Improving industrial productivity through energy efficient advancements

# energy savers

Progress Energy

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## Variable Speed Drives (VSD)

### CONCEPT

Consider these facts:

- Electric motors consume roughly one-third of the electric power generated in the United States.
- Equipment is oversized for added assurance in meeting the most extreme system requirements.
- Motors are upsized to the nearest integral horsepower above that required for the oversized equipment. In most cases, only rarely is full performance required of the system.
- The motor is usually in continuous, full-speed operation.

The output of the equipment is typically adjusted by various means (clutches, brakes, valves, dampers) to satisfy dynamic system requirements; however, these adjustments waste energy to varying degrees. Variable speed drives save energy by providing the capability to modulate the output of the motor to satisfy changing system requirements. As electricity costs continue to rise, it becomes more and more appropriate to evaluate the costs and benefits of potential variable speed drive applications.

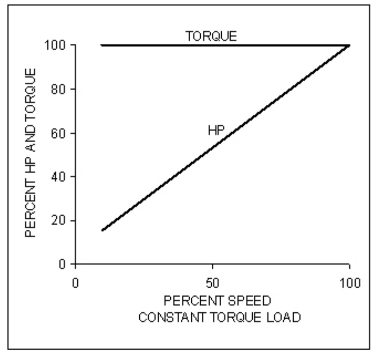
### GUIDELINES

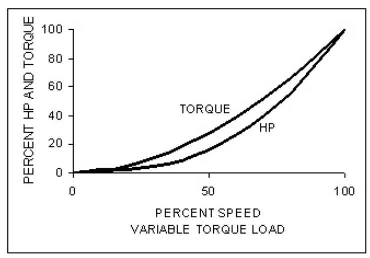
Dynamic loads are typically categorized as constant torque, variable torque or constant horsepower (see Figure 1 and Table 1).

Many systems exhibit constant torque requirements throughout their speed range. An air handling unit may be equipped with controls to maintain a constant discharge static pressure. A centrifugal pump may serve a system which requires a constant pressure. In these cases, the constant pressure necessitates a constant torque input. Conveyors and screw feeders require the same torque at low or high speeds, once put into motion. The horsepower varies linearly with the speed in these applications; when the speed doubles, the power requirements doubles (see Figure 1).

In cases where the centrifugal blower or pump discharge pressure is allowed to vary, the loads will require a varying torque. The relationships between speed, flow, pressure and power are illustrated in Figure 2. Flow varies linearly with speed, pressure and torque vary with the square of the flow (speed), while power varies with the cube of the flow (speed).

Finally, some machines exhibit constant horsepower requirements throughout the speed range. Center-driven winders and drilling/milling machines tend toward constant horsepower. The winder requires a constant tension on the spool; however, it starts with a small diameter spool (low torque) at a high speed and finishes with a large diameter spool (high torque) at a low speed, requiring a constant horsepower drive. (See bottom graph in Figure 1.)



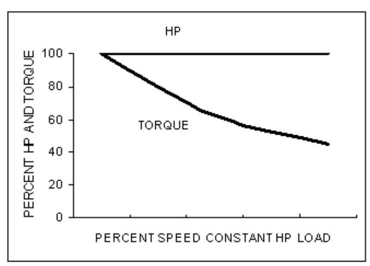




**Figure 1. Types Of Adjustable Speed Loads**

In addition to the running torque power/speed relationships just discussed, consideration must also be given to torque/power requirements for start-up and acceleration of these loads. The **breakaway torque** is required to start a load from rest (to overcome the static friction). For conveyors, the breakaway torque is usually greater than that required at any other time. Drive components must be adequately sized to provide the breakaway torque of the particular machine. The **accelerating torque** is that torque required to increase the speed of the machine. High-inertia machines with flywheels, large blowers or other large rotating masses may require high torque for rapid acceleration. **Running torque** is that required to maintain the machine at the desired output. Centrifugal fans and pumps require maximum torque at full output pressure (assuming a moderate acceleration), while the center winder requires maximum torque at low speed when the spool is full. Operating characteristics of the load throughout the entire speed range must be evaluated to determine how torque and power requirements vary.

**Table 1. Torque/Speed Characteristics Of Typical Loads**

| Variable Torque | Constant Torque | Constant Horsepower |
|---|---|---|
| Centrifugal Blowers with<br>Variable discharge static pressure:<br><br>• VAV<br>• Cooling tower fans | • Packaging machines<br>• Conveyors<br>• Agitators<br>• Compressors<br>• Web processing equipment<br>• Centrifugal blowers with constant discharge S.P. in VAV Systems | • Drilling/milling machines<br>• Center winders |
| Centrifugal pumps with<br>variable discharge pressure:<br>• Condenser water<br>• Circulating chill/heating water systems | Centrifugal pumps with<br>constant discharge pressure:<br>• Domestic water boosters<br>• Constant tank level control | |

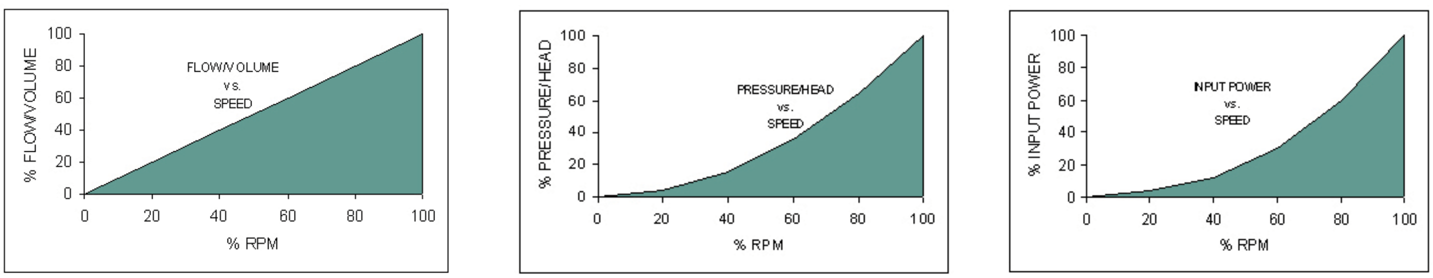



**Figure 2. Ideal Curves Showing Relationship Of Flow, Pressure and Power With Speed Of A Centrifugal Fan Or Pump**

Table 2 highlights basic operational characteristics and outstanding capabilities and limitations of the different variable speed drives. The mechanical drives include traction transmissions and adjustable pitch sheaves. Hydraulic drives include hydrodynamic, hydrostatic and hydroviscous types. The electrical drives include eddy-current clutches, DC motor controls and variable frequency/voltage AC motor controls.

When considering applications for variable speed drives, it is important to consult with the driven equipment manufacturer at an early period in the design. There are characteristics of certain types of variable speed drives which need to be considered in the design of the driven equipment to ensure safe and reliable operation. Of particular importance is ensuring that the expected operating points are not on any resonant frequencies of components of the driven equipment. For a new design, the driven equipment manufacturer should be informed of the expected operation speed range and the type and manufacturer of the drive so that the design of the equipment can accommodate the expected operation. For retrofit application, the same type of information should be communicated to the driven equipment manufacturer to ensure that the variable speed application is compatible with the existing equipment. In some retrofit applications, testing of the existing equipment may be recommended by the manufacturer.

### Example 1: Centrifugal Blower

Consider the typical constant volume air handling unit of the 5-to30-hp size. It is equipped with a centrifugal blower driven by a single-speed AC motor in continuous operation. This piece of equipment could account for up to half of the annual operating costs of an HVAC system. Throughout the year, the varying conditioning load, hence the air flow actually required, will rarely be as great as the maximum system capacity and will more likely vary between 30 and 75 percent of the maximum capacity. If the supply air temperature is held constant, then the flow of cold supply air must be reduced at times to avoid overcooling the zone (out-dated systems employ reheating).

Efficient systems employ VAV components for throttling. The simplest but least efficient means consists of a modulating damper at the blower discharge to throttle the cold air flow to satisfy the zone thermostat. As this damper closes, it imposes increasing back pressure on the blower, decreasing the supply air flow according to the particular fan performance curve. Although the blower and motor are in continuous, full-speed operation, the reduced flow rate in turn reduces power consumption. Notice in Figure 3 that if the required flow were 50 percent of the maximum blower output, then the power required would be 75 percent of that required at maximum output.

Some air handling units are equipped with variable inlet guide vanes, which impart a spin to the air entering the blower. The spin effectively changes the angle of attack of the blower blade, modifying the fan curve and reducing air flow and power consumption. With this method of throttling, roughly 62 percent of the full flow power is required to move 50 percent of the full flow (from figure 3) with the motor and blower in full-speed operation.

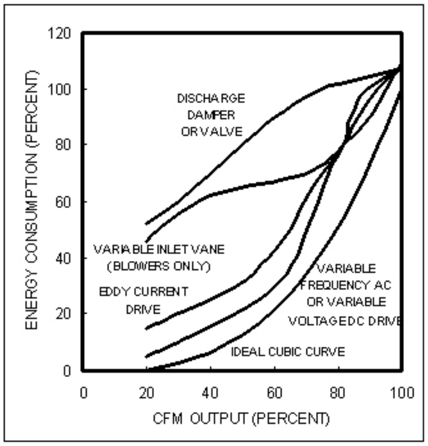



**Figure 3. Typical Energy Requirements Of A Centrifugal Fan Or Pump**

**Table 2. General Characteristics Of Variable Speed Drives**

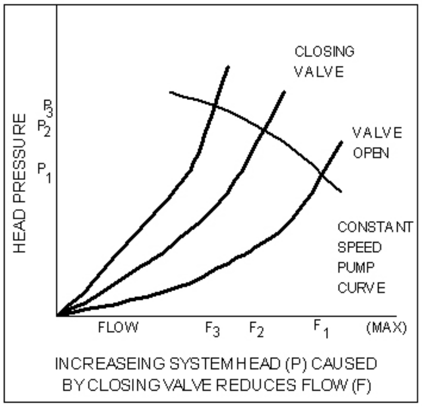
| Drive Type | Output (a) | Ratio | Efficiency Range (b) | Relative Costs Installation | Maintenance | Comments |
|---|---|---|---|---|---|---|
| **Mechanical** | | | | | | |
| Traction transmission | CH | 12 | 0.7 to 0.75 | High | Low | 1,2,4,6,7,8,13 |
| Variable pitch sheaves | CH | 8 | 0.5 to 0.75 | Low | Medium | 1,2,6,7,8,14 |
| **Hydraulic** | | | | | | |
| Hydrostatic | CT,CH | 40 | 0.5 to 0.7 | Medium | Low | 1,2,4,7,8,9,15 |
| Hydrodynamic | VT | Unlimited | 0.0 to 0.6 | Medium | Low | 1,2,8 |
| Hydroviscous | CT | 10 | 0.1 to 0.9 | Medium | Low | 1,2,8 |
| **Electrical** | | | | | | |
| Eddy-current clutch | VT | 35 | 0.0 to 0.7 | Low | Low | 1,2,4,8 |
| Variable armature voltage DC drive | CT | 100 | 0.75 to 0.9 | Medium | Low | 1,2,4,7,8,9, 10,11,12 |
| Variable field voltage DC drive | CH | 100 | 0.75 to 0.9 | Medium | Low | 1,2,4,7,8,9, 10,11,12 |
| Variable frequency/ AC motor control | VT,CT | 30 | 0.85 to 0.95 | Low | Low | 1,2,3,4,5,8,9 10,11,12,16 |

(a) CT = Constant torque | VT = Variable torque | CH = constant horsepower capability.
(b) Efficiency value accounts for motor, drive and not power factor | line kVA/shaft kW: from 0 to 100% speed.

**Comments**

1. Linear acceleration/deceleration (soft start/stop). Prolongs motor and belt life.
2. Power factor of driver motor falls considerably as power output is reduced.
3. High constant power factor option available.
4. Precise speed regulation capability.
5. May transmit electrical noise into building power supply.
6. Must be oversized for constant torque loads.
7. Must be oversized for loads in which torque increases with RPM.
8. Inherent overload protection.
9. Reversing capability.
10. Many optional control capabilities.
11. Low speed operation at high torque outputs necessitates additional motor cooling.
12. Extended speed range capability.
13. 100 hp maximum.
14. 50 hp maximum.
15. 600 hp maximum.
16. Efficiency falls rapidly after 30% speed reduction.

Alternately, the air handling unit may be equipped with a variable speed drive. It could have an eddy-current clutch between the motor and the blower. The motor would still operate at full speed; however, slip in this magnetic clutch would reduce the speed of the blower. Reducing the speed of the blower will reduce the air flow in direct proportion as well as reduce vibration and noise. From Figure 3, roughly 30 percent of the full flow power is required to move 50 percent of the full flow.



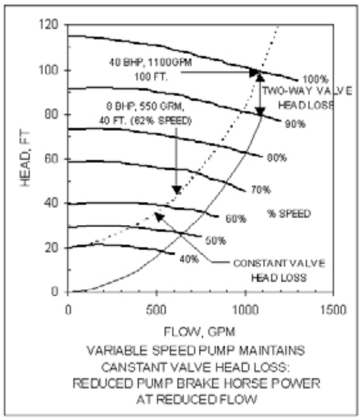




**Figure 4. Typical Head / Capacity Curves For A Centrifugal Pump**

Blower speed reduction can also be accomplished by a variable pitch sheave drive, in which case the motor is in full-speed operation; however, the discs of the drive sheave are automatically separated to reduce the pitch, hence varying the drive ratio. From Figure 3, roughly 20 percent of the full flow power is required to move 50 percent of the full flow.

Note that the speed of the motor is constant with the above types of drives. As the motor shaft load decreases, so does the current draw and power factor, and consequently the input kW. Additional benefits may be realized by reducing the speed of the motor to match the load requirements. The air handling unit could be equipped with a DC motor which changes speed as the armature voltage is adjusted. Since most air handling units are equipped with standard three phase, design-B, alternating current motors, a variable frequency/voltage motor control could be provided to automatically adjust the speed. As indicated in Figure 3, there are generally no additional energy savings using variable speed DC/AC motors over the variable pitch sheave drive. However, consideration of maximum power requirements and power factor penalties, as well as other costs and benefits described in Table 2, will reveal the most appropriate device for your application.

### Example 2: Centrifugal Pump

Consider a centrifugal pump used to supply cold water to a mixing tank to maintain the mixture at a constant temperature. The pump is powered by an AC motor, and flow is modulated by a thermostatically controlled throttling valve at the tank; i.e. the valve opens to pass more cold water into the tank as needed. The motor is in continuous operation. As the valve closes to throttle flow, it imposes an increasing back pressure on the pump. The flow decreases according to the pump curve (see Figure 4). The graph indicates how the system curve changes as the valve closes, and the flow is reduced. The “discharge damper or valve” curve in Figure 3 is applicable to this example as well as to centrifugal blower; i.e., 75 percent of full power is required at 50 percent of full flow. If the motor were controlled by a variable frequency motor control in order to displace the throttling valve, roughly 20 percent full flow power would be required at 50 percent full flow. Actual energy savings would depend on the actual cold water requirements throughout the year. For a 10-horsepower motor and a 50 percent average annual flow requirement, the average annual pumping power requirement would be 10 hp x 0.75 = 7.5 hp, with throttling valve flow control, or 10 hp x 0.2 = 2 hp with the variable frequency motor control (see Figure 3). The power requirement of a 10-horsepower motor at 75 percent load would be approximately 5 kW, 43,800 kWh/year, or $3,066 (at 7 cents/kWh and no demand charge). At 20 percent load, the power requirement would be approximately 1.5 kW, 13,000 kWh/year, or $910 per year.

With variable frequency control, the pump curves change as the pump speed changes (see Figure 4). If the pump were serving a circulating chilled water distribution system, then a constant differential pressure across the systems would have to be maintained at all speeds to ensure adequate flow through two-way valves and cooling coils. Thus, the dashed curve in Figure 4 is offset from the system curve by a fixed pressure throughout the flow/speed range. Potential energy savings are somewhat less that ideal, but they are attractive for most circulating chilled or heating water systems. Additional benefits include reduced vibration and system noise, and reduced impeller and seal water.

## BENEFITS

In addition to the economic benefits of lower energy costs, variable speed drive can enhance product quality and reduce equipment maintenance. Flow rates and equipment speeds can be automatically and instantaneously adjusted to meet changes in production process requirements. This helps ensure product uniformity and reduce material waste. If equipment often runs at less than its maximum speed, wear can be reduced considerably and maintenance intervals can be extended.

## CREDITS

- NEMA MG-10 (Figure 1)
- Reliance Electric Co. (Figure 2)
- Emerson Electric Co. — Industrial Control Division (Figure 3)
- HPAC Magazine (Figure 4)

**FOR ADDITIONAL INFORMATION ABOUT *Variable Speed Drives*,** contact your Progress Energy representative.