Refrigeration and Air conditioning Engineering.
3rd year – refrigeration and Air conditioning Course

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Fans - Part2

Lecture -9

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3.4- Fan Total Pressure

As previously stated, a fan impeller imparts static and kinetic energy to the air. This energy is represented in the increase in total pressure and can be converted to static or velocity pressure. These two quantities are interdependent: fan performance cannot be evaluated by considering one alone. Energy conversion, indicated by changes in velocity pressure to static pressure and vice versa, depends on the efficiency of conversion, where the energy conversion occurs in the discharge duct connected to a fan being tested.

Thus, the *fan static pressure* (Pr_{SF}) is the pressure increase produced by a fan, while the *fan velocity pressure* (Pr_{vF}) is the velocity pressure corresponding to the mean velocity of air at the fan outlet based on the total outlet area without any deductions for motors, fairings, or other bodies. The total pressure created by a fan or the *fan total pressure* (Pr_{TF}) is the algebraic difference between the total pressure at the fan outlet and the total pressure at the fan inlet as:

$$Pr_{TF} = Pr_{T2} - Pr_{T1} \qquad \dots (3.8.a)$$

Where:

Pr_{T1} = Total pressure at the fan inlet

$$= Pr_{S1} + Pr_{v1} \qquad \dots (3.8.b)$$

And:

Pr_{T2} = Total pressure at the fan outlet

$$= Pr_{S2} + Pr_{v2} \qquad \dots (3.8.c)$$

As preceded, the total pressure at a point is the sum of static pressure and velocity pressure at that point. Thus, for a fan:

Fan total pressure = Fan static pressure + Fan velocity pressure

i.e. $$Pr_{TF} = Pr_{SF} + Pr_{vF} \qquad \dots (3.9.a)$$

As the fan static pressure (Pr_{SF}) therefore:

$$Pr_{SF} = Pr_{TF} - Pr_{v2} \qquad \dots (3.9.b)$$

3.5 - Fan Air Power

The power output of a fan is expressed in terms of air power and represents the work done by the fan. Mathematically, the total fan air power P_{aT} "based on fan total pressure, Pr_{TF}" is:

$$P_{aT} = Q \times P_{rTF} \times K_p \quad (W) \qquad \dots (3.10.a)$$

Where:

Q = Total quantity of air flowing at the fan inlet in m^3/min,

Pr_{TF} = Fan total pressure in mm of water,

K_P = Compressibility coefficient.

Similarly, the static fan air power H_{aS} based on the fan static pressure (Pr_{SF}) is:

$$P_{aS} = Q \times P_{rSF} \times K_p \quad (W) \qquad \dots (3.10.b)$$

3.6 - Fan Efficiency

The ratio of the total fan air power to the driving power (or shaft power) required for the fan shaft is known as the *total fan efficiency* or the *mechanical efficiency* of the fan, which is expressed as:

$$\eta_{TF} = \frac{\text{Total Fan air Power } (P_{aT})}{\text{Input or shaft Power } (B.P)} \qquad \dots (3.11.a)$$

Similarly, the static fan efficiency,

$$\eta_{SF} = \frac{\text{Static Fan air Power } (P_{aS})}{\text{Input or shaft Power } (B.P)} \qquad \dots (3.11.b)$$

3.7- Fan Laws

Fan laws relate the performance variables for any geometrically similar series of fans. The variables involved are the fan size *D*, rotational speed *N*, gas density ρ, volume flow rate *Q*, pressure P_t or P_s, power *H* (either air or shaft), and mechanical efficiency η_{TF}. Those laws can be summarised as:

1. The volume flow rate or capacity (*Q*) of a fan is directly proportional to the fan speed (*N (r.p.m)*) and cube of th
   $Q \propto N \propto D^3$ … (3.12)
2. The fan total pressure (P_{TF}), static pressure (P_{SF}) and velocity pressure (P_{vF}) at the fan discharge are directly proportional to the square of the fan speed (N^2) as:
   $(Pr_{TF}, Pr_{SF}, Pr_{vF}) \propto N^2$ … (3.13)
3. The fan power (P_f) is directly proportional to the cube of the fan speed (N^3) as:
   $P_f \propto N^3$ … (3.14)
4. At constant fan speed and flow rate, the fan power (P_f) along with the fan total pressure (Pr_{TF}), static pressure (Pr_{SF}), and the velocity pressure (Pr_{vF}) at the fan discharge are directly proportional to the air density (ρ_a) as:
   $(P_f, Pr_{TF}, Pr_{SF}, Pr_{vF}) \propto \rho_a$ … (3.15)
5. At constant fan pressure, the fan speed (*N*), volume flow rate (*Q*) and the fan power (P_f) are inversely proportional to the square root of the air density (ρ_a) as:
   $$(Q, P_f, N) \propto \frac{1}{\sqrt{\rho_a}} \quad \text{… (3.16)}$$
6. At constant mass flow rate the fan speed (*N*), the volume flow rate (*Q*) and fan pressure "fan total pressure (Pr_{TF}), fan static pressure (Pr_{SF}) and the velocity pressure (Pr_{VF})" are inversely proportional to the air density (ρ_a); while the fan power (P_f) is inversely proportional to the square root of the air density (ρ_a) as:
   $$(Q, \mathrm{Pr}, N) \propto \frac{1}{\rho_a} \quad \text{… (3.10.a)}$$
   $$P_f \propto \frac{1}{\sqrt{\rho_a}} \quad \text{… (3.10.b)}$$

Example 1- A fan having an efficiency of *0.65* is used to suck air from a room and then push it through a duct system, where a grill is installed at the end of duct to distribute the air delivered. Consider that the airflow rate through the duct is $1 m^3/s$, while the equivalent diameter of the duct is *335 mm*. If the grill causes a pressure drop of *30Pa* and the static pressure drop along the duct and elbows is *110.25Pa*, calculate the fan power.

Solution:

Total static pressure= $\Delta P_{Duct\ \&\ Elbows} + \Delta P_{Grill}$

ΔP_{st} = 110.25+30=140.25 *Pa*

The mean air velocity in the room is zero, while it is increased to the velocity in the main duct, which can be evaluated from **Fig.(Fraction chart)** at airflow rate of $1 m^3/s$ and equivalent diameter of *310mm* to be:

$V_2 = 11.1\ m/s$ Thus, the change in the dynamic pressure through the fan is:

$$\Delta P_v = \frac{1}{2}\rho\left(V_2^2 - V_1^2\right)$$

$= 0.5 \times 1.2 \times [(11.1)^2 - 0]$, "The ideal density of air is considered =1.2 kg/m^3"

= 73.926 *Pa*

Total fan pressure:

$Pr_t = Pr_s + Pr_v$

=140.25+73.926=214.176 *Pa*

Air power:

$P_a = Q \times Pr_t$

$= 1 \times 214.176 = 241.65\ W$

Fan power:

$P_f = P_a / \eta$

$= 214.176/0.65 = 329.5\ \grave{}W$

Example 2- A fan delivers *8.2m³/s* of air at static pressure *250kPa* when the speed of fan is *256rpm* and requires a power of 34 *kW*. If the fan speed is changed to 300 *rpm*, find the new air flow rate, static pressure and the power required.

Solution:

As, $Q \propto N$

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

$$\Rightarrow Q_2 = 8.2 \times \frac{300}{256} = 9.61\ m^3/s$$

And, $(Pr_{TF}, Pr_{SF}, Pr_{vF}) \propto N^3$

$$\frac{P_{rSF1}}{N_1^2} = \frac{P_{rSF2}}{N_2^2}$$

$$P_{rSF2} = 250 \times \left(\frac{300}{256}\right)^2 = 343.3\ Pa$$

$P_f \propto N^3$

$$\frac{P_{f1}}{N_1^3} = \frac{P_{f2}}{N_2^3}$$

$$P_{f2} = 3.4 \times \left(\frac{300}{256}\right)^3 = 5.47\ kW$$

PROBLEMS*: (Homework)*

1- A centrifugal fan supplies 4.7m3/s of air at a total static pressure of 325Pa. If the fan efficiency is %60 and rotates at a speed of 950rpm and supplies air with a velocity of 12m/s, determine the fan total pressure, air power, and fan power?

Ans. 411 Pa

2- If the efficiency of the fan given in Problem-1 becomes 70%, determine the power required for running it. Then, find the power required and airflow rate supplied if the fan speed is increased to 1050rpm. Also, assume that the fan static pressure does not change and determine the air velocity out of the fan.

Ans. 4.6kW, 6.21kW, 5.195m3/s, 17.2m/s