Energy Savings With Adjustable Frequency Drives

for Centrifugal Fans
Centrifugal Fan

Fans are designed to be capable of meeting the maximum demand of the system in which they are installed. Quite often the actual demand varies and may be much less than the designed capacity.

The centrifugal fan imparts energy into air by centrifugal force. This results in an increase in pressure and produces airflow at the outlet of the fan. Below is an example of what a typical centrifugal fan can produce at its outlet at a given speed.

The curve is a plot of outlet pressure in static inches of water versus the flow of air in cubic feet per minute (CFM). Standard fan curves will usually show a number of curves for different fan speeds and includes fan efficiency and power requirements. These are useful for selecting the optimum fan for any application, and are required to predict fan operation and other parameters when the fan operation is changed.
The system curve shows the requirements of the vent system that the fan is used on. It shows how much pressure is required from the fan to overcome system losses and produce airflow.

Many systems require operation at a wide variety of points. There are several methods used to modulate or vary the flow (or CFM) of a system to achieve the optimum points. These include:

- **Cycling** – As done in home heating systems. This produces erratic airflow and is unacceptable for commercial or industrial uses.
- **Outlet Dampers** – Control louvers or dampers are installed at the outlet of the fan. To control airflow, they are turned to restrict the outlet, which reduces the airflow.
- **Variable Inlet Vanes** – by modifying the physical characteristics of the air inlet, the fans operating curve is modified which changes the airflow.
- **Variable Frequency Drives** – By changing the actual fan speed, the performance of the fan changes producing a different airflow.
By changing the airflow, or the fan speed, the system or fan curves are affected which produces a different natural operating point. In so doing, they may also change the fan's efficiency and power requirements.

Outlet Dampers

The outlet dampers affect the system curve by increasing the resistance to airflow. The system curve can be stated as

\[ P = K \times (\text{CFM})^2 \]

Where:
- \( P \) is the pressure required producing a given flow in the system
- \( K \) is a function of the system that represents the resistance to airflow
- CFM is the airflow desired

The outlet dampers affect the \( K \) portion of the formula. The diagram below shows several different system curves indicating different outlet damper positions.
The power requirements for this type of system decrease gradually as flow is decreased as shown in the following diagram.

**Variable Inlet Vanes**

This method modifies the fan curve so that it intersects the system curve at a different point. Below is a representation of the changes in the fan curve for different inlet vane settings.
The power requirements for this method decrease as airflow decreases, and to a greater extent than the outlet damper.

Variable Frequency Drives

This method takes advantage of the change in the fan curve that occurs when the speed of the fan is changed. These changes can be quantified in a set of formulas called the affinity laws.

$$\frac{Q_2}{Q_1} = \frac{N_2}{N_1}$$

$$\frac{P_2}{P_1} = \left(\frac{N_2}{N_1}\right)^2$$

$$\frac{HP_2}{HP_1} = \left(\frac{N_2}{N_1}\right)^3$$

Where:
N = Fan speed
Q = Flow (CFM)
P = Pressure (Static Inches of Water)
HP = Horsepower
Note that when the flow and pressure laws are combined, the result is a formula that matches the system curve formula – $P = K \times (\text{CFM})^2$.

\[
P_2 = P_1 \times \left(\frac{N_2}{N_1}\right)^2
\]

\[
\frac{Q_2}{Q_1} = \frac{N_2}{N_1} \quad Q_2 = \frac{N_2}{N_1} \quad \frac{HP_2}{HP_1} = \left(\frac{N_2}{N_1}\right)^3
\]

By substituting $(Q_2/Q_1)^2$ for $(N_2/N_1)^2$ in the first equation gives us:

\[
P_2 = P_1 \times \left(\frac{Q_2}{Q_1}\right)^2 \quad \text{or} \quad P_2 = \left(\frac{P_1}{(Q_1)^2}\right) \times (Q_2)^2
\]

The quantity $P/(Q)^2$ coincides with the system constant, $K$. This shows that the fan will follow the system curve when its speed is changed.
As the fan speed is reduced, a significant reduction in power requirement is achieved.

The variable speed method achieves flow control in a way that closely matches the system or load curve. This allows the fan to produce the desired results with the minimum of input power.
Fan Energy Savings

It is possible to estimate the power consumption for each of these various methods and associate a cost of operation with them. To accomplish this, an actual load profile and fan curve is required as shown below.
As an example, a simple analysis of the variable speed method compared to the outlet damper method follows.

Using the fan curve shown previously, assume the fan selected is to be run at 300 RPM and 100% CFM is to equal 100,000 CFM as shown on the chart. Assume the following load profile.

For each operating point, we can obtain a required horsepower from the fan curve. This horsepower is multiplied by the percent of time (divided by 100%), that the fan operates at this point. These calculations are then summed to produce a “weighted horsepower” that represents the average energy consumption of the fan.

### Outlet Damper Method

<table>
<thead>
<tr>
<th>CFM</th>
<th>Duty Cycle (% of Time)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>10%</td>
</tr>
<tr>
<td>80%</td>
<td>40%</td>
</tr>
<tr>
<td>60%</td>
<td>40%</td>
</tr>
<tr>
<td>40%</td>
<td>10%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CFM</th>
<th>Duty Cycle</th>
<th>Horsepower</th>
<th>Weighted HP</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>10%</td>
<td>35</td>
<td>3.5</td>
</tr>
<tr>
<td>80</td>
<td>40%</td>
<td>35</td>
<td>14.0</td>
</tr>
<tr>
<td>60</td>
<td>40%</td>
<td>31</td>
<td>12.4</td>
</tr>
<tr>
<td>40</td>
<td>10%</td>
<td>27</td>
<td>2.7</td>
</tr>
</tbody>
</table>

Total 32.6

Similar calculations are done to obtain a weighted horsepower for variable speed operation. However, the fan curve does not have enough information to read all the horsepower values for our operating points. We can use the formulas from the affinity laws to overcome this.
The first point is obtained from the fan curve. 100% flow equals 100% speed equals 35 HP. The flow formula $Q_2/Q_1 = N_2/N_1$ can be substituted into the horsepower formula, $HP_2/HP_1 = (N_2/N_1)^3$ to give us:

$$\frac{HP_2}{HP_1} = \left(\frac{Q_2}{Q_1}\right)^3$$

When $Q_1 = 100\%$ and $HP_1 = 35\%$, $Q_2$ and $HP_2$ will have the following values:

$$Q_2 = 80$$

$$\frac{MP_2}{35} = \left(\frac{80}{100}\right)^3$$

$$MP_2 = 18$$

Now sufficient information is available to calculate the weighted horsepower.

<table>
<thead>
<tr>
<th>CFM</th>
<th>Duty Cycle</th>
<th>Horsepower</th>
<th>Weighted HP</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>10</td>
<td>35</td>
<td>3.5</td>
</tr>
<tr>
<td>80</td>
<td>40</td>
<td>18</td>
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<tr>
<td>60</td>
<td>40</td>
<td>7.56</td>
<td>3.024</td>
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<tr>
<td>40</td>
<td>10</td>
<td>2.24</td>
<td>0.224</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td>13.948</td>
</tr>
</tbody>
</table>

Comparing the results of the two methods of control indicates the difference in power consumption.

In order to get a dollar value of savings kilowatt-hours used must be known. To calculate this, multiply the horsepower by 0.746 and then multiply the result by the hours the fan will operate in a period of time. This would typically be for a month.

This example shows a cost saving of more than $700 per month by using a variable speed method. Note that the example is very basic and does not consider motor and drive efficiency.

<table>
<thead>
<tr>
<th>Outlet Damper</th>
<th>Horsepower</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weighted HP</td>
<td>13.948</td>
</tr>
<tr>
<td>$X\ kW/HP$</td>
<td>0.746</td>
</tr>
<tr>
<td>$X\ Hours\ per\ Month$</td>
<td>730</td>
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<tr>
<td>= $k\ WH\ per\ Month$</td>
<td>17,753</td>
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<tr>
<td>$X\ Cost$</td>
<td>0.07</td>
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<tr>
<td>= Total Cost</td>
<td>$1,242.73</td>
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</table>

Calculate your potential energy savings using AC drives for fans at: http://www.rockwellenergycalc.com/