fan shaft bearings.

Mechanical drive losses. The mechanical drive includes the components that connect the motor to the fan. Traditionally this was a belt and sheaves with the associated friction losses although other connection methods are also possible.

Motor losses. Motor losses include both electrical losses, e.g., hysteresis, and mechanical losses, e.g. windage and motor bearing losses.

Control losses. Control in this sense refers to any electric or electronic components used with the motor. For some motor types controls are added to vary the speed, other motor types require controls because of their design.

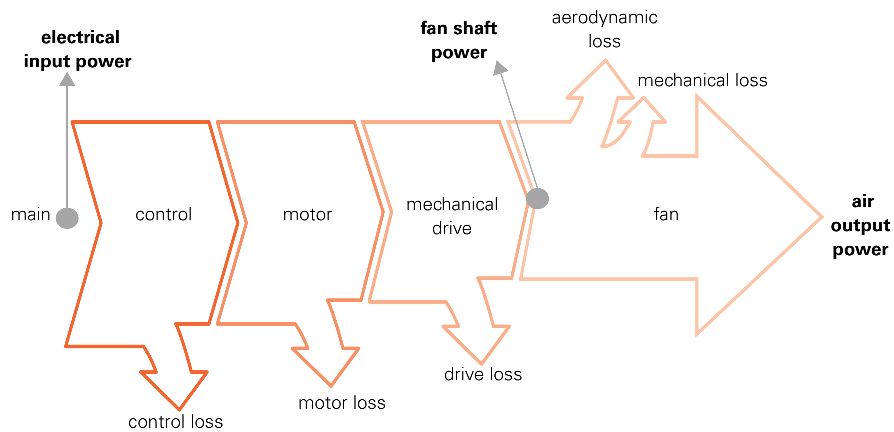
Part of the difficulty of measuring efficiency for this system is that not all fan systems use all of these components and in some cases multiple components are packaged in a way that makes measuring the efficiency of individual components difficult.

Complicating Factors

Load/speed. Motors are typically rated at their full-load/ full-speed condition with motor efficiency determined at this load. This presents two problems. First, most motors spend very little time at full load. Part-load efficiency is lower than full-load efficiency but how much lower depends on the motor loading and the type of motor.

Secondly, general duty motors come in finite sized steps so a motor selected for a given application is typically larger than the load requires. Said another way, the motor is running at a part-load condition even when the application is at full load.

Figure 1. Overall efficiency of a complete fan system



Calculation of component efficiencies. How are the efficiencies of each component of the fan system calculated? Standards exist for some components, notably airflow performance can be tested in accordance with a standard such as ANSI®/AMCA® Standard 210 or rated in accordance with AMCA Publication 211.

Electric motor efficiency standards require motor manufacturers and labellers to certify that their motors meet minimum efficiency values before they are allowed to sell their products. The Energy Independence and Security Act (EISA) of 2007 defines energy efficiency standards for general purpose electric motors and specialty motor designs. The standards require electric motors to have a nominal full load efficiency that is equal to or greater than the energy efficiency defined in National Electrical Manufacturers Association (NEMA®) Standards Publication MG1-2009.

The Energy Policy and Conservation Act (EPCA) standards include all general purpose motors, but exclude "definite purpose motors" and "special purpose motors."

Efficiency ratings for the controls portion of the fan system is evolving. In a typical fan system consisting of an induction motor and VFD, the motor full load efficiency is regulated and cataloged, but the VFD efficiency can be difficult to determine.

First published in 2011 by the Air-Conditioning, Heating & Refrigeration Institute, AHRI 1210 titled "VFD Full Load Efficiency Rating Standard" is a rating standard intended to help make trusted VFD full load efficiency easily available. The standard defines testing and rating requirements for VFD system efficiency, power line harmonics, and motor insulation stress. By providing a uniform method of measuring and reporting efficiency data the standard allows confident comparison of VFDs between different models or manufacturers. As more VFD manufacturers participate in the rating program and publish their data it will become possible to easily validate efficiency claims.

While procedures are provided to record data at several load points, in its present version AHRI 1210 requires reporting of VFD system efficiency only at full load. Knowing the full load efficiency of the motor and VFD provides a starting point for comparing drive systems. However, since most systems spend very little time operating at full load, to fully compare VFD and motor systems more data will be needed across the operating range.

ASHRAE® is also working on a standard that will reveal the efficiency of the control portion of fan systems. ASHRAE Proposed Standard 222P "Standard Method of Test for Electric Power Drive Systems," once published, will extract the method of test from AHRI® 1210 and expand it to include other motor types like brushless DC motors. Once the standard is finalized the method of test details will be removed from AHRI 1210, which will then reference the ASHRAE standard.

Variations in fan system components. Some fan systems don't hinclude all of the components shown in Figure 1. For example constant flow applications may not include a control component; the motor runs at a constant speed and the speed of the fan, also constant, is determined by the sheave selection.

In other fan systems multiple components may be packaged together making it difficult to determine individual component efficiencies. This isn't a problem if you are looking at total fan system efficiency but it can be a problem if efficiency comparisons are made from product to product based on a single component.

Temperature. Motors and control efficiency are negatively affected by temperature. Increasing temperature results in decreasing efficiency. As a result placement of the components matters. Motors and controls integrated with the fan will be exposed to the air-stream. Controls separate from the motor can be placed in a lower temperature area.

Wire-to-Air

Much of the difficulty in determining fan system efficiency can be eliminated by measuring electrical input to the fan system. This includes the total "wire-to-air" conversion efficiency from electrical input energy to the useful work imparted to the air.

This concept is not only important to analyze integrated systems such as motorized impellers, but it is becoming increasingly important as we strive for the most efficient systems possible.

The wire-to-air concept is not fully addressed in today's codes and standards. However, upcoming regulation by the U.S. Department of Energy (DOE) and the California Energy Commission® (CEC) is expected to address the importance of electrical input power, not just shaft power.

AMCA recently released Standard 207, "Fan System Efficiency and Fan System Input Power Calculation." It provides guidance, a method, and tabulated data to calculate fan system input power and overall efficiency of the complete fan system. This will include the fan efficiency, the electric motor efficiency, and the efficiency of the power transmission and/or motor controller, if present.

The scope of the standard includes all electric motor driven fan systems that use a specific combination of components:

- Fan airflow performance tested in accordance with a standard like ANSI/AMCA Standard 210 or rated in accordance with AMCA Publication 211
- Polyphase induction motors within the scope of programs like EPCA
- Pulse-width modulated VFDs with constant V/Hz motor operation
- Mechanical power transmissions like V-belts

While direct measurement of fan system input kW is preferred, the large number of fan system configurations often makes testing impractical. To accommodate, the standard offers a standardized method to estimate fan system performance by modeling commonly used components. Calculations reported in accordance with this standard offer fan users a common basis for calculation and comparison.

The standard includes a series of standardized motor and VFD curves. Because the standardized curves aren't actual, they could show lower (or higher) efficiency than reality. Considering variations in manufacturer designs, installation practices, control settings and design versus actual operation conditions, the user should expect a difference between this calculation and a tested fan system. Therefore, caution is advised when comparing the calculated result to tested configurations with like components.

In-addition to the recently published AMCA Standard 207 AMCA International is presently working on Standard 208 which will define a performance based efficiency requirement called fan efficiency index (FEI). Such a metric will address fan peak efficiency, operating point efficiency, and the extended fan system for a complete wire-to-air approach. See the references for additional information.

Why Does All This Matter?

Knowing how "fan efficiency" is determined is important and **motorized impeller (MI)** fan systems are a good example of why. MI fans are a type of direct-drive plenum (DDP) fan that utilize electronically-commutated (EC) motors in an integrated assembly (see Figure 2). The assembly consists of a direct-driven impeller, an EC motor, and a variable-speed drive—all in one package.

The EC motor is an external rotor motor where a portion of the motor protrudes through the fan inlet. This compact package is tightly integrated making it difficult to separate the components in an effort to evaluate efficiency independently.

Fan Efficiency. Many motorized impellers utilize a high-efficiency, backward-curved impeller. The aerodynamic efficiency of the impeller should thus be similar to a traditional DDP fan—especially when evaluating smaller diameters. As the diameter increases however, many traditional DDP fans use a slightly more efficient impeller with airfoil blades. Consider also the external rotor motor design of the typical MI fan—the protrusion through the fan inlet can reduce the aerodynamic efficiency.

Motor efficiency. EC motors use permanent magnets in the rotor to increase power density and reduce loss compared to AC induction motors. Typically, 20-25 percent of the internal losses of an AC induction motor are attributed to the windings in the rotor. Much of this loss is eliminated by replacing the rotor windings with permanent magnets.

Optimally designed stator windings, along with greatly reduced rotor losses, result in a motor that is more efficient and physically smaller than an AC induction motor of equivalent output power. Although this applies to EC motors in general, the EC motors used in MI fans are often definite purpose and designed to be as compact as possible. Compared to general purpose induction motors, this design practice can offset the efficiency gains of going to an EC motor, all other things being equal.

However, it should be noted that brushless DC motor construction is not dictated by standards like NEMA®-MG-1, and their efficiencies are not regulated by EISA. So while this motor design should be inherently more efficient, there can be significant differences in motor performance, reliability, and energy efficiency across manufacturers and models.

Variable-speed drive efficiency. Like a motor, VSD efficiency is a function of the load: the nearer the VSD is to full load, the more efficient it will be. With an MI fan, the integral VSD is engineered to match the EC motor and ensure that the combination is as efficient as possible during normal operation.

Performance and efficiency of the VSD controller used can also have a significant effect on motor performance since so much of the motor performance depends on the details of commutation.

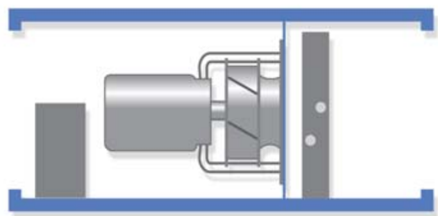
Temperature has an important effect on VSD efficiency as well. Because of its compact design, an integrated VSD may not have the same heat rejection provisions present with a VFD. However, VFDs are designed for a range of environments whereas the integrated VSD on an MI fan will always be in the airstream.

Motorized impellers: Input kW vs. shaft power. Fan schedules and selection programs traditionally reference fan shaft power or motor nameplate power. The fan shaft power, or brake horsepower, is commonly used to compare the energy requirements amongst a number of fan options. It is also used to size the motor. The motor nameplate horsepower, or maximum applied horsepower, is then included in the schedule.

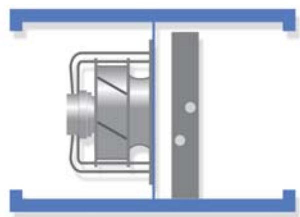
For traditional DDP fans, the motor, VSD and fan assembly are normally sourced separately. As such, the components of a traditional DDP fan are generally compared separately. Being an integrated assembly, motorized impellers are measured and reported in terms of input kW to the entire assembly—all components included.

The only accurate way to compare a motorized impeller with another fan type is to measure the input energy to the other fan type. However, high variation among components, and a lack of a complete test standard, make this a difficult task to accomplish. To enable a comparison, some manufacturers will provide an estimate of fan shaft power for motorized impellers.

Figure 2. Traditional direct-drive plenum fan versus motorized impeller



traditional direct-drive plenum (DDP) fan



motorized impeller (MI)

Impact on ASHRAE 90.1. As mentioned earlier, motorized impellers are rated in terms of input kW which can make determining whether a system complies with the fan power limitation of ASHRAE 90.1 more confusing. How to address this depends on which fan power limitation option is chosen.

Option 1 is based on the motor nameplate horsepower. The UL standard for air-handling units requires that a motor horsepower be reported on the unit nameplate. For motorized impellers, a conversion from input kW to horsepower is typically used for the unit nameplate to satisfy this requirement.

So for a unit with motorized impellers, nameplate horsepower is reported similar to how a traditional direct-drive plenum fan with a factory-installed VFD is reported. Keep in mind that this value includes VSD and motor losses, so you might have a higher nameplate horsepower when using a motorized impeller compared to a traditional direct-drive plenum fan. However, the unit horsepower for a motorized impeller could be lower if the direct-drive plenum fan had to jump up to the next higher NEMA horsepower increment—from 7.5 to 10 horsepower, for example.

If determining compliance using Option 2, use the estimated brake horsepower for the motorized impeller.

Summary

While fan systems are simple in concept, the variety of fan, motor, and control configurations create a complex array of choices. Criteria for choosing a particular system can include cost, reliability, redundancy, ease of maintenance, as well as efficiency.

Comparing fan system efficiencies is complicated by a combination of factors as previously described. Standards, intended to simplify comparisons, are either not complete or, are so new that limited compliant fan data is available.

The expanded scope of Standard 222P will allow reliable comparison of brushless DC motors systems not only with similar systems but with VFD systems as well. There are no current plans to include this expanded scope into the AHRI 1210 rating program, but having a formal method of testing defined can still yield reliable, comparable efficiency data.

And finally, until a reliable wire-to-air test method is widely used it will be necessary to understand the intricacies of fan systems when evaluating efficiency comparisons.

By Bob Coleman and Dustin Meredith, systems engineers and Dave Guckelberger, application engineer, Trane. You can find this and previous issues of the Engineers Newsletter at trane.com/engineersnewsletter. To comment, e-mail us at ENL@trane.com.

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Additional Resources

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Trane, "Motorized Impellers - Advanced DDP Fans" white paper, CLCH-PRB054A-EN. La Crosse, Wisconsin: Trane, 2015.

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