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Analysis and Optimization of Centrifugal Blower Using CFD

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ABSTRACT: Centrifugal blowers play an important role in many industries. This project presents a design methodology to examine various parameters of the centrifugal blower using computational fluid dynamics approach and Finite Element Analysis concept. The effects of blower geometry, blower speed, impeller geometry, and blade design and fillet radius have been assessed. Total discharge and blower total efficiency are the output parameters calculated.

The blower is modelled using Pro-E and after simplification the modelled blower is meshed in Gambit CFD. The solution is obtained using FLUENT. The post processing is carried out using ANSYS and the results are presented and discussed in detail. Based upon the ANSYS results once again blower parameters are changed and examined. Finally the optimum values of the parameters are obtained. These obtained values need to be implemented into the design for better performance of the blower.

KEY WORDS: Centrifugal blower, Computational Fluid Dynamics (CFD), Optimization.

I. INTRODUCTION

A centrifugal blower is a mechanical device for moving air or other gases. The terms "blower" and "squirrel cage fan" (because it looks like a hamster wheel) are frequently used as synonyms. These fans increase the speed of air stream with the rotating impellers. They use the kinetic energy of the impellers or the rotating blade to increase the pressure of the air/gas stream which in turn moves them against the resistance caused by ducts, dampers and other components. Centrifugal blowers accelerate air radially, changing the direction (typically by 90o) of the airflow. They are sturdy, quiet, reliable, and capable of operating over a wide range of conditions. Centrifugal blowers are constant CFM devices or constant volume devices, meaning that, at a constant fan speed, a centrifugal fan will pump a constant volume of air rather than a constant mass. This means that the air velocity in a system is fixed even though mass flow rate through the fan is not. The centrifugal blower is one of the most widely used fans. Centrifugal blowers are by far the most prevalent type of fan used in the HVAC industry today. They are usually cheaper than axial fans and simpler in construction. It is used in transporting gas or materials and in ventilation system for buildings. They are also used commonly in central heating/cooling systems. They are also well-suited for industrial processes and air pollution control systems. It has a blower wheel composed of a number of blower blades, or ribs, mounted around a hub. The hub turns on a driveshaft that passes through the blower housing. The gas enters from the side of the fan wheel, turns 90 degrees and accelerates due to centrifugal force as it flows over the fan blades and exits the blower housing.

1.1 Components of Centrifugal Blower:

Main parts of a centrifugal blower are:
1. Blower Housing
2. Impeller or Fan Wheel
3. Inlet and outlet ducts
4. Drive Shaft
5. Drive mechanism

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Other components used may include bearings, couplings, impeller locking device, fan discharge casing, shaft seal plates etc.

1.2 Types of drive mechanisms:

The blower drive determines the speed of the fan wheel (impeller) and the extent to which this speed can be varied. There are three basic types of fan drives.

1.2.1 Direct drive:

The fan wheel can be linked directly to the shaft of an electric motor. This means that the fan wheel speed is identical to the motor's rotational speed. With this type of fan drive mechanism, the fan speed cannot be varied unless the motor speed is adjustable. Air conditioning will then automatically provide faster speed because colder air is denser.

Some electronics manufacturers have made centrifugal fans with external rotor motors (the stator is inside the rotor), and the rotor is directly mounted on the fan wheel (impeller).

1.2.2 Belt drive:

A set of sheaves are mounted on the motor shaft and the fan wheel shaft, and a belt transmits the mechanical energy from the motor to the fan. The fan wheel speed depends upon the ratio of the diameter of the motor sheave to the diameter of the fan wheel sheave and can be obtained from this equation:

Chain drive fans are not common due to their complex workup, high maintenance, noisiness, and speed and flexibility limitations which prevents them from being operated at high speeds, but they are much more durable, require less operating space, have a cheaper initial and installation cost, don't slip, and are resistant towards many hostile environments. They can be just as efficient as belt drive; however, both will require tensioning. Where,

rpmfan = Fan wheel speed, revolutions per minute

rpmmotor = Motor speed, revolutions per minute

Dmotor = Diameter of motor sheave

Dfan = Diameter of fan wheel sheave

Fan wheel speeds in belt-driven fans are fixed unless the belt(s) slip. Belt slippage can reduce the fan wheel speed by several hundred revolutions per minute (rpm).

1.2.3 Variable drive:

Variable drive fans use hydraulic or Magnetic couplings (between the fan wheel shaft and the motor shaft) that allow r speed. The fan speed controls are often integrated into automated systems to maintain the desired fan wheel speed.

An alternate method of varying the fan speed is by use of an electronic variable-speed drive which controls the speed of the motor driving the fan. This offers better overall energy efficiency at reduced speeds than mechanical couplings.

1.3 Bearings:

Bearings are an important part of a fan. Sleeve-ring oil bearings are used extensively in fans. Some sleeve-ring bearings may be water-cooled. Water-cooled sleeve bearings are used when hot gases are being moved by the fan. Heat is conducted through the shaft and into the oil which must be cooled to prevent overheating of the bearing.

Since lower-speed fans have bearings in hard-to-reach spots, grease-packed anti-friction bearings are used.

1.4 Fan dampers and Vanes:

Fan dampers are used to control gas flow into and out of the centrifugal fan. They may be installed on the inlet side or on the outlet side of the fan, or both. Dampers on the outlet side impose a flow resistance that is used to control gas flow. Dampers on the inlet side (inlet vanes) are designed to control gas flow by changing the amount of gas or air admitted to the fan inlet.

Inlet dampers (Inlet vanes) reduce fan energy usage due to their ability to affect the airflow pattern into the fan.

1.5 Fan ribs:

The fan wheel consists of a hub on which a number of fan blades are attached. The fan blades on the hub can be arranged in three different ways: forward-curved, backward-curved or radial. 7

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1.5.1 Forward-curved blades:
Forward-curved blades, as in Figure 1.3(a), curve in the direction of the fan wheel's rotation. These are especially sensitive to particulates. Forward-curved blades provide a low noise level and relatively small air flow with a high increase in static pressure.

1.5.2 Backward-curved blades:
Backward-curved blades, as in Figure 1.3(b), curve against the direction of the fan wheel's rotation. Smaller blowers may have backward-inclined blades, which are straight, not curved. Larger backward-inclined/-curved blowers have blades whose backward curvatures mimic that of an airfoil cross section, but both designs provide good operating efficiency with relatively economical construction techniques. These types of blowers are designed to handle gas streams with low to moderate particulate loadings. They can be easily fitted with wear protection but certain blade curvatures can be prone to solids build-up. Backward curved wheels are often lighter than corresponding forward-curved equivalents, as they don't require so many blades.
Backward curved fans can have a high range of specific speeds but are most often used for medium specific speed applications, high pressure and medium flow applications.
Backward-curved fans are much more energy efficient than radial blade fans and so, for high power applications may be a suitable alternative to the lower cost radial bladed fan. 8

1.5.3 Straight radial blades:
Radial blowers, as in Figure 1.3(c), have wheels whose blades extend straight out from the centre of the hub. Radial bladed wheels are often used on particulate-laden gas streams because they are the least sensitive to solid build-up on the blades, but they are often characterized by greater noise output. High speeds, low volumes and high pressures are common with radial blowers, and are often used in vacuum cleaners, pneumatic material conveying systems and similar processes.

1.6 Principle of Working:
The centrifugal fan uses the centrifugal power generated from the rotation of impellers to increase the pressure of air/gases. When the impellers rotate, the gas near the impellers is thrown-off from the impellers due to the centrifugal force and then moves into the fan casing. As a result the gas pressure in the fan casing is increased. The gas is then guided to the exit via outlet ducts. After the gas is thrown-off, the gas pressure in the middle region of the impellers decreases. The gas from the impeller eye rushes in to normalize this pressure. This cycle repeats and therefore the gas can be continuously transferred.

1.7 Velocity Triangle:
Velocity triangle helps us in determining the flow geometry at the entry and exit of a blade. A minimum number of data are required to draw a velocity triangle at a point on blade. Some component of velocity varies at different point on the blade due to changes in the direction of flow. Hence an 9 infinite number of velocity triangles are possible for a given blade. In order to describe the flow using only two velocity triangles we define mean values of velocity and their direction. Velocity triangle of any turbo machine has three components as shown:
Fig. 1.4: Velocity triangle of any turbo machine
Velocity triangle for forward facing blade
• U - Blade velocity
• Vr – Relative Velocity
• V - Absolute velocity

These velocities are related by the triangle law of vector addition: -
• V=U+Vr

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This relatively simple equation is used frequently while drawing the velocity diagram. The velocity diagram for the forward, backward face blades shown are drawn using this law. The angle α is the angle made by the absolute velocity with the axial direction and angle β is the angle made by blade with respect to axial direction.

1.8 Centrifugal fan ratings:
Ratings found in centrifugal fan performance tables and curves are based on standard air SCFM. Fan manufacturers define standard air as clean, dry air with a density of 0.075 pounds mass per cubic foot (1.2 kg/m³), with the barometric pressure at sea level of 29.92 inches of mercury (101.325 kPa) and a temperature of 70 °F (21 °C). Selecting a centrifugal fan to operate at conditions other than standard air requires adjustment to both static pressure and power. 11

At higher-than-standard elevation (sea level) and higher-than-standard temperature, air density is lower than standard density. Air density corrections need to be taken into account for centrifugal fans that are specified for continuous operation at higher temperatures. The centrifugal fan will displace a constant volume of air in a given system regardless of the air density.
When a centrifugal fan is specified for a given CFM and static pressure at conditions other than standard, an air density correction factor must be applied to select the proper size fan to meet the new condition. Since 200 °F (93 °C) air weighs only 80% of 70 °F (21 °C) air, the centrifugal fan will create less pressure and require less power. To get the actual pressure required at 200 °F (93 °C), the designer would have to multiply the pressure at standard conditions by an air density correction factor of 1.25 (i.e., 1.0/0.8) to get the system to operate correctly. To get the actual power at 200 °F (93 °C), the designer would have to divide the power at standard conditions by the air density correction factor. 12

II. PROBLEM IDENTIFICATION

The main problems which are occurred frequently in the centrifugal blower, as follows:
2.1Vibration:
Machine vibration has several categories of causes that we have discovered after so many repairs, but it is useful now to review them to gain more confidence in the diagnosis. The Major categories of diagnoses are,
• Design defects
• Manufacturing defects
• Operational stresses
• Maintenance actions
• Aging
Design defects are mostly structural related with active resonances built-in because of improper sizing and proportioning of the parts statically, the structure seems good, but it remains dynamically weak. This is not discovered until the machine is energized and brought up to the required speed. This is more common than it should be, but the designers are not well equipped to predict or test for natural frequencies. In addition, the owners' foundation or base has a significant effect on natural frequencies, which the designer has little control over.

Hence, resonances are best detected during startup testing and corrected on-site with strategic stiffeners added. Manufacturing defects are built-in during the casting, machining, heat-treating, and assembly processes. They are latent defects that may show up in the first 24-hours of running, or they may not be obvious during the run-in period, appearing years later. The machine does not survive to a normal life expectancy as vibration may or may not be present.

An example is residual stresses in a shaft that gradually distorts the shaft over a period of years. Manufacturing defects are difficult to control, impossible to predict, and elusive to fix. The best strategy to deal with both design defects and manufacturing defects is to insist on start up vibration testing with limits of acceptability in accordance.
Other maintenance activities that affect on blower vibration are,
• Excessive localized heating, like welding on a shaft

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- Too high belt tension
- Shaft, or bearing, misalignment
- Substandard replacement parts
- Coupling, or other component, binding
- Lack of lubrication
- Loose hardware
- Replacing hardware with different weights that Affects on balance
- Re-assembling hardware in different orientations (also affect on balance)
- Hammering on a bearing
- Unclean, or burred, precision machine surfaces

Aging effects are only be detected with long term vibration monitoring.

2.2 Blower noise:
Noise is a repetition of a change of pressure and air velocity and pressure are interchangeable. When the pressure being proportional to velocity squared, there is a fluctuation in the air velocity. It is a source of noise and it should be avoided. To stop and start flow every cycle at least creates a noise of the frequency of operation of the cycle; usually it excites a lot of other noise too.

Secondly, explosions or implosions of pockets of air create a lot of noise, not only by exciting the natural frequency of the space in which they occur, but also all other spaces that they meet in their travels before they are damped out. It takes very little energy to make a chamber resonate if the energy is supplied at regular intervals at some harmonic of, or in tune with the noise waves. Thirdly, there is turbulence. Eddies, contain air moving at greatly differing velocities and so they are in effect pressure disturbances and make noise. They are the major source of noise in the centrifugal blower.

2.3 Cracks in shaft:
Due to vibration in the blower, the crack initiated and propagated in any moving part of the blower, especially in shaft. The mass from the crack zone removed while natural frequency of shaft increases. Due to removal of material which carries significant stresses when defect is a narrow crack. It results the local decrease in stiffness of structure and natural frequency. Due to presence of crack there is local influence which results from reduction and second moment of area of cross section where it is located. This reduction is equivalent to lowering the local bending stiffness of beam. Finally shafts get failure.

III. LITERATURE REVIEW

The performance of the fan is governed by different fan laws. Hence lot of emphasis is given to understand the basic theory of fans, their types and their working. The selection of critical parameters is very essential while determining the performance of the fans [1].

The basic equations mainly continuity equation, momentum equations and energy equations need to be considered while following the computational fluid dynamics approach. While considering any practical problem the best turbulence model and order of accuracy needs to be selected for good results [2].

When carrying out the design optimization of centrifugal fans, centrifugal blower where the mass flow variation is controlled by mobile ante rotor and not by speed variation of the electrical motor [3].
For vibration analysis of blower need to know the parameters which cause vibration and also the method to measure vibration with proper setup arrangements [4].
Due to vibration in blower the life of bearing reduced. The life of bearing can be improved by carrying corrective actions on blower & modifying its accessories like Plumber block to prevent bearing failure [5].

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For any fan, noise vibrations directly affect the performance of the fan. So without compromising on the quality, fan can be redesigned to reduce this with various numerical approaches [6].

Analysis of crack achieved by inverse method of fault detection in moving parts. One of the failures might be due to the crack initiation and propagation in any of the moving part. Being susceptible to minute changes, the natural frequency is monitored to access crack location and crack size in beam. The study is based on observation of changes in natural frequency. In theoretical analysis, the crack is simulated by a spring connecting the two segments of the beam. The model of beam is generated using Finite Element Method of analysis. In Finite Element Analysis, the natural frequency of beam is calculated by Modal Analysis using the software ANSYSTM whereas for experimentation purpose, Fast Fourier Transform (FFT) Analyzer is used. [7].

An existing blower model details and their analysing techniques are very important to carry out this project. Different parameters of blower geometry and their meshing procedure are determined and compared [8].
The blower parameters are examined continuously until the optimum value will exist. Optimum value obtained by using various numerical methods. For simplifying this longest numerical methods, go with software. FLUNT is the best for finding converged value of any analysis. It is based upon CFD. CFD considerations and analysis are taken. [9]

IV. METHODOLOGY

For this study of centrifugal fan, the methodology followed comprises of following steps:
a) Literature survey
b) Identification and selection of parameters to be studied
c) Modelling, meshing and analysis of the fan
d) Mathematical validation
e) Result comparison and selection of best combination.
4.1. Identification and selection of parameters
The main parameters identified for this particular fan are impeller diameter, fan speed and fillet radius at the inlet. The main purpose of this study is to study the combined effect of these parameters on the performance of the fan along with their importance.

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