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TIME DOMAIN SOUND SPECTRUM MEASUREMENTS IN DUCTED AXIAL FAN UNDER STALL REGION AT THROTTLE POSITION 2 CM

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ABSTRACT

Performance of axial fan is found to reduce drastically when instability is encountered during its operation. Performance of an axial fan is severely impaired by many factors mostly related to system instabilities due to rotating stall and surge phenomenon experienced during its operation. The present work involves measuring the time domain sound signal in ducted axial fan under stall region at throttle positions 2 cm from the casing. Objective of the experiment is to measure the time domain sound signal in terms of decibel and comprehend the sound Characteristics in ducted axial fan by using sound spectrum analyser. Different types of time domain sound signals have been measured under stall region at throttle position 2 cm from the casing for different rotor speed and different graphs are plotted for ducted axial fan.

Keywords: Microphone, BNC connector, Data Acquisition System, LABVIEW, Spectrum Measurements, Throttle position, Rotor speed.

1.0 INTRODUCTION

Mining fans and cooling tower fans normally employ axial blades and or required to work under adverse environmental conditions. They have to operate in a narrow band of speed and throttle positions in order to give best performance in terms of pressure rise, high efficiency and also stable condition.

Since the range in which the fan has to operate under stable condition is very narrow, clear knowledge has to be obtained about the whole range of operating conditions if the fan has to be operated using active adaptive control devices. The performance of axial fan can be graphically represented as shown in figure 1.

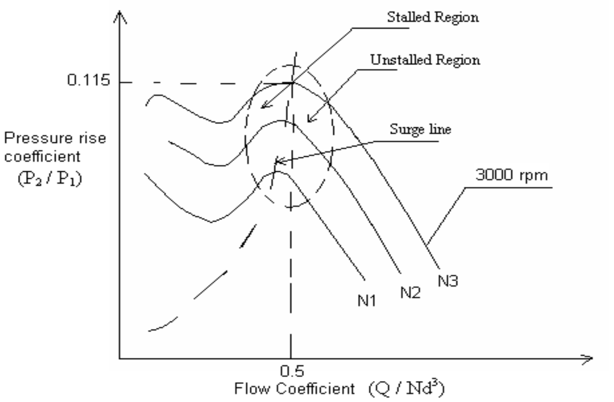

Fig.1 Graphical representation of Axial Fan performance curve

2.0 TEST FACILITY AND INSTRUMENTATION

Experimental setup, fabricated to create stall conditions and to introduce unstall conditions in an industrial ducted axial fan is as shown in figure 2 to figure 5.

Fig. 2 Ducted Axial Fan Rig

Fig. 3 Side View of Ducted Axial Fan Rig

A 2 HP Variable frequency 3-phase induction electrical drive is coupled to the electrical motor to derive variable speed ranges. Schematic representation of ducted fan setup is shown in figure 6.

Fig.4 Variable frequency Drive for speed control

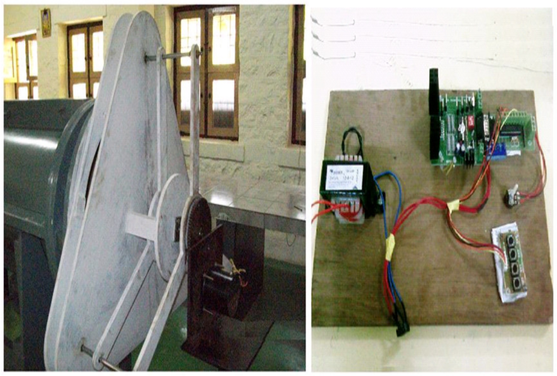

Fig.5 Automatic Throttle controller

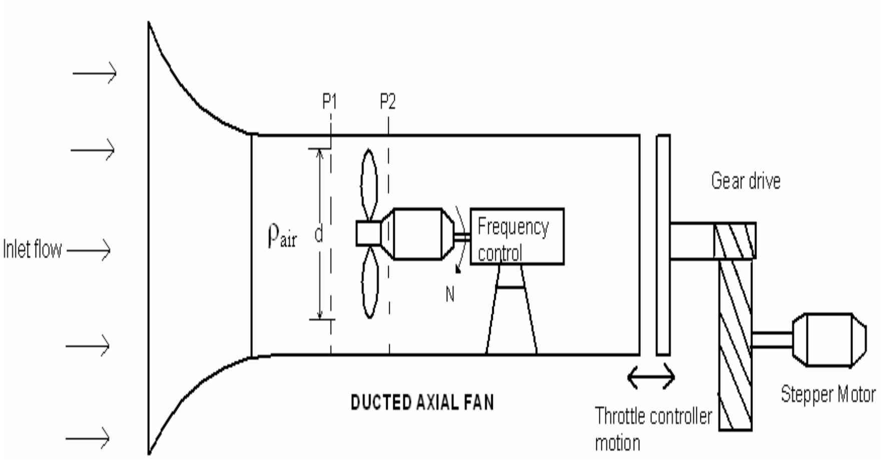

Fig. 6 Ducted Axial Fan - Schematic

The flow enters the test duct through a bell mouth entry of cubic profile. The bell mouth performs two functions: it provides a smooth undisturbed flow into the duct and also serves the purpose of metering the flow rate. The bell mouth is made of fiber reinforced polyester with a smooth internal finish. The motor is positioned inside a 381 mm diameter x 457 mm length of fan casing. The aspect (L/D) ratio of the casing is 1.2. The hub with blades, set at the required angle is mounted on the extended shaft of the electric motor. The fan hub is made of two identical halves. The surface of the hub is made spherical so that the blade root portion with the same contour could be seated perfectly on this, thus avoiding any gap between these two mating parts. An outlet duct identical in every way with that at inlet is used at the downstream of the fan. A flow throttle is placed at the exit, having sufficient movement to present an exit area greater than that of the duct.

3.0 SOUND MEASUREMENT ANALYSIS AND EVALUATION

Sound requies a Source, a Medium for its transmission and a Receiver. The source is the axial fan wherein the vibration of air molecules takes place due to external energy source. The medium is the substance which carries the sound energy from one molecule to another. The sound energy is transmitted through a medum back and forth in a way similar to the vibration of the sound source.

The fan which is transmitting the energy while transferring the pressurized air, creates compression of air. The slight increse in pressure is passed onto the molecules which are successively farther away from the sound source of an axial fan resulting in a slightly high pressure area moving away from the source. When the sound source completes its motion to the right it begins to move back to the left. This results in a reduction of pressure next to the object allowing the air molecules to spread apart, producing a rarefaction. This slight decrease in pressure is found in the air which is away from the fan signal sound source.

During the motion of the fan sound signal back and forth, it successfully ensures compression followed by a rarefaction of air to form the sound wave. The receiver is the microphone which senses the signal. The sound pressure variation is periodic, one complete variation in sound pressure is referred to as a cycle. The time T for one complete cycle is called the period of sound pressure oscillation.

The frequency of pressure change (f) is defined as the number of cycles per unit time. i.e.,

$$f = \frac{1}{T}$$

The sound pressure variation with time is,

$P(t) = P_a \text{ Sin}(\omega t + \emptyset)$

P_a = Amplitude of Pressure Fluctuation

ω = Frequency of Pressure Fluctuation = $\frac{2\pi}{T} = 2\pi f$ (rad/s)

$\emptyset$ = Phase of Sound Signal, measured relative to some reference.

Velocity of Propagation ‘c’ of the Sound, $c = \frac{\Delta x}{\Delta t}$

where Δx = Distance, the sound would propagate during a time interval Δt.

The wavelength is defined as the distance through which the sound propagates during the time T.

k= Wave Number = $\frac{2\pi}{\lambda} = \frac{2\pi f}{c} = \frac{\omega}{c}$ (rad/m)

c = Propagating Velocity or Speed of Sound in the Medium (m/s)

$P(x,t) = P_a \sin(kx - \omega t)$ (pa)

x = Distance along horizontal axis of the Tube (m)

$$c = \sqrt{\frac{\gamma P}{\rho}}$$

γ = Ratio of Specific Heat

P = Static Pressure of Fluid (air)

ρ = Density of the Fluid

3.1 Basic Sound Spectrum Analyser System

Basic sound Spectrum analyzer schematic diagram consists of various components as shown in fig.7. Microphone acquires the sound pressure fluctuation and converts them to an analog signal. BNC connector sends the signal to Data acquisition system. Data Acquisition system receive the signal from the BNC connector and sends to LABVIEW software. Once the amplitude of the signal has been measured, the computer system displays the measurement signal of spectrum through LABVIEW software.

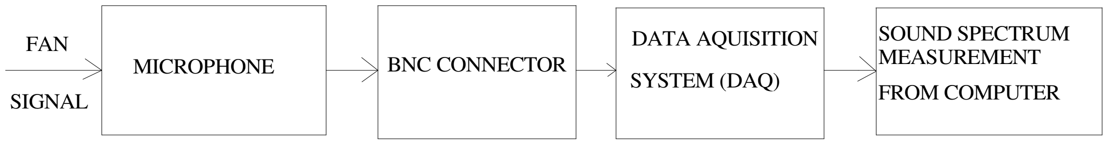

Fig.7 Schematic diagram of Sound Spectrum Measurement

3.2 Sound Spectrum Analyser

Experimental setup of Spectrum analyzer consists of various components is shown in fig.8. Microphone acquires the sound signals, frequency range from 0 Hertz to 11100 Hz and measure the decibel range from 0 to 130 decibel. Microphone sensitivity is the ratio of of its electrical output to the sound pressure at the diaphragm of the microphone. Since a microphone output is usually measured in millivolts (mv) and sound pressure is measured in pascals. The unit of sensitivity of microphone is mv/Pa. microphone connects to BNC connector. BNC connector transmits the signal to DAQ system. DAQ card consists 2 channel input port to acquire the signal and send the signal to system achieve through LABVIEW software inbuilt with National Instruments noise and vibration acquisition system and 2 channel output port to receive the signal from the system and to make a active feedback control system in ducted axial fan.

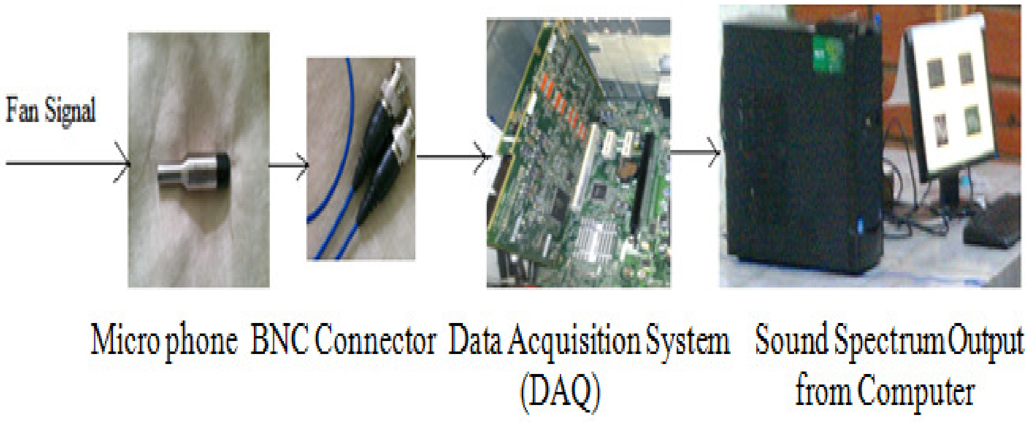

Fig.8 Experimental Rig for Sound Spectrum Analyser

3.3 Time Domain Sound Spectrum Measurements

Experiments are carried out to analyse the nature of time domain sound pressure signal variations in a ducted axial fan under stall conditions by varying the rotor speeds from 2400 to 3600 rpm, keeping the throttle position at 2 cm as invariant by employing Sound Spectrum Analyser and the results are shown in figs.9 to 13.

In an axial fan setup, eight number of axial fan blades are involved in transferring the energy to the fluid. In one rotation of axial fan, the fluctuation in pressure amplitude happens eight times. Every aerofoil blade transfers the energy to the fluid through an increase in the pressure levels in transmission medium of the fluid. Due to change in static pressure of the fluid, the velocity of sound propagation will increase. It is also known that the static pressure is directly proportional to velocity of sound.

In the stall region, flow separation would also occur. When the flow separation starts in the aerofoil section of an axial fan, rotating stall occurs. Rotating stall is defined as the unstable flow around the annulus region of fan blade. These rotating stall cells rotate at some particular frequency and this situation would lead to pressure changes. Increase in the rotating stall frequency leads to creation of more number of stall cell pockets leading to stalling of the axial fan. The static pressure is found to decrease in the stall region whereas there would be an increase in the stagnation or total pressure of the system. Creation of more number of stall cells leads to reversal of flow thus making a complete flow cycle in ducted axial fan. The rise in total pressure in the stall region leads to an increase in the velocity of sound.

Variation in sound pressure amplitude of air at a throttling position of 2 cm from the casing when the rotor rotates at 2400 rpm is shown in fig.9. Maximum sound pressure amplitude is found to be 10 db whereas its minimum magnitude is found to be -12.5 db, which is attributable to combinatorial effects of blockage in mass flow, rotating stall, periodic vibration due to air flow and excitation of fan blades.

Variation in sound pressure amplitude of air at a throttling position of 2 cm from the casing when the rotor is rotating at 2700 rpm is shown in fig.10. Maximum sound pressure amplitude is found to be 16 db whereas its minimum magnitude is found to be -22 db.

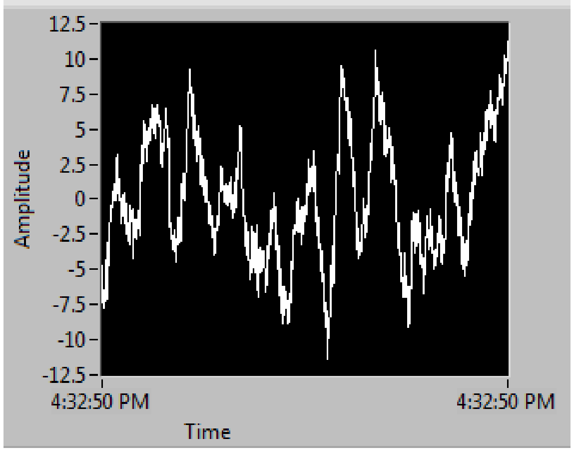

Fig.9 Rotor Speed 2400 Rpm

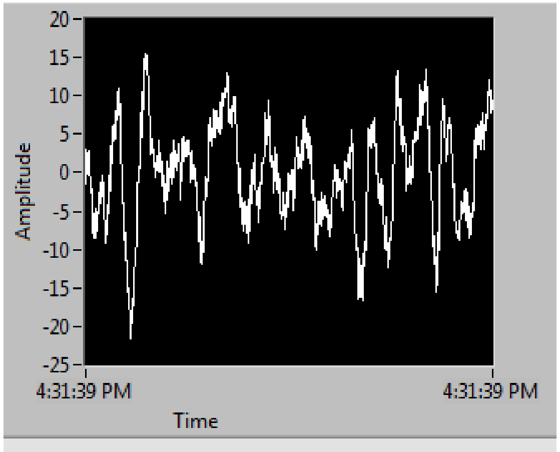

Fig.10 Rotor Speed 2700 Rpm

Variation in sound pressure amplitude of air at a throttling position of 2 cm from the casing when the rotor is rotating at 3000 rpm is shown in fig.11. Maximum sound pressure amplitude is found to be 25 db whereas its minimum magnitude is found to -17 db.

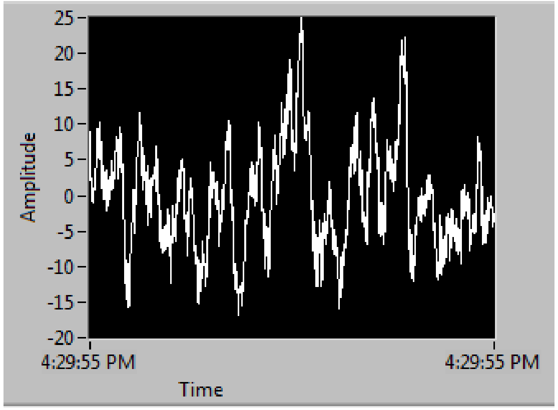

Fig.11 Rotor Speed 3000Rpm

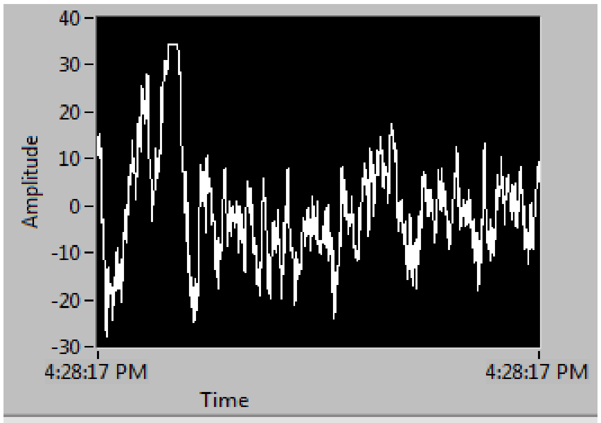

Fig.12 Rotor Speed 3300 Rpm

Variation in sound pressure amplitude of air at a throttling position of 2 cm from the casing when the rotor rotates at 3300 rpm is shown in fig.12. Maximum sound pressure amplitude is found to be -27 db at stall conditions and its minimum magnitude is found to be 88 db.

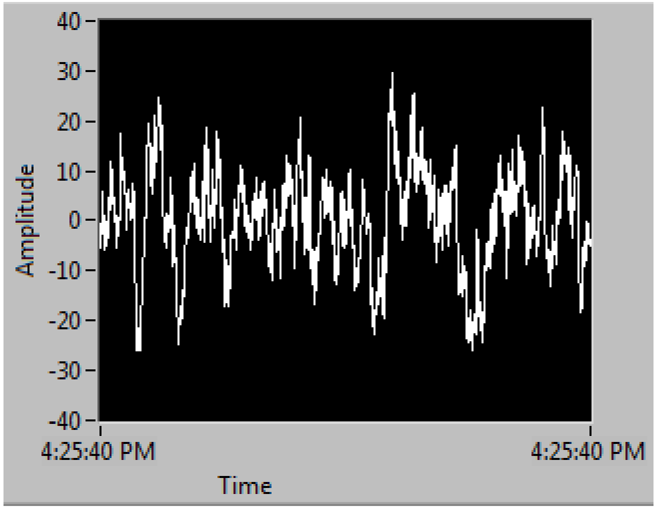

Fig.13 Rotor Speed 3600 Rpm

Variation in sound pressure amplitude of air at a throttling position of 2 cm from the casing when the rotor is rotating at 3600 rpm is shown in fig.13. Maximum sound pressure amplitude is found to be 31 db and its minimum magnitude is found to be -27 db.

4.0 CONCLUSION

In this paper, an attempt has been made to measure the sound spectrum signal in time domain under stall region at throttle position of 2 cm with respect to rotor speeds in ducted axial fan by using spectrum analyzer. It is useful to examine the characteristics of stall in ducted axial fan. Further, this work can be extended by working on the mathematical model of sound spectrum study in ducted axial fan. The results so far discussed, indicate that time domain sound spectrum measurements of ducted axial fan is very promising.

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NOMENCLATURE

v_w = Whirl velocity in m/s
ψ = Pressure ratio
N = Tip speed of the blades in rpm
Δp = Pressure rise across the fan in N/m^2
d = Diameter of the blade in m
ρ_{air} = Density of air in kg/m^3
L p = Sound Pressure Level in db
BPF = Blade passing frequency in Hz
L_N = Normalized Sound Level in db

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