MODULATING AIRFLOW

Although fans must be selected to meet airflow requirements under maximum conditions, they may be operated at reduced flow a large part of the time. Reducing airflow as conditions permit can return substantial savings in power use and reduced noise level.

The purpose of this paper is to set out the relationships between airflow, horsepower and noise levels in a way that will assist the designer of a system to select the most effective method of providing for airflow modulation.

Two methods for reducing velocity are considered:

METHOD I: REDUCE BLADE ANGLE
For example, using automatic fan hubs and single speed motors

METHOD II: REDUCE FAN RPM
For example, using variable-speed motors.

Each of these methods, when provided with suitable sensing and control devices, can provide a fine degree of control as ambient conditions change. They vary considerably, however, in the savings they return.

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HOW HORSEPOWER VARIES WITH CFM

When the velocity is reduced (by either Method I or Method II), the CFM is reduced by the same proportion. The velocity pressure (Pv) is reduced as the square of the velocity and, therefore, as the square of the CFM (See Eq. 2).

An approximate rule-of-thumb states that "The horsepower will vary as the cube of the CFM".

$$HP_{NEW} = HP_{OLD}\ (CFM_{NEW}/CFM_{OLD})\ (CFM_{NEW}/CFM_{OLD})^2$$

$$= HP_{OLD}\ (CFM_{NEW}/CFM_{OLD})^3$$

From the horsepower equation (Eq. 1) it can be seen that this would only be true in a free-air situation — where the static pressure (Ps) equals zero — or if the static pressure also varied as the square of the CFM.

The static pressure does vary with the CFM but to a degree that is determined by the characteristics of the resistance. If the resistance consists of a typical finned tube bundle, the degree of variation will be as shown in Eq. 3. For other resistances, the degree of variation must be determined before the exact relationship can be calculated.

Eq. 4 shows the degree of variation for the total pressure (Pv + Ps) for aerial coolers based on a range of pressures typical of these units. Referring again to Eq. 1 (neglecting any change in efficiency) it can be seen that:

For aerial coolers:

$$HP_{NEW} = HP_{OLD}\ (CFM_{NEW}/CFM_{OLD})\ (CFM_{NEW}/CFM_{OLD})^{\sim 1.75 \text{ to } 1.8}$$

$$= HP_{OLD}\ (CFM_{NEW}/CFM_{OLD})^{\sim 2.75 \text{ to } 2.8}$$

SYSTEM EFFICIENCY

Fan Efficiency:

Fan efficiency depends in part on fan pitch. Pitch is defined as the distance the air advances, in an axial direction, per revolution of the fan wheel. In order to simplify calculations, Moore refers to pitch in hub diameters. As all standard series of Moore fans are aerodynamically scaled, the pitch, when given in hub diameters, is a dimentionless figure applicable to all series of units with similar blade shape.

The formula for pitch in hub diameters is given as Eq. 5 on the following page.

Eq. 1:

$$HP_{INPUT} = \frac{Pt \times CFM \times 5.2}{33{,}000 \times E}$$

Where:

HP_{INPUT} is the input horsepower at the fan shaft

Pt = Total Pressure in Inches H_2O

= Static Pressure (Ps) + Velocity Pressure (Pv)

CFM = Air Volume in Cubic Feet per Minute

E = Efficiency expressed as a decimal

Eq 2:

$$\frac{Pv_{NEW}}{Pv_{OLD}} = \left[\frac{CFM_{NEW}}{CFM_{OLD}}\right]^2$$

Eq 3:

For finned tube bundles

$$\frac{Ps_{NEW}}{Ps_{OLD}} = \left[\frac{CFM_{NEW}}{CFM_{OLD}}\right]^{1.68}$$

Eq 4:

For typical aerial coolers:

$$\frac{Pt_{NEW}}{Pt_{OLD}} = \left[\frac{CFM_{NEW}}{CFM_{OLD}}\right]^{\sim 1.75 \text{ to } 1.8}$$

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FAN EFFICIENCY (CONTINUED)

Efficiency for a fan of a particular design can be predicted by an empirical equation from the fan diameter, hub diameter, tip seal and pitch. Only the pitch, which appears in an exponential function, will be affected.

The effect of a reduction in pitch can be seen in the slope of the solid line in the illustration at right. At or near full load, efficiency is very little changed. The effect of reduced pitch becomes increasingly apparent as velocity is further reduced.

Method I, reducing velocity by reducing blade angle, results in a change in efficiency because the velocity is reduced while the RPM remains constant. Method II, reducing velocity using a variable speed motor, does not result in a this change in efficiency since the velocity and RPM are reduced by the same proportion and the pitch, therefore, remains constant.

Eq. 5:

P_{HD} = The axial advance of the air stream per revolution of the wheel, expressed in hub (air seal) diameters

$$P_{HD} = \frac{12\ V}{S\,(RPM)}$$

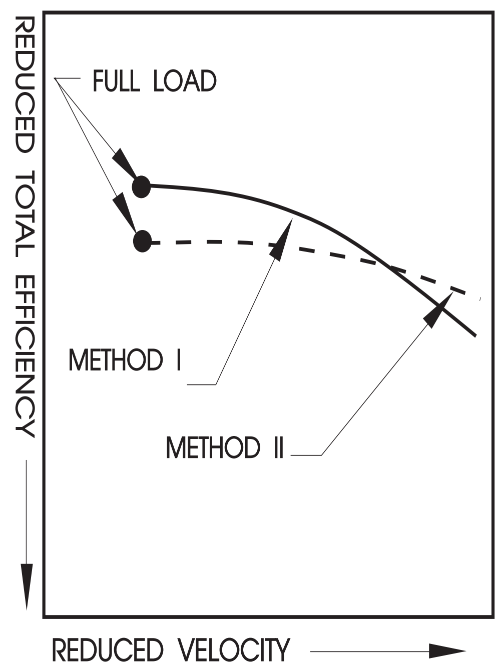
Where:

V = velocity in feet per minute

S = Series of fan (air seal diameter in inches)

TOTAL EFFICIENCY

It is not sufficient to consider only the fan efficiency. The total efficiency of the motor, controls and fan is what matters — that is, the power input to the motor compared to the power output by the fan. Variable speed motors and controls, by their nature, consume more energy in operation than do single speed motors. The total system efficiency, therefore, is somewhat lower for Method II at or near full load than it is for Method I. The motor manufacturer should be consulted to determine the total efficiency. In order to determine the most efficient method for a given application, then, it is necessary to consider the relative amount of time the unit will be operating near full load compared to the time it will operate at more reduced load.



OTHER CONSIDERATIONS

Automatic fans (Method I) are more commonly used than variable speed motors (Method II). They are considerably less expensive and require simpler controls.

Automatic fan blades may be set to provide reverse flow to overcome convection currents, a useful feature in some applications.

Variable-speed motors, however, are more efficient when operating at low loads and, as explained in the next section, provide a greater reduction in noise level.

Variable-speed motors should not be operated at the resonant frequencies of the fan. The need to avoid critical speeds can be eliminated by using Moore fans with blades attached to the hub by a pivot. This resilient mounting reduces stresses caused by the air load and entirely eliminates resonant frequencies, making variable-speed motors more attractive.

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NOISE LEVEL REDUCTION

Sound Power Level (PWL)

The total sound power level of the fan can be calculated using Eq. 7. Note that the PWL is determined by the tip speed and the horsepower of the fan. (Horsepower does not directly effect the noise level but is the result of velocity, pressure and efficiency which do.)

The effect of the tip speed on noise level is much greater than the effect of HP. Both Method I and Method II result in lower horsepower. Method II, by reducing the RPM, reduces the tip speed. Method I does not. It can be seen then that the reduction in noise level resulting from Method II is substantially greater than from Method I.

Eq. 7:

$$PWL = 56 + 30 \log V_T + 10 \log HP$$

Where:

V_T = Fan tip speed in ft/min x 10^{-3}
= π X Dia. X RPM / 1000

HP = Input Fan Horsepower (Not motor horsepower)

PWL is in DBA

All logs are to the base 10

Sound Pressure Level (SPL)

The sound pressure level (SPL) is related to the sound power level (PWL) as shown in Eq. 8. "K" in this formula is an expression that distributes the sound power in space and depends on the fan diameter and the point of measurement. The value of K is not effected by modulating the airflow.

From Eq. 8 it can be seen that the SPL of the fan will be reduced by the same amount as the PWL. The ground reflection (if any) will also be reduced and can be added to the fan SPL logarithmically.

Eq. 8:

$$SPL_F = PWL - 10 \log K$$

Where:

SPL_F = The Sound Pressure Level of the fan

PWL = The Sound Power Level in dBA as calculated in Eq. 7

K = A constant - see text

FOR MORE INFORMATION

Noise level calculations are described in detail in a paper entitled "Noise Level Prediction for Moore Fans" (TMC-651) which is free on request. The paper is also included with any request for software discussed below.

FAN SELECTION SOFTWARE

Moore provides free fan selection software consisting of two programs:

Fan Rating for Moore Fans:
Used to select fan for given performance. Gives complete fan rating and noise level at standard points of measurement.

Noise Level Prediction:
Calculates noise levels at user-defined locations and for multiple fans in aerial cooler units.

Both programs are on one 360K disk. Requires IBM compatable and DOS. Includes TMC-651

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