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Volume Control of Fans to Reduce the Energy Demand of Ventilation Systems

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Synopsis

The fan and the ductnetwork ist designed for 100 % ventilation rate. Because the fan energy is the main important energy consumption in systems all over the year it is worthwile to control the systems correctly. By reducing the air volume rate the pressure drop in the ductnetwork drops nearly with the second power.

The energy demand at the fans is:

$$P = \frac{\dot{V} \cdot \Delta p}{\eta}$$

As the pressure drop ist nearly the volumerate to the second power, the energy consumption goes nearly with the third power of the volumerate. This means to find a very effective control strategy of the fans. There are four possibilities: 1. Damper control, 2. Bypass control, 3. Vortex damper control, 4. Speed control.

The comparison of the four strategies show clearly that the speed control can be the best of the fan design ist good on the optimum efficiency line in the $\Delta p / \dot{V}$-diagram follows about the equation:

$$\Delta p / \dot{V}^{1,9}$$

An other important point is the high efficiency at the electrical drive in part load conditions at low power.

1. Introduction

The main tasks in ventilation systems is the transport of air in order to be able to decrease the air contamination in the rooms. This needs transportation energy which can be calculated:

$$P = \frac{\dot{V} \cdot \Delta p}{\eta}$$

The air systems also have great differences in this value because of the high range of pressure drop.

2. System characteristics

The conservative plants have duct-velocities up to about 7 m/s and give the possibility to put the air-inlets direct to the ducts without any throttle.

To be able to reduce the size of the ducts, high velocity plants have been introduced about 20 years ago. The velocities in the ducts rise up to about 25 m/s.

In these systems between the main duct and the air inlet there must be a throttling unit to reduce the pressure. The main effect is the equilbration of the air distribution in large duct systems.

Caused by the high velocity the energy consumption to transport the air is higher than in conservative plants.

Regarding the above mentioned equation for calculating the energy consumption of the fan we have a simple proportionality between pressure drop Δp and power P, because the air flow rate $\dot{V}$ is constant.

In air ducts we almost always have turbulent flow, therefore the influence of diameter or reference diameter at constant air flow rate is given at smooth ducts by:

$$\Delta p \approx d^{-4,75}$$

and in extremly rough ducts:

$$\Delta p \approx d^{-5}$$

The partial energy amount for transport in the ducts is therfore:

$$P \approx d^{-4,75} or \;\; P \approx d^{-5}$$

if $\dot{V}$ = const. and η = const.

The pressure drop in the central units does not change.

3. Dimensionless Numbers for fans

the energetical behaviour of a fan can be shown by dimensionsless numbers:

$\phi_N = \frac{c_{ax}}{u_N}$ .....velocity ratio

$\psi_N = \frac{\Delta p}{\frac{\rho}{2} u_N^{\,2}}$ .....pressure ratio

$\lambda - \frac{\phi_N \cdot \psi_N}{\eta_i}$ .....power input coefficient

$\mathrm{Re}_u = \frac{u_N \cdot d_H}{\nu}$ .....Reynolds'Number for tangential velocity

$\mathrm{Re}_c = \frac{c_{ax} \cdot d_H}{\nu}$ .....Reynolds'Number for axial velocity

with $d_H = d_s - d_N$ .....hydraulic diameter

4. Part load characteristic

The load of a ventilation system is changing sometimes over a large range and therefore it is necessary to vary either the specific enthalpy difference between supply air and return air or the air flow rate.

Using the varying volume systems there is a decrease of the transportation energy depending on the air flow rate.

As we saw this part of energy amount is fairly large and therefore it is very interesting to discuss all possibilities from the point of view of the whole energy amount. Reducing the air flow rate the velocity in the ducts decreases proportionally. The pressure drop and the power decreases also but with a higher power if the efficiency η of the fan is constant:

Smooth tube: $\Delta p \approx w^{1,75}$ *and* $P \approx \dot{V}^{2,75}$

Very rough tube: $\Delta p \approx w^{2}$ *and* $P \approx \dot{V}^{3}$

In the middle range of practical use the tubes and the whole system will follow an equation of:

Therefore it is necessary to discuss the possibilities of the variation of the air flow rate with the fans.

5. Part flow characteristic of fans

The energy consumption of fans can be calculated from the equation:

$$P = \lambda \cdot A \cdot \frac{\rho}{2} \cdot u^3$$

with A as total flow area in m^2

ρ as air density in $\frac{kg}{m^3}$

u as periphal speed in $\frac{m}{s}$

λ as the power amount coefficient

P as as energy amount in W

With constant rpm P is proportional to λ. The air volume $\dot{V}$ moved by this fan is:

$$\dot{V} = A \cdot w_{ax}$$

with w_{ax} as the axial velocity in m/s.

To describe this air flow rate by a dimensionless number we state:

$$\varphi = \frac{w_{ax}}{u}$$

A diagram $\lambda = f(\varphi)$ shows therefore the power consumption as function of air flow rate.

Figure 1 shows this function for air control by air flow dampers. We see an increase of λ over a wide range of decreasing φ. A variation of air flow rate by this method of fan control therefore does not reduce the energy consumption for air transportation.

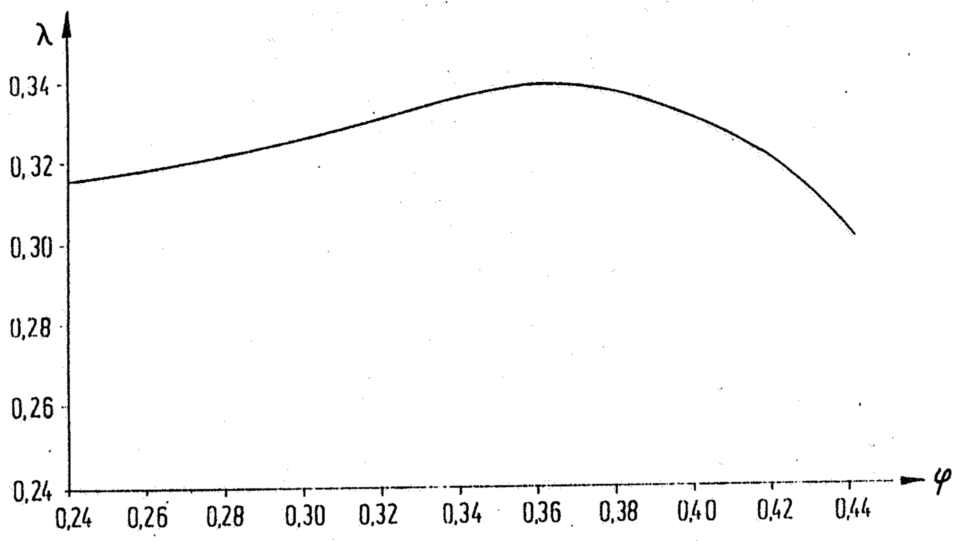

Figure 1: Control-Characteristic using Air-Dampers

Much better we find the control characteristic of the fans using spin dampers at the entrance to the fan (figure 2). We see a very high decrease of energy consumption by changing the angle of the blades.

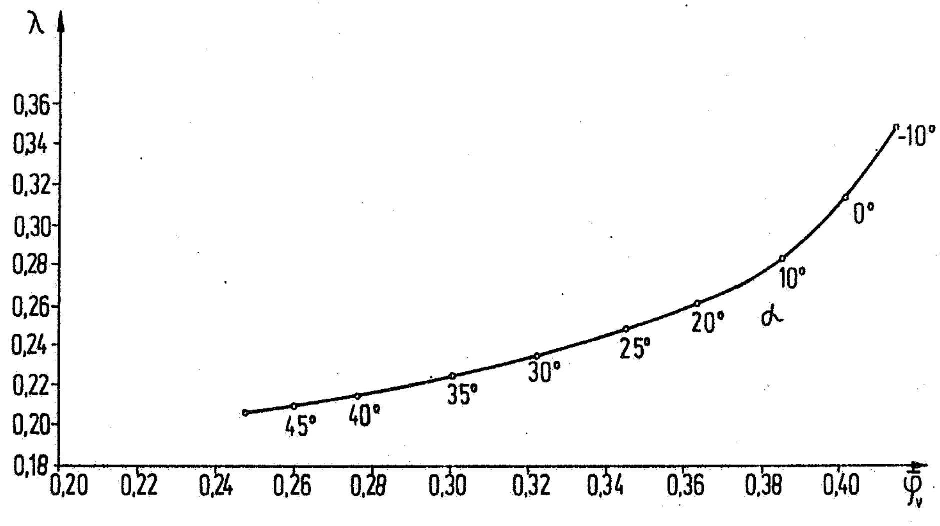

Figure 2: Control-Characteristic using Spin-Dampers

Very good characteristics can be shown by using a speed variation of the fan to control air volume. Figure 3 shows a characteristic diagram of a fan, where we can see that for instance the line of the highest efficiency η_i is a parabolic curve.

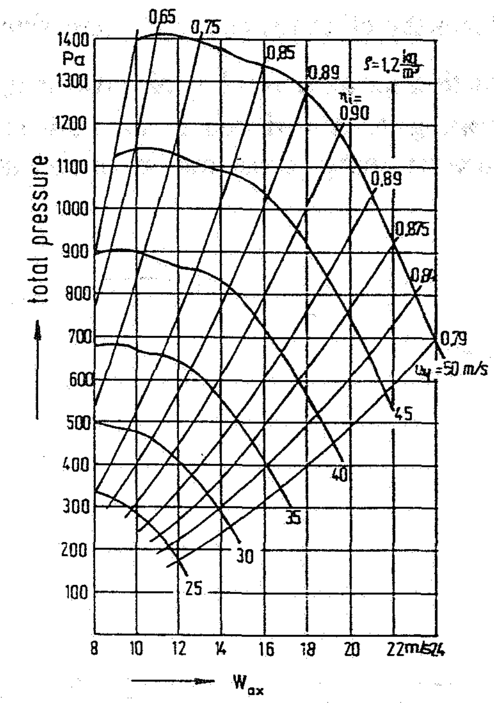

Figure 3: Characteristic of Fan

As we showed in chapter 4 the pressure drop depends nearly on $w^{1,9}$. This means ist would be the best to design the axial fans with a characteristic line for the optimal efficiency following the equation:

$$\Delta p \approx w^{1,9}$$

There it is possible to vary air flow rate by changing the draft speed of the fan nearly with constant efficiency.

to be able to decrease the energy consumption it is necessary therefore to install a fairly simple variation of shaft speed by electrical circuit.

Conclusion

The energy demand of the fan is very important for ventilation systems. The most effective way to vary the air volume rate is the control of shaft speed. Using a good fan design it is possible to remain always at the highest fan efficiency, which can really save energy.