SHAPA TECHNICAL PAPER 20

Controlling Fans with Variable Loads

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Introduction

Fans are often required to operate over a wide range of load conditions.

For example, many industrial ventilation systems see variable loads due to changes in ambient conditions, occupancy of halls, theatres etc., day/night operation and seasonal changes.

In many industrial applications, fans are often used directly to support production (material handling) or to maintain comfortable or safe working conditions (ventilation). In many cases the fan duty requirements may vary with load or ventilation requirements. It is possible that fans will operate at part load duties for long periods.

Fans are usually sized to handle the largest expected operating or peak condition. Considering this, normal operating duties are often well below these design conditions.

It must also be understood that system designers often add a safety factor on system pressure calculations. This duty requirement with the added safety factor will be used by the fan supplier to select a suitable fan at its peak efficiency. If subsequently the fan does not operate at this point the fan will be over performing & working at a position on its characteristic away from peak efficiency.

Consequently, the combination of extended operating times at part loads & the tendency to oversize the fan creates a need for efficient flow control.

This paper considers various forms of flow control devices. Each method has advantages & drawbacks in terms of initial costs, control effectiveness & control efficiency.

This paper considers the four principal methods of flow control for centrifugal fans:-

- **A) Discharge Damper Control.**
- **B) Inlet Vane Control.**
- **C) Inlet Box Damper Control.**
- **D) Speed Control.**

In addition to the above it also considers **Blade Pitch Adjustment** on Axial Flow Fans.

A) Discharge Dampers

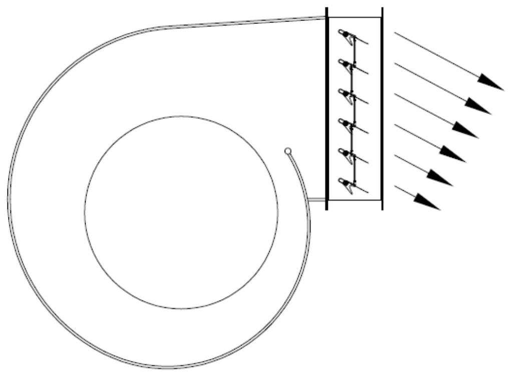
Firstly, as the name suggests these should only be fitted on the fan discharge. Fitting this form of damper directly to the inlet of the fan will seriously affect its performance & aerodynamic stability possibly leading to premature failure.

These will take the form of flat or aerofoil vanes located in a separate section on the fan discharge. Vane operation will be parallel bladed or opposed bladed depending on the fan discharge ducting configuration.

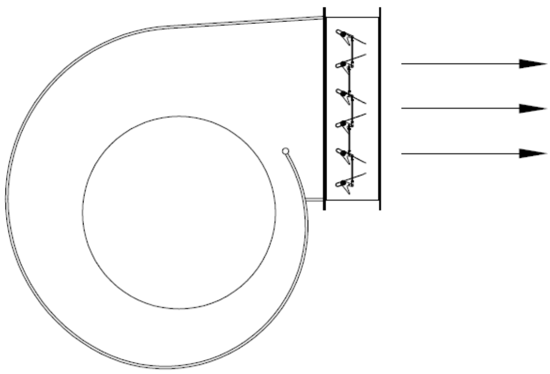
Operation can be manual via linkages & lever, or power operated via linkages & an actuator. The actuators are usually pneumatic, electric or electro-pneumatic.

The sketch below shows examples of parallel versus opposed blade.

The parallel bladed damper illustrates the airflow being diverted downwards, this is ideal for fan discharges fitted with a bend. The vane direction would depend on the bend direction. The opposed blade damper illustrates non-diverting flow which is ideal for straight discharge duct configurations.



PARALLEL BLADED DAMPER
ILLUSTRATING DIVERTED FLOW



OPPOSED BLADED DAMPER
ILLUSTRATING NON-DIVERTING FLOW

Discharge Damper Operation

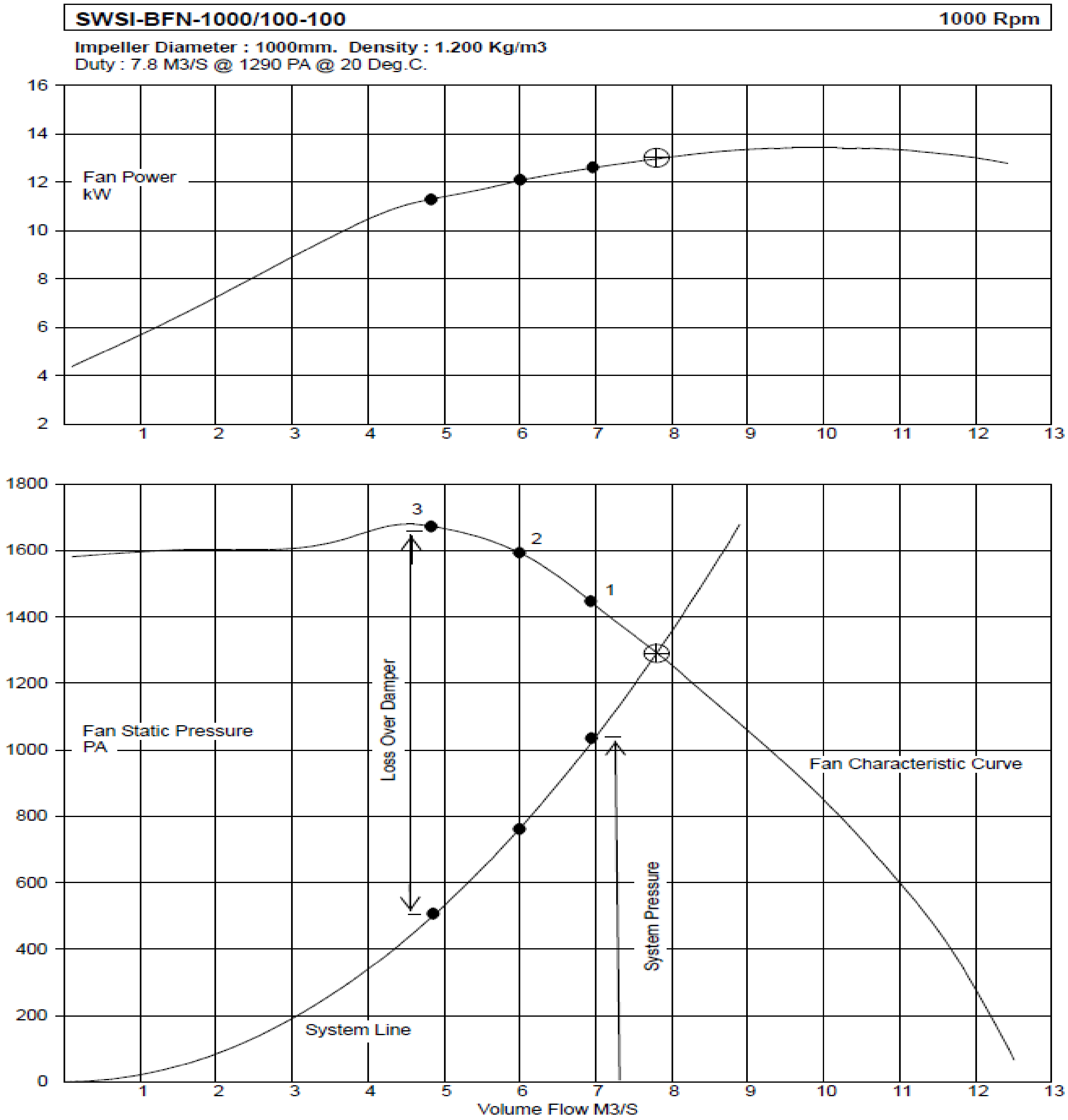
Discharge dampers provide flow control by increasing the pressure resistance in the airflow path. As the damper closes it increases the pressure on the discharge side of the fan hence reducing the flow rate.

By increasing the system resistance the damper the fan to work against a back pressure & shifts the operating to the left along its performance curve. If the fan had been selected at peak efficiency it will have the effect of moving the operating point away from the peak efficiency point.

The performance curve below shows a centrifugal fan operating at a duty of $7.8m^3/s$ at 1290 Pa. along with a system line.

As the damper closes, the operating point will move to position 1, 2, 3 & eventually to full shut off when the damper is closed. It can be seen that the pressure below the system line is the pressure available to satisfy the system & the pressure above is the pressure loss over the damper.

It can also be seen that the fan power absorbed runs along the fully open power characteristic.



SWSI-BFN-1000/100-100
1000 Rpm
Impeller Diameter : 1000mm. Density : 1.200 Kg/m3
Duty : 7.8 M3/S @ 1290 PA @ 20 Deg.C.
Fan Power
kW
Fan Static Pressure
PA
Loss Over Damper
System Pressure
Fan Characteristic Curve
System Line
Volume Flow M3/S

Discharge Dampers. Advantages / Disadvantages

Advantages

- Cheaper initial cost compared with inlet vanes
- Simple operating mechanism.
- Possible airflow advantages when used correctly with a discharge bend.

Disadvantages

- Less efficient compared with other forms of flow control.
- Increased operating costs compared with other methods.
- Possible aerodynamic instability problems if inappropriate vane configuration is used.

B) Inlet Vanes

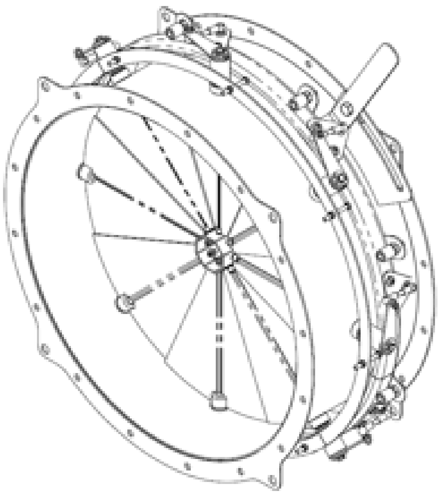
Inlet vanes are most effective on centrifugal fans with high flow rate, wide backward bladed impellers. It is ideal where pressure rises considerably above the duty condition, the power is non-overloading and the inlet velocity is such a magnitude that they can be suitably affected.

These take the form of flat or aerofoil radial blades located at the inlet to a fan. They can be fitted into either a separate casing Barrel type) or directly into the fan inlet cone. The vanes will be configured to direct the flow in the same direction as the impeller rotation.

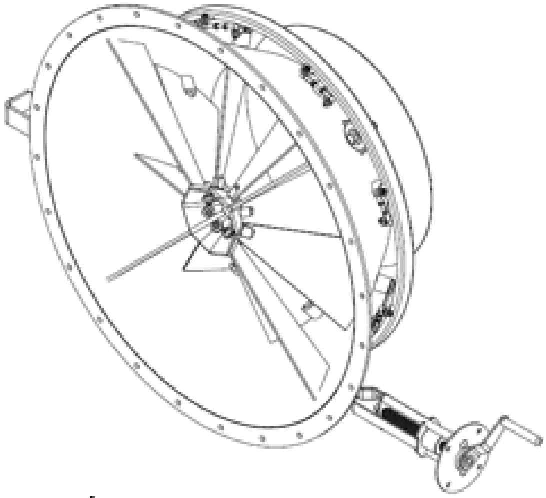
Operation can be manual via a linkages & lever or power operated via linkages & an actuator. The actuators are usually pneumatic, electric or electro-pneumatic. The sketch below shows examples Barrel type & Inlet Cone type Inlet Vanes.

It can be seen that the linkage mechanism on the barrel type is located on the outside of the casing & is accessible for operation & maintenance. The Inlet Cone type mechanism is on the outside of the inlet cone which is effectively inside the fan. The operating mechanism needs to be extended to outside the casing to effect operation.

For maintenance the whole arrangement will require removing from the fan. On normal temperature applications the vanes are usually connected to a central support boss. On high temperature applications the vanes are cantilevered from a double bearing support arrangement on the outside. On inlet cone vanes, due to the closer proximity of vanes to impeller, the control is more effective; however, due to the increased velocity over the vanes the pressure loss is greater than barrel type.



Barrel type cased IVC



Inlet cone type IVC

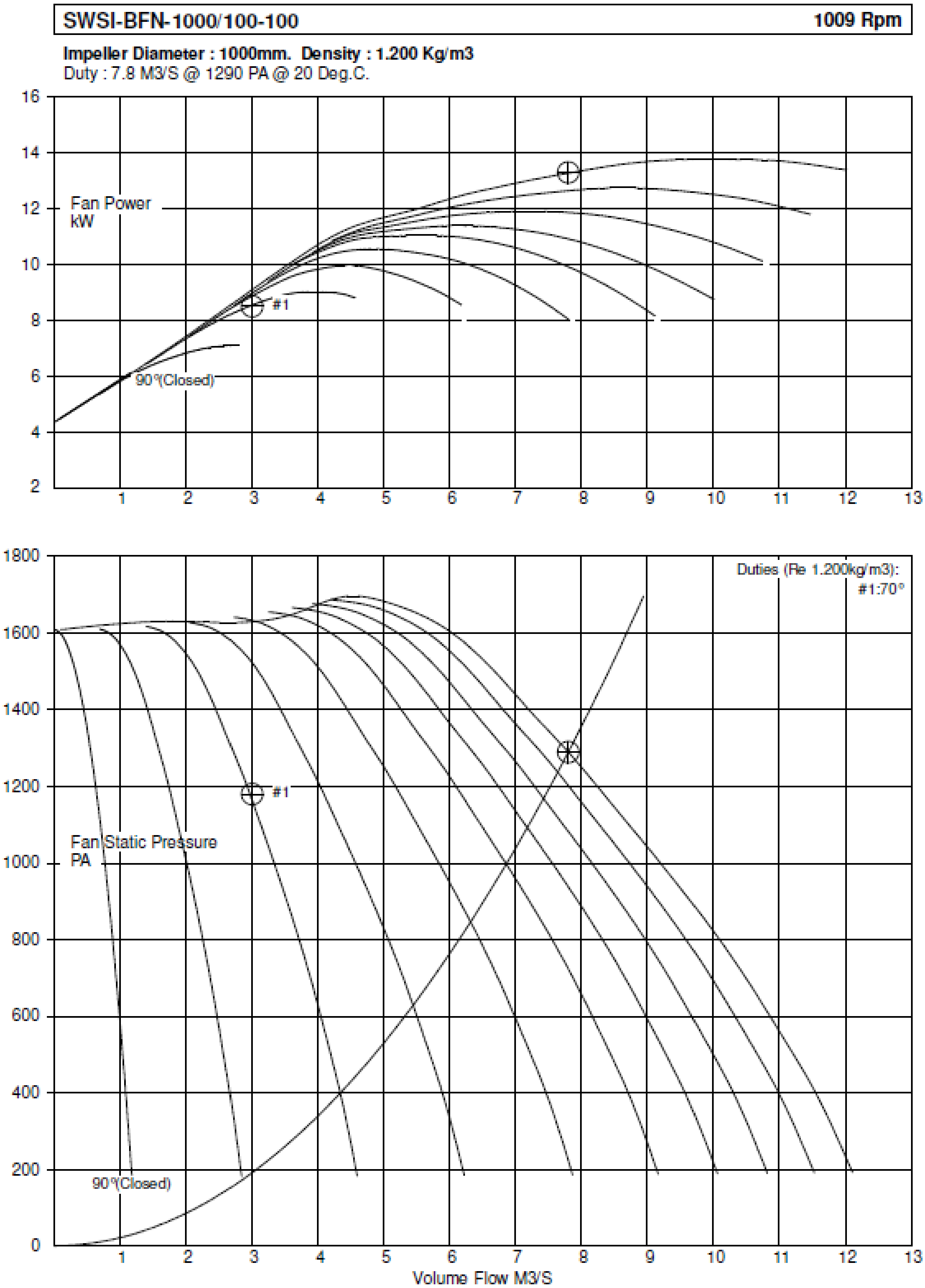
Inlet Vane Operation

Inlet vanes change the profile of an airstream entering a fan inlet. Inlet vanes create a swirl that rotates in the same direction as the fan impeller. This pre-rotating swirl lessens the angle of attack between the incoming air and the fan blades, which lowers the load on the fan and reduces fan pressure and airflow.

By changing the severity of the inlet swirl, inlet vanes essentially change the fan performance characteristic curve. The fan efficiency will be substantially maintained therefore the power consumption can be considerably reduced with lowering fan flow rate.

The performance curve below shows a centrifugal fan operating at a duty of 7.8m³/s at 1290 Pa. along with a system line. It can be seen that as the inlet vanes close from fully open (0˚) to 10˚, 20˚, 30˚ etc a separate flow rate / pressure characteristic along with flow rate / power characteristic is formed.

It can be seen that inlet vane control is also effective when other required duty points are away from the maximum duty point system. For example a duty point of 3.0 m³/s @ 1180 Pa is shown. This is available at a vane angle of 70˚ with a power absorbed of 8.5 Kw. This duty would be on an unstable section of the characteristic if control by speed control was used.


SWSI-BFN-1000/100-100
1009 Rpm
Impeller Diameter : 1000mm. Density : 1.200 Kg/m3
Duty : 7.8 M3/S @ 1290 PA @ 20 Deg.C.
Fan Power
kW
#1
90°(Closed)
Duties (Re 1.200kg/m3):
#1:70°
Fan Static Pressure
PA
Volume Flow M3/S

Inlet Vanes Advantages / Disadvantages

Advantages

- More efficient than discharge dampers.
- Savings on operating costs.
- Improvement in high turndown load stability, especially when used in conjunction with speed control.

Disadvantages

- More complicated operating mechanism, especially when vanes are located in the inlet cone.
- Higher pressure loss, especially when vanes are located in the inlet cone.

C) Inlet box damper control.

When a centrifugal fan is fitted with an inlet box for side entry, it is possible to fit a set of damper blades at the entry to the box.

These take the form of flat or aerofoil vanes and are usually fitted in a separate casing which is positioned at the entry to fan inlet box.

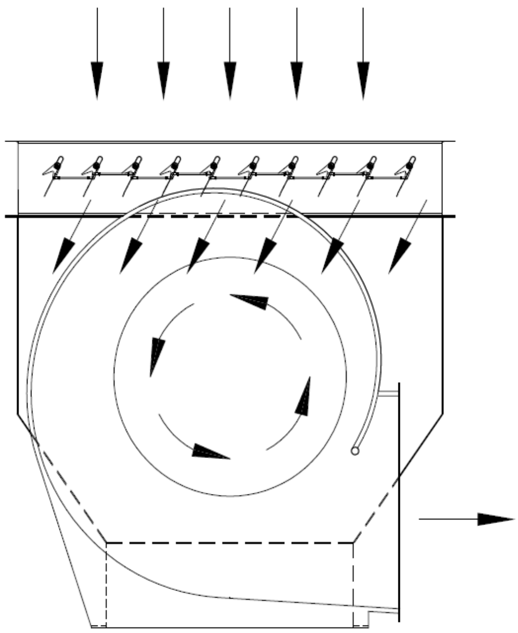
For efficient control it is normal for the vanes to be configured to create swirl in the direction of impeller rotation. This will give control similar to inlet vanes but not quite as efficient.

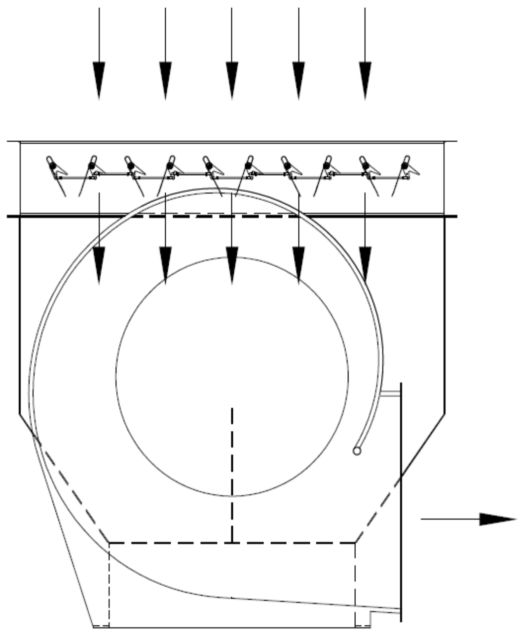
In some instances inlet box dampers are fitted with opposed blades. In this case flow control will be the same as normal control as discussed in section A).

The sketches below show examples of parallel operation were the vanes are oriented to create swirl in the direction of impeller rotation and blades with opposed blades which act as a simple damper operation.

It will be noted that an inlet box splitter is required for this method to ensure that swirl cannot be initiated.

Sketches showing parallel & opposed blades with air circulation lines.





Inlet Box Damper Operation

Similar to inlet vanes, inlet box dampers change the profile of an airstream entering a fan inlet. They create swirl that rotates in the same direction as the fan impeller. This swirl lessens the angle of attack between the incoming air and the fan blades which lowers the load on the fan which reduces fan pressure and air flow.

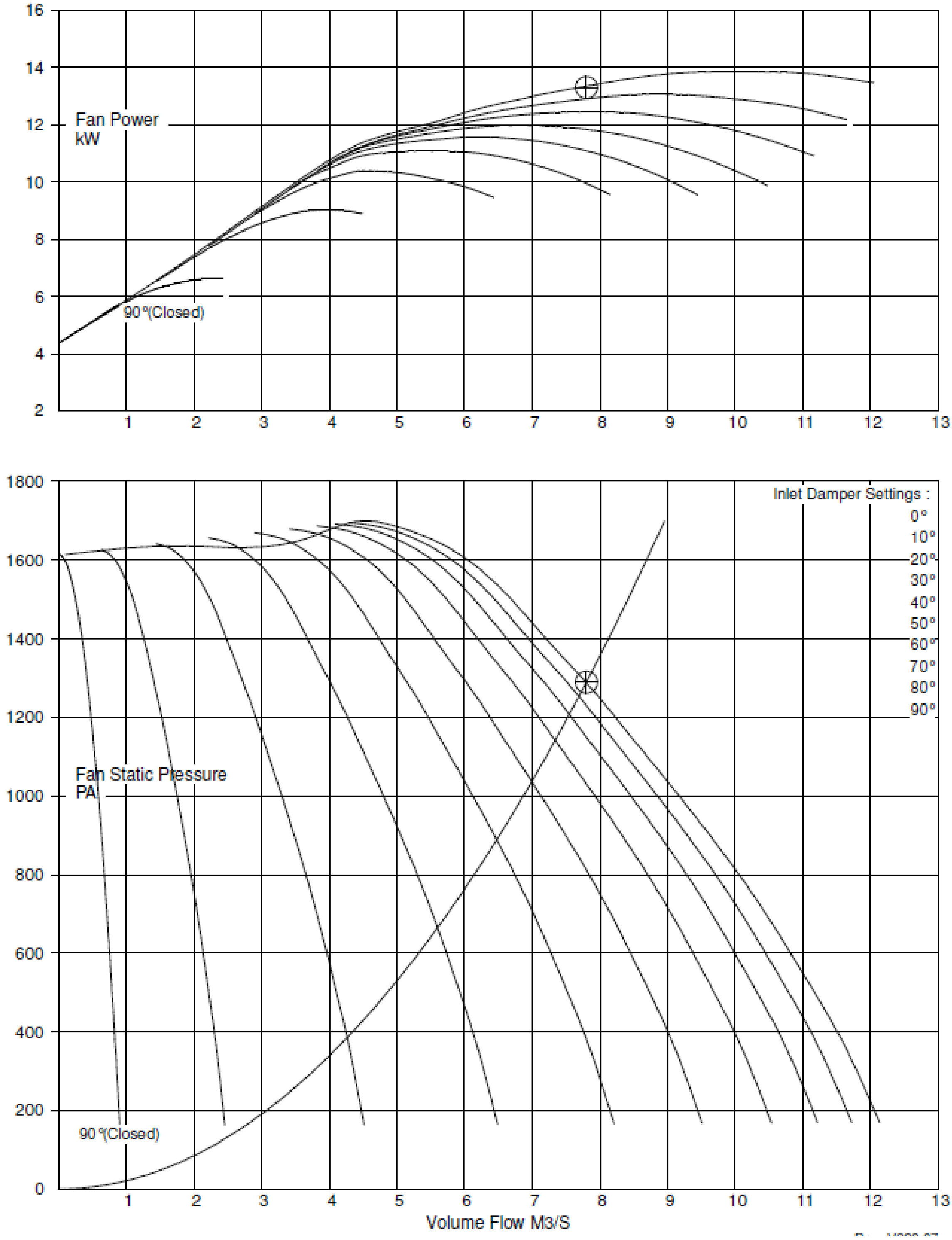
By changing the inlet swirl, inlet box dampers essentially change the fan characteristic curve. This reduction in performance is also associated with a reduction in fan power and creates a new reduced power characteristic. Due to the distance between the vanes and the fan inlet the swirl is less severe than the swirl created by inlet vanes, hence the control less effective and efficient.

Depending on the inlet box cross sectional area and aspect ratio, the most effective control is achieved by varying the size and number of vanes.

The performance curve below again shows a centrifugal fan operating at a duty of 7.8m³/s at 1290 Pa along with a system line. Control is similar to Inlet Vanes but it can be seen that for a particular part load, the corresponding power absorbed is greater than the Inlet Vane.

SWSI-BFN-1000/100-100 **1011 Rpm**

Impeller Diameter : 1000mm. Density : 1.200 Kg/m3
Duty : 7.8 M3/S @ 1290 PA @ 20 Deg.C.



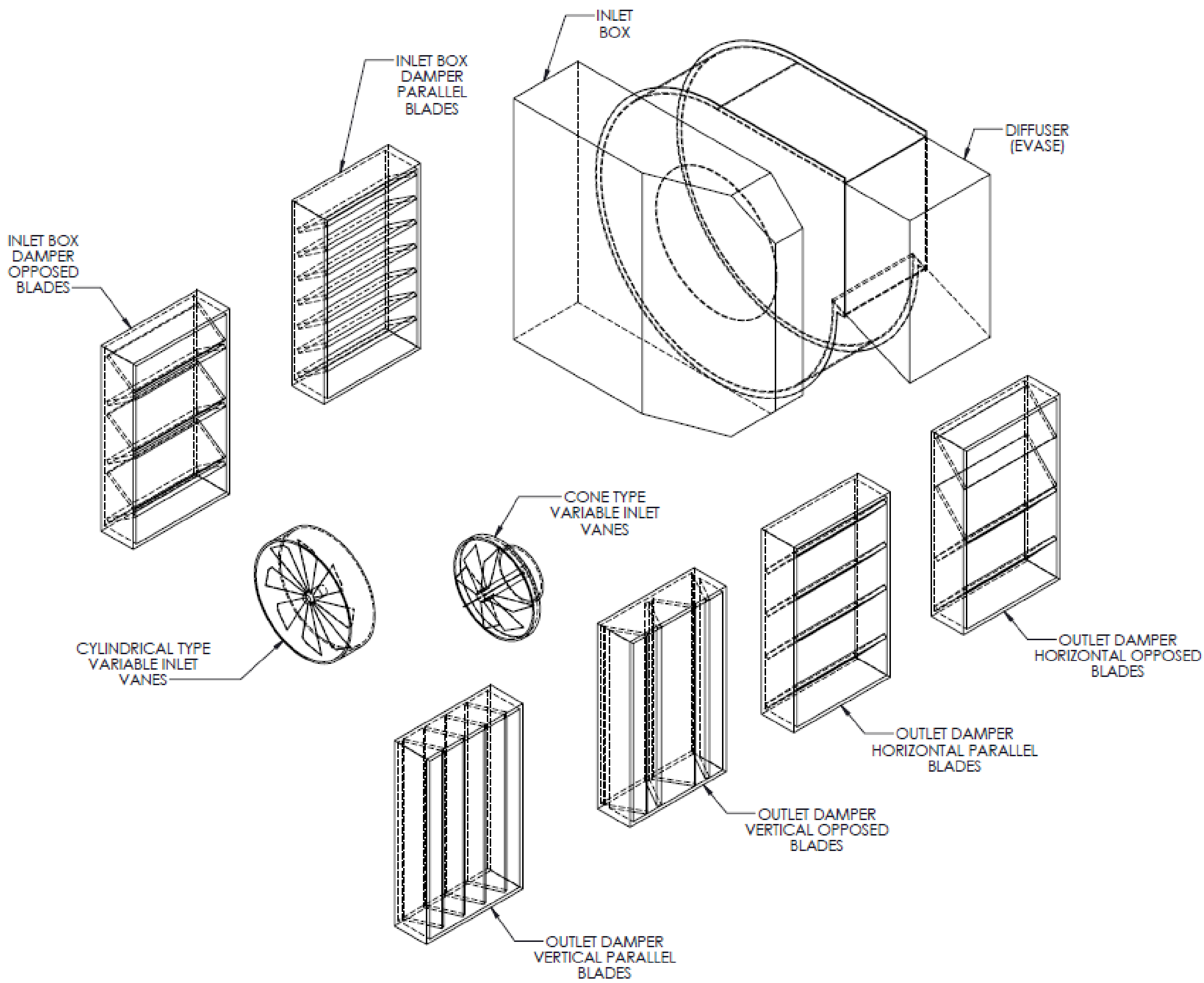
Inlet Box Damper Advantages / Disadvantages

Advantages

- More efficient than discharge dampers.
- Savings on operating costs over discharge dampers.
- Improvement in high turndown load stability, especially when used in conjunction with speed control.
- Reduced pressure loss when compared with inlet vanes.

Disadvantages

- Due to size the initial costs will be greater than discharge dampers.
- Due to reduced swirl intensity the control efficiency is not as good as inlet vanes.



The sketch above shows the combination of flow control hardware for centrifugal fans.

D) Speed Control

Fan speed control provides the most efficient method of flow control.
Suitable prime movers for variable speed drives include the following:-

- AC Electric Induction Motors with Inverter Drives.
- Multi Speed AC Motors.
- Slip ring and commutator type AC Motors.
- DC Electric Motors.
- V Belt drives with AC Motors.
- Steam Turbines.

Varying fan speed effectively creates a completely new fan characteristic in respect to flow rate / Fan Pressure and Fan Power Absorbed.
So long as the fan system remains constant, the fan efficiency for the original selection will generally be maintained through the speed range.
To understand its operation we have to understand the "Fans Laws" in respect to speed change.
"Fan Laws" : The fan laws are the basic proportional relationships between fan speed Impeller diameter, flow rate, pressure and fan power absorbed. They are used for determining fan performance from a known fan performance to a desired fan performance. They only apply for like types were size change is truly geometric.

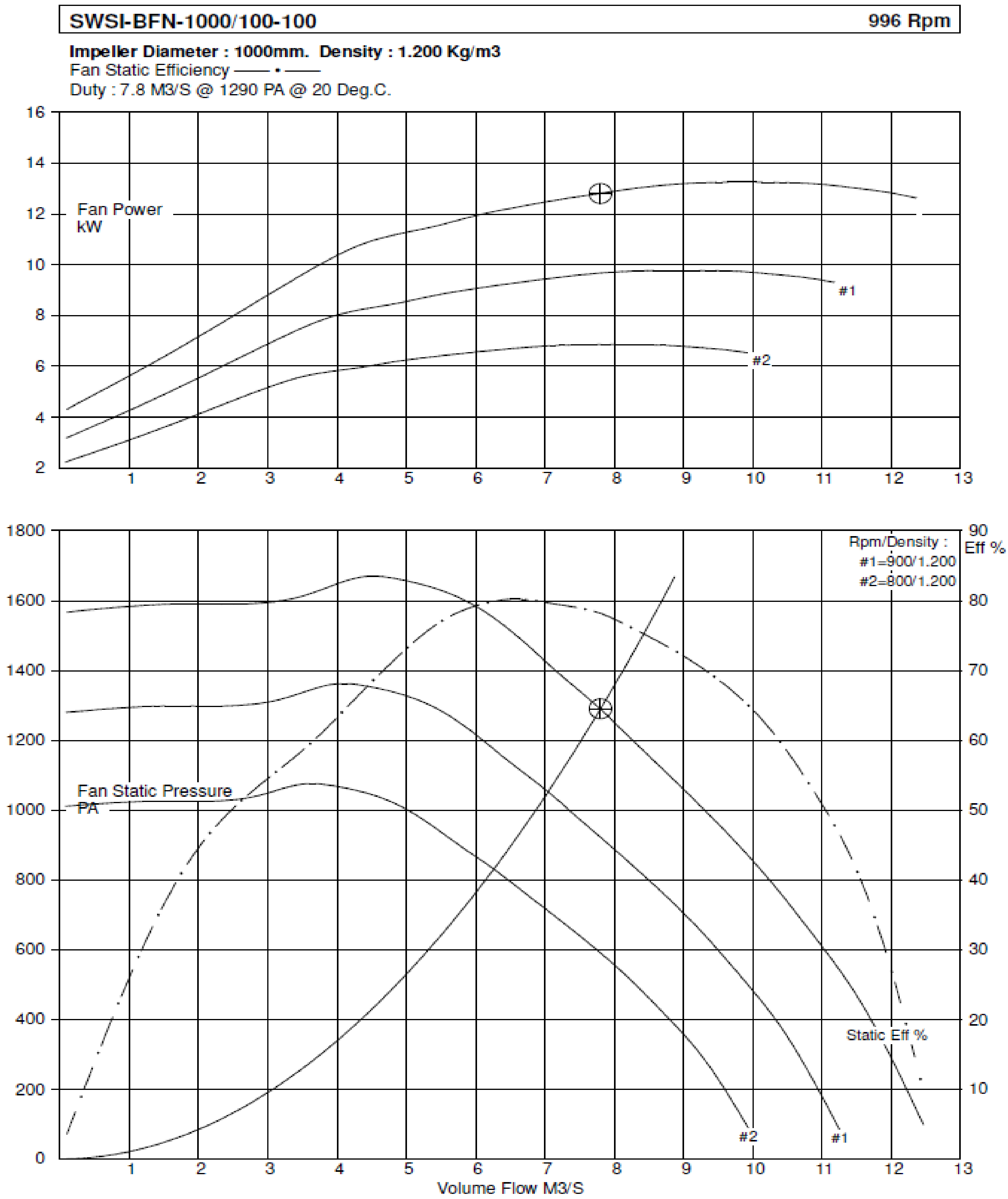
Flow Rate (Q) varies **directly** as the speed ratio.
$\mathbf{Q_2}$ (m^3/s) = (RPM_2 / RPM_1) x $\mathbf{Q_1}$ (m^3/s).

Pressure (P) varies as the **square** of the speed ratio.
$\mathbf{P_2}$ (Pa) = (RPM_2 / RPM_1)^2 x $\mathbf{P_1}$ (Pa).

Power (PA) varies as the **cube** of the speed ratio.
$\mathbf{PA_2}$ (kW) = (RPM_2 / RPM_1)^3 x $\mathbf{PA_1}$ (kW).

The performance curve below again shows a centrifugal fan operating at a duty of $7.8m^3/s$ at 1290 Pa. along with a system line. The operating speed to achieve this duty is 996 RPM and the associated fan efficiency is approx. 78%. Also drawn are reduced speed performance characteristics for 900 RPM and 800 RPM. These characteristics are calculated in accordance with the above rules.

By following the system line from one characteristic to another it can be seen that the line crosses the characteristic at the same relative position, therefore the corresponding efficiency is maintained at each point.



SWSI-BFN-1000/100-100
996 Rpm
Impeller Diameter : 1000mm. Density : 1.200 Kg/m3
Fan Static Efficiency
Duty : 7.8 M3/S @ 1290 PA @ 20 Deg.C.
Fan Power kW
#1
#2
Rpm/Density :
#1=900/1.200
#2=800/1.200
Eff %
Fan Static Pressure PA
Static Eff %
Volume Flow M3/S

Speed Control. Advantages / Disadvantages

Advantages

- Most efficient method of flow control.
- Savings on operation costs.
- The cost of inverter drives have reduced in recent years.
- Programmable operation when use with an inverter.

Disadvantages

- Possible problems with fan over speeding. (If speed control is variable, a maximum speed must be determined and built into the operating system).
- Possible problems with resonant frequencies at certain speeds. (It is the responsibility of the fan manufacturer to guarantee that the fan is stable at the maximum speed and any other specified duty speeds when operated on the supplied mounting structure. It is possible that the foundation or mounting structure has a resonant frequency within the running range of the fan. It is important that fan is not operated for extended periods in this condition).
- Limitations on high turn down loads that are off system.

Blade Pitch Adjustment on Axial Flow Fans

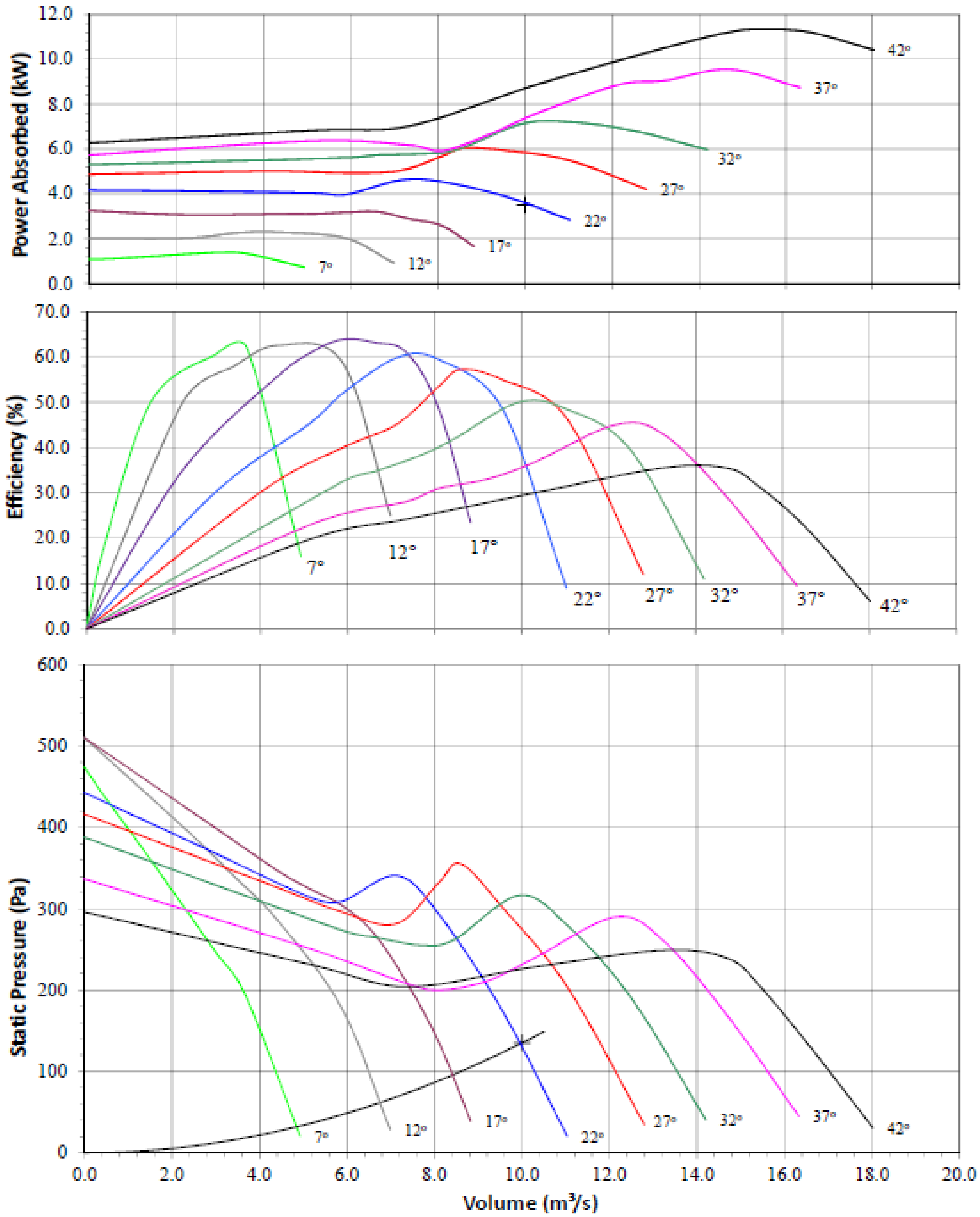
An option with some types of axial flow fans is the incorporation of variable pitch feature for the fan blades. Variable pitch fans allow the fan blades to tilt, changing the angle of attack between the incoming airflow and the blade.

Reducing the angle of attack reduces both the airflow and the fan power absorbed. Consequently the use of variable pitch fans offer the possibility of a large operational envelope with a small reduction in peak efficiency.

Blade adjustment is usually manual which requires the impeller removal from the fan casing. An alternative method of pitch adjustment in motion is possible but this is a very expensive option and is usually limited to high power fans in power generation, mining or tunnelling industries.

The performance curve below shows typical characteristics for a 1000mm diameter fan running at 1000 RPM. The blade settings vary from 7˚ to 42˚. These refer to the blade angle at the tip of the blade. It can be seen that a wide range of duties are available from a single size and speed fan. From the performance it can be seen that high peak efficiencies are maintained over a range of 7˚ to 27˚ with efficiencies falling away after that. It can also be seen that the lower blade angles (7˚ to 17˚) offer stall free operation.

When selecting direct drive (impeller on motor shaft) fans with large pitch angles and corresponding large fan powers, care must be taken to ensure that the required motor fits within the selected fan casing. To avoid pressure losses associated with blade shading by the motor carcass, it is usual to select a rotor with a hub diameter equal or greater than the motor carcass diameter.



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