Fan Performance: damper regulation and inlet whirl

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Synopsis

Centrifugal fans are generally designed to work in several points on the pressure-flow rate characteristic in order to fit different requirements in industrial processes: this fan regulation may be done by varying its speed or changing the system resistance, e.g. installing a damper. This paper describes how the fan performance changes according to damper regulation, focusing on the spin given to the fluid by inlet damper systems. It is indeed a fluid dynamic effect consisting in a pre-rotation of the fluid approaching the fan inlet, which may be spinning in same the rotation direction of the impeller. Inlet damper regulation combines the effect of aeraulic resistance and this fluid dynamic effect, influencing fan's performance, efficiency and power absorption and depending on inlet damper type and whirl's spinning direction, since it changes velocity vectors of the fluid entering the fan.

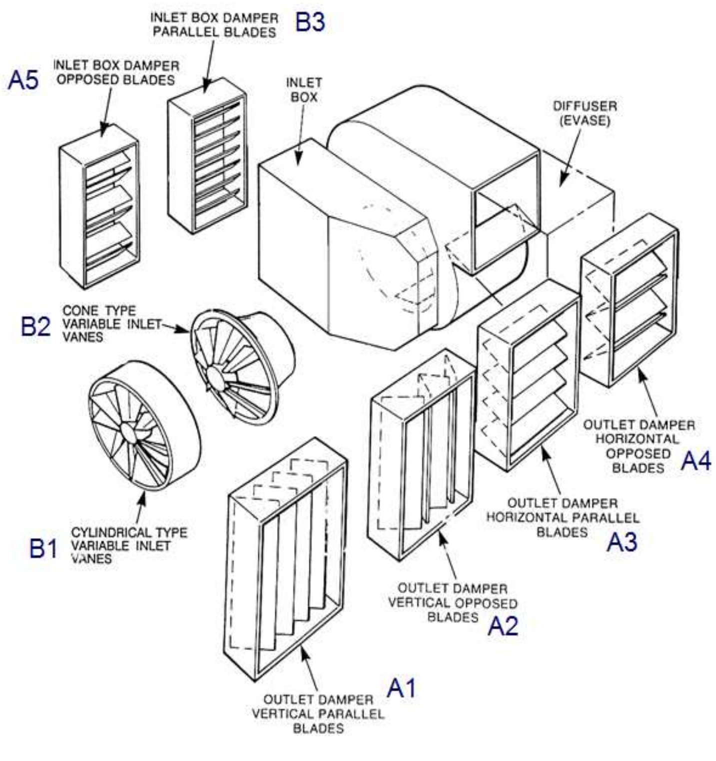
Keywords: Centrifugal fan; fan performance; fan regulation; inlet vane; VIV; damper; inlet whirl

1. Introduction

Centrifugal fans generally need to work in several points to fit different working conditions in a process: consider for example a boiler which changes load during operation, thus needing fan regulation in order to provide the correct amount of combustive air.

It is in fact known that a fan coupled with a fixed-speed driver, with fixed resistance system configuration, will only work in one point which is the intersection between the fan characteristic and the resistance curve of the aeraulic system.

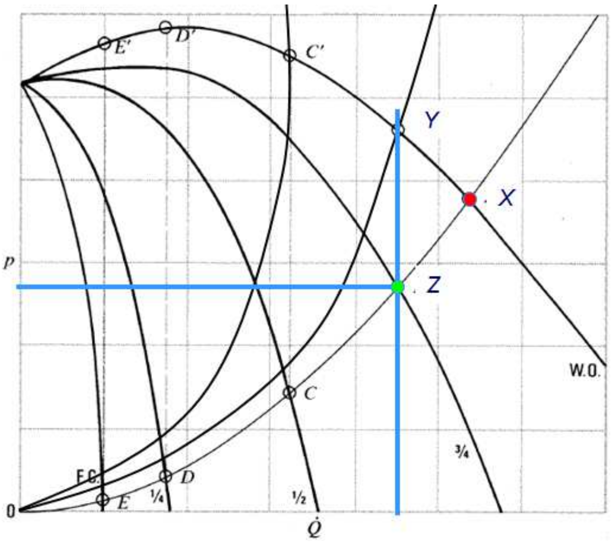
The working point of a fan may be nonetheless modified by varying the fan speed with a variable frequency driver or a hydraulic coupling or by utilising a damper, both at fan inlet or outlet side.



1. Fan regulation devices

This paper will consider only damper regulation, focusing in particular to its effect on fan performance. Figure 1 shows indeed various dampers arrangements that are usually installed on an industrial centrifugal fan. They are divided in two groups: type "A" and type "B" devices, depending on the method they use to modify the performance of the fan.

2. Fan performance, regulation and efficiency



2. Fan performance change in regulation

Figure 2 shows the performance map of a fan with the curves modified by type A and type B devices seen in Fig. 1.

Progressive closure damper curves are plotted ("B" curves), considering the device as a part of the fan, i.e. there is no change in the system resistance, but each position gives a different fan performance curve from the wide open (WO) to fully closed (FC) condition, increasingly depressed as the damper gradually closes.

"A" curves instead change the resistance of the system, moving the operation point along the fan's characteristic curve.

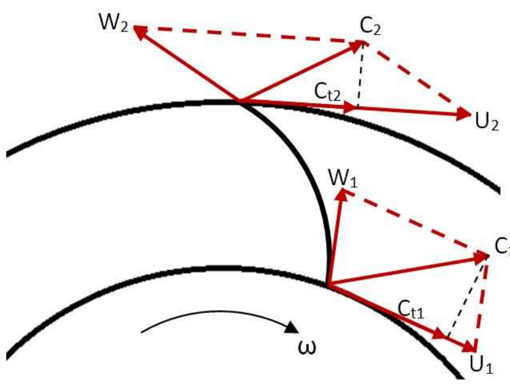
Those considerations apply at both outlet and inlet dampers, but "A" type dampers have only a resistance effect on the aeraulic system, while "B" type dampers may produce also an effect due to the spinning given to the fluid entering the fan.

This inlet whirl, or pre-rotation, can be positive or negative respect to impeller rotation depending on the geometry of the inlet damper and this affects the performance of the fan.

Whirl in the same direction of rotation will reduce absorbed power and developed pressure, while counter-rotating whirl will have opposite effects. This effect is clear by looking at the energy transfer equation (see also figure 2), considering constant flow rate (ṁ) and angular velocity (ω) :

$$\mathrm{Power} = \dot{m}\omega(r_2 C_{t2} - r_1 C_{t1})$$

Since Ct2 (outlet tangential velocity) does not change with the inlet whirl, positive Ct1 (inlet tangential velocity) corresponding to co-rotating whirl will lower Power, while negative Ct1 will increase it. Pre-rotation in the same sense of the impeller rotation has virtually no upper limit in intensity, while counter rotating whirl has practical interest only with small intensities. Indeed high intensity would cause dramatic increase in power absorption against negligible performance increase and thus low efficiency. This is generally not used as regulation of the fan, but to gain some performance with little counter rotating whirl.



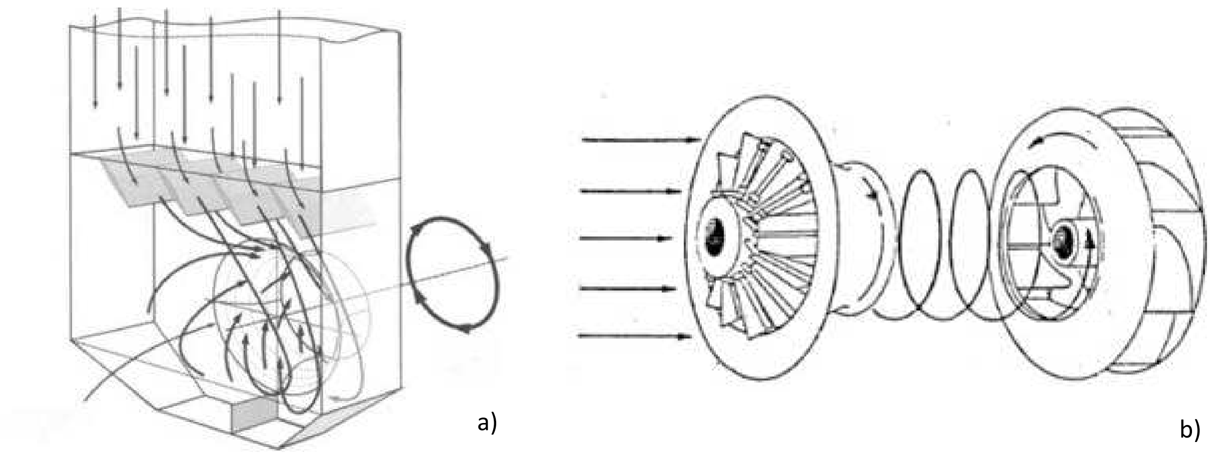
3. Velocity triangles

Velocity components are shown in figure 3, representing Eulerian theory of velocity. Absolute velocity C is the vectorial sum of the peripheral velocity U and relative velocity W, thus composing a triangle that fully characterise the monodimensional aeraulic behaviour of the impeller in term of angles and vector's intensity.

Inlet whirl would indeed modify the velocity triangle at the blade leading edge, changing direction and intensity of C velocity vector and the relative velocity vector W as well.
These pre-rotating whirl cause the airflow to approach the blade with lower angle of attack, causing lower load, pressure and flow rate. Entity of reduction is proportional to the intensity of the whirl and this is most effective when the flow is between 80 and 100 percent of full flow; at lower airflow rates inlet whirl become less efficient.

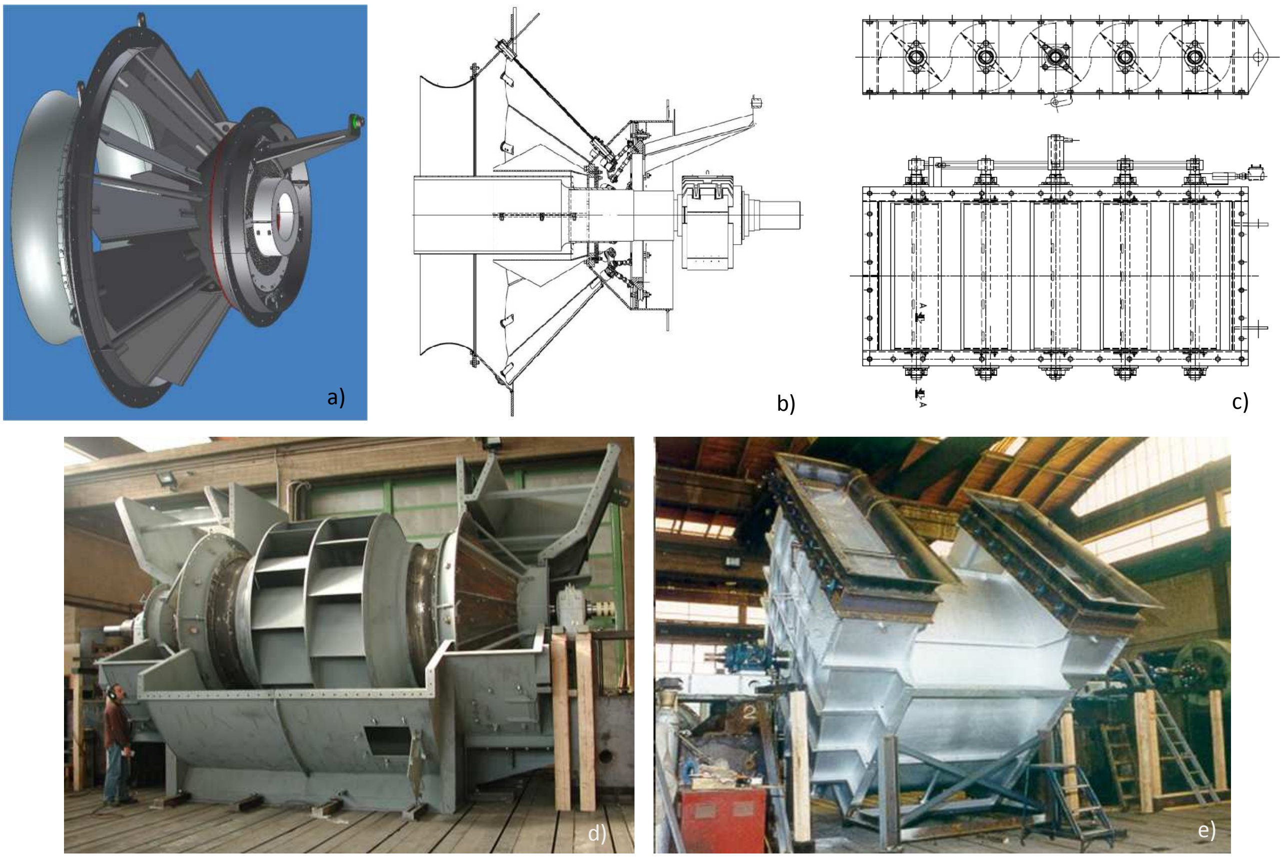
3. IBD AND VIV CHARACTERISTICS AND FIELD OF UTILISATION

To produce inlet whirl both inlet box damper (IBD) and inlet vanes (variable inlet vanes -VIV- or inlet guided vanes -IGV-) can be used and both systems feature the double effect of aeraulic resistance and fluid path modification.
IBD is generally simpler and cheaper, while VIV is more efficient and further affects fan performance and power reduction respect to inlet box dampers. VIV is actually positioned within the inlet bell, thus providing more intense whirl in the very proximity of the impeller.
Figure 4 represents the inlet spin due to IBD and IGV co-rotating with the fan impeller, while figure 5 on shows drawings for the different systems VIV and IBD to highlight the different positioning and constructive features.



4. Inlet box damper whirl (a) and inlet vanes whirl (b)

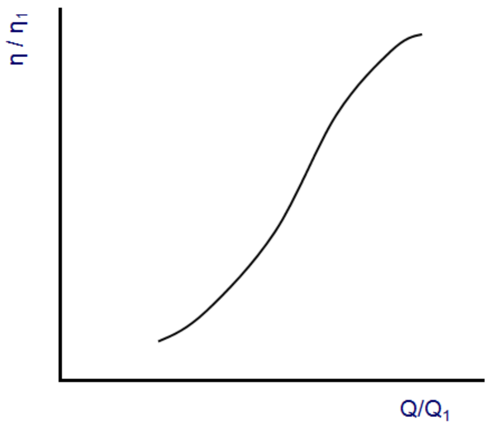
The IBD is generally less efficient than VIV, but features way easier maintenance since the bearings are placed outside the flow of the fan, so it is suggested when the flow is dirty if the efficiency is not the main parameter to be considered.
VIV on the other hand has very high efficiency, but it is a delicate device with difficult maintenance, since the bearings are within the flow of the fan. It is indeed suggested for clean flow application, or anywhere high efficiency is demanded, e.g. ID fans on power station boilers where is not acceptable to have low efficiency.



5. Variable inlet vanes (a,b,d) and Inlet Box Damper (c,e) drawings and pictures

3. Fan shaft power change with throttling devices

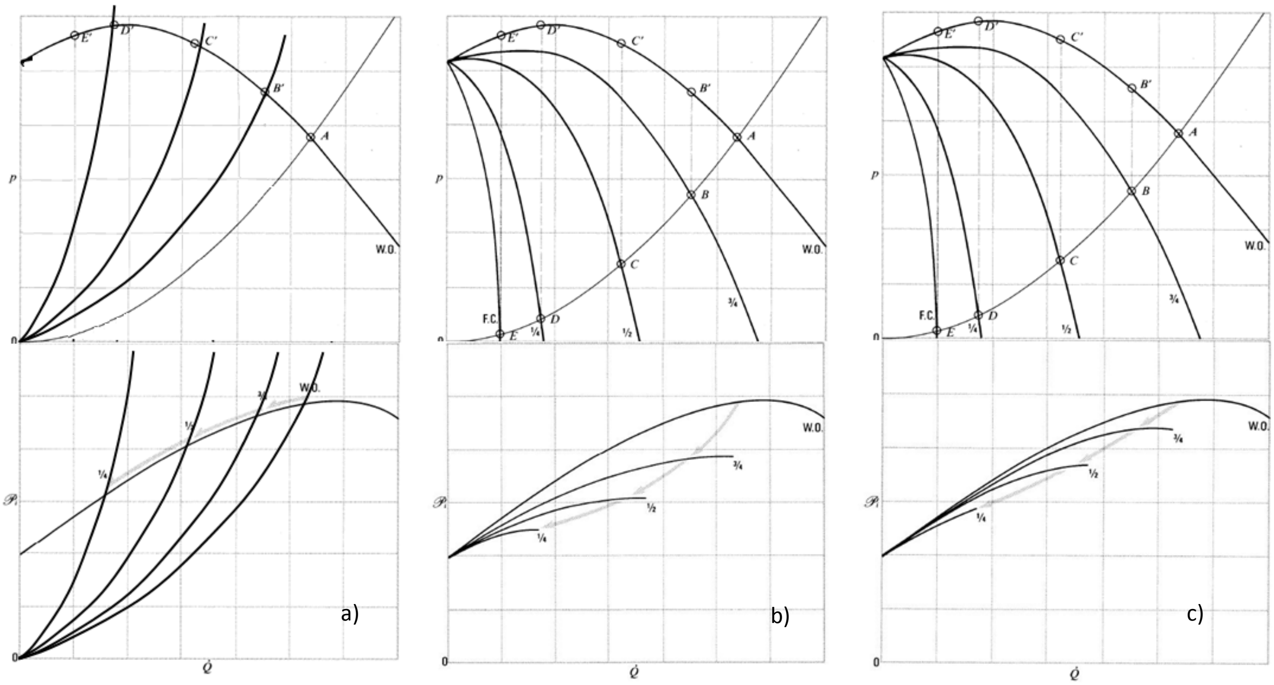
Figure 6 shows the qualitative curve representing the decrease of efficiency with the decrease of capacity in regulation. This typically S-shaped curve justifies all the following consideration on the shaft power reduction in regulation.



6. Curve of efficiency decrease in regulation

The curve of power reduction for "A" type devices is plotted in figure 7a showing the power reduction curve together with the performance curve of the fan , where less power is required as the damper position is changed from wide-open to 3/4, and still less at the 1/2 and 1/4 positions.

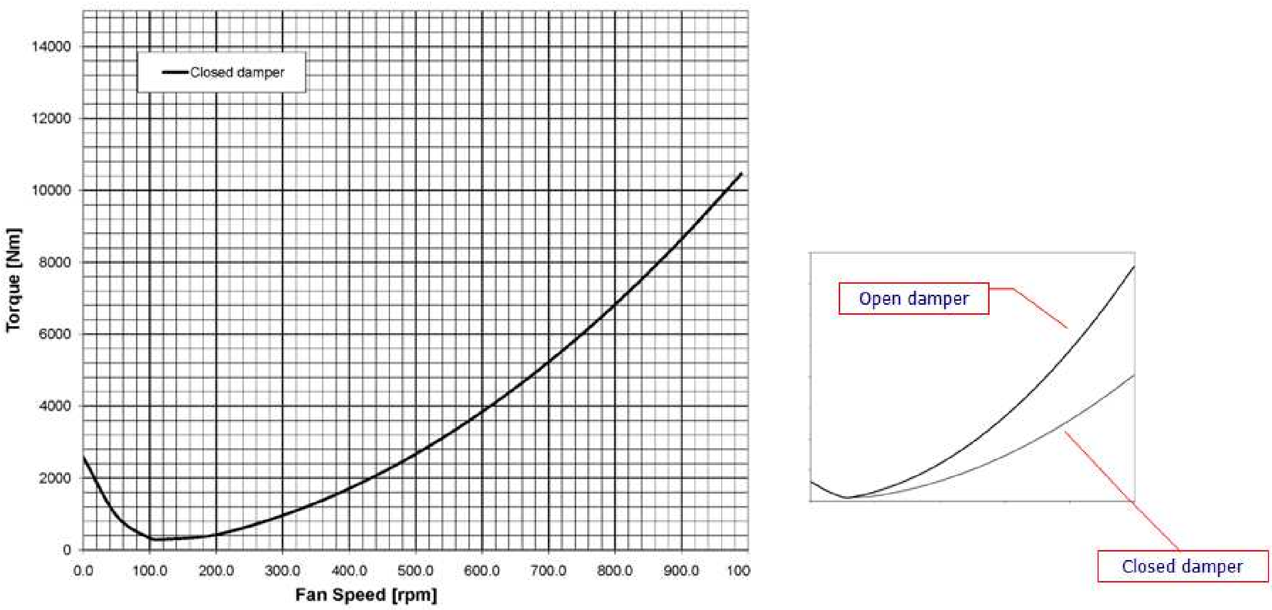
However systems featuring "B" type devices. i.e. IBD and even more VIV, allow higher effectiveness in power saving. This is evident looking at figure 7b and 7c, showing IBD and VIV performance curves and flow rate-power curve change according to damper closure. They are qualitative curves but one can note that the VIV ones are significantly more shifted than IBD ones.



7. A type regulation device (a), Variable Inlet Vanes (b) and Inlet Box Damper (c) power reduction

This behaviour is important not only during regulation, but also at the start-up of the fan. Indeed, since low power is absorbed with closed throttling device, it is advisable to start the fan in this configuration and successively open it to the required operation point.

Figure 8 shows a typical start-up torque curve and a qualitative indication of how it changes with open or closed damper.



8. Start-up curve with closed or open throttling device

4. TROUBLESHOOTING

This paper illustrates how an inlet damper system affects the performance of a fan. It is an effective method of regulation, but if not correctly installed and utilised it may cause the fan to work in non optimal conditions and therefore impair the whole fan performance.

Here is provided a sort of troubleshooting to identify the most common problems related to damper regulation. Please note that for every symptom there could be a number of other possible causes not directly depending on dampers, but they are not considered here.

Symptom	Possible Cause	Action suggested
Low flow with low pressure and low power	Undesired inlet whirl co-rotating with the impeller	Redesign inlet ducts avoiding elbows near the fan
Low flow with high pressure and low power	Damper closed	Open the damper until required condition is reached
High flow with high pressure and high power	Inlet whirl counter-rotating respect to the impeller	Install the damper backward
Negligible performance enhancement with co-rotating whirl	Inlet box damper too far from fan inlet (weak whirl)	Re-design inlet box geometry or change from IBD to VIV
Noise, unstable fan operation	Damper too closed (fan stall due to flow separation from blade, flow too low)	Open the damper until required condition is reached
Motor overload	Damper too much open (too low system resistance)	Close the damper until required condition is reached
Temperature increase in the fan	Damper closed for too long time	Open the damper to allow cooling flow in the fan

5. REFERENCES

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