Experimental Investigation Of Stresses, Noise & Flow In Centrifugal Fan Impeller

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ABSTRACT

Stress analysis of fan impeller by experimental and finite element method has shown that, the stress pattern in impeller components is highly complex. The stresses in the impeller components can be reduced by using the stiffening rings on the blades. In this paper, experimental & finite element approach has been discussed to study the stresses in centrifugal fan impeller. The flow of centrifugal fan has been also determined by using the standard set-up as per AMCA & NAFM standards. The effect of the stiffening rings on the stresses & fluid flow has been also discussed.

INTRODUCTION & LITERATURE REVIEW

Centrifugal Fans have wide applications in industries for continuous flow of air required for various applications. The impeller of the fan is a highly stressed component. The stresses due to centrifugal forces are predominant in fan impellers. The study of stresses in fan impellers is of great interest since past and carried out by many researchers. Haerle [1], Glessner [2], Deutsch [3], Ho [4] and Thurgood [5], used analytical techniques for determination of stresses in fan impeller. Later experimental analysis of fan impeller is carried out by Patton [6] , Bell [7] & Ramamurti [8]. The Finite Element Analysis by Bell [7], Bhope [9], Ramamurti [8] & Nabi [10], showed that, the stress pattern due to centrifugal forces is highly complex in backsheet, shroud and blades of the impeller. Authors [11] have investigated the effect of stiffening rings on the stress distribution and deflections in the components of impeller by finite element method. Two rings are equispaced at the nose of the blade and one ring is centrally placed at the tail of the blades, between backsheet and shroud. It is observed that, the stresses and deflections have been considerably reduced due to stiffening. The effect of, location & size of stiffening rings on the stress distribution in centrifugal fan impeller is also studied by the Authors [12], using the finite element technique. Desai and Badve

[13] also used the stiffening rings on the impeller blades. They have found that, the impeller rotating at 735 rpm can be rotated safely at 910 rpm, using the stiffening rings. It is necessary to verify the results of Finite element analysis, experimentally. So, Authors [14] have proposed experimental techniques & setups, for experimental stress analysis of centrifugal fan impeller.

PROBLEM FORMULATION

The backward inclined impeller is considered for the analysis. The impeller is designed and fabricated as per the specifications of Discharge – 0.5 cu.m per second, Static Pressure – 250 MPa, Total Pressure – 280 MPa, Speed – 1440 RPM.

By using the elementary theory of fan design [15,16,17,18], the dimensions of the impeller are determined. The minimum thickness of the impeller components are determined using elementary theory of strength of material [16]. The volute casing has been designed as per the guidelines given by Bleier [15]. Following types of investigations are carried out for the fan impeller.

1. The impeller without stiffening ring is analysed for stresses using finite element method & experimental technique. The flow & pressure parameters of the fan are measured using standard set-up. The noise generated by the fan is also measured.
2. The impeller with stiffening ring is analysed for stresses using finite element method.
3. The effect of stiffening ring & it's shape, on the flow pattern is studied using CFD.

The various types of analysis carried out and their results are given in forthcoming discussions.

STRESS ANALYSIS OF FAN IMPELLER WITH & WITHOUT STIFFENING RING BY FINITE ELEMENT METHOD

The impeller without stiffening ring is analysed for stresses using finite element method. The triangular & quadrilateral plate (shell) elements [19] are used for the discritization. The analysis is carried out using processor CSA/NASTRAN [20] with pre-post processor FEMAP [21]. The stresses in the backsheet, blades & conesheet are determined and are given in Table 1.

Table 1 - Comparison of Stresses in the Impeller Components with & without Stiffening Ring.

Impeller Component	VonMises Stress (MPa)	
	Without Stiffening Ring	With Stiffening Ring
Shroud	31.70	15.15
Blade	74.28	33.13
Backsheet	30.64	12.94

Stiffening Ring 2 mm thick	--	30.48

It is seen that the stresses in the blades are of high magnitude. The stresses can be reduced, by using the cylindrically shaped stiffening rings on the blades. So, various combinations of the stiffening rings on the blades are tried and their effects are investigated. To minimize the effect of stiffening ring on the flow, it is advisable to use minimum number of rings on the blades. It is seen that, the stiffening ring placed at the center of blade span, leads to minimum stresses.

Initially, cylindrically shaped stiffening ring of 2 mm thickness is considered at the center of the blade span, located at the nose of the blade. The width of the stiffening ring is increased progressively up to the half of the width of the blade. The similar analysis is carried out using the stiffening ring at the tail of the blade. It is seen that the stresses in the impeller components are of same magnitude for both the cases. But the ring placed at the tail of the blade has more volume & hence the weight, than the ring placed at the nose of the blade. So, for minimum weight of the impeller, it is concluded to use only one ring at the center of the blade span and at the nose of the blade. It is also seen that, increase in the thickness of the stiffening ring has very little effect on the stresses in impeller components and it reduces the stresses only in the ring. With the increase in the width of the ring, the stresses in impeller components & the ring decreases to a great extent. This is due to more support provided to the blade over it's span, thus reducing the bending stresses in the blade. The stresses in the impeller components using cylindrically shaped stiffening ring are given in Table 1. By comparison of the stresses given in Table 1 shows that, the stresses are reduced by more than 50% by using the stiffening ring.

EXPERIMENTAL STRESS ANALYSIS OF CENTRIFUGAL FAN IMPELLER WITHOUT STIFFENING RING

The stresses and strains calculated by FEM are to be verified experimentally, to validate the FE model of the impeller. So, it is felt necessary to verify the strains at certain locations on impeller components using strain gages.

The main difficulty in such type of measurements is that, the strain gages are to be mounted on the impeller, which is a rotary component. So, the measurement of the strain gage reading becomes very critical. For this purpose slip rings & telemetry systems are normally used. These systems are quiet costly and also the noise associated with these types of measurement may lead to inaccuracy. So, authors have used the miniature data recorder, which is directly mounted on the impeller shaft, to store the voltage output of the bridge. The data recorder used for this purpose is a 16 bit differential voltage storage device, which stores voltages from –100mv to +100mv with the minimum sampling time of 1 sec and the resolution of 5 micro volts. The weight of the data recorder is only 35 gm., which do not appreciably load the shaft of the impeller.

The data recorder with bridge circuit is initially tested for the bending strains in the cantilever beam and tensile strains in the rotary plate, subjected to centrifugal force. It is seen that, the analytical results are in close agreement with the experimental results for these two test cases. Thus, the validity of this experimental technique is ensured.

The impeller is investigated for strains using the strain gages. The temperature compensated strain gages are fixed to the impeller components. The strain gages are oriented in the direction of the principle strains, obtained by FE analysis. The bridge circuit, voltage regulator circuit, battery and data recorder are mounted on the shaft of the impeller. The set-up is shown in Fig. 1. The strain gage is connected in one arm of the wheatstone bridge. Due to the rotation of the impeller, the centrifugal forces will induce the strain in the impeller components. Due to this, the strain gage resistance changes & this change is converted to differential voltage by the wheatstone bridge. This differential voltage is stored by the data recorder. After stopping the impeller, the voltage values stored in the data recorder are downloaded to the computer through RS232 port using the software. With the knowledge of bridge supply voltage & gage factor, voltages are converted into the strain readings. It is seen that, the experimental strains are within 10 % band of FE results. This difference in the stress values is may be due to the effect of the weldment & vibrations, which are not considered in FE modeling & analysis.

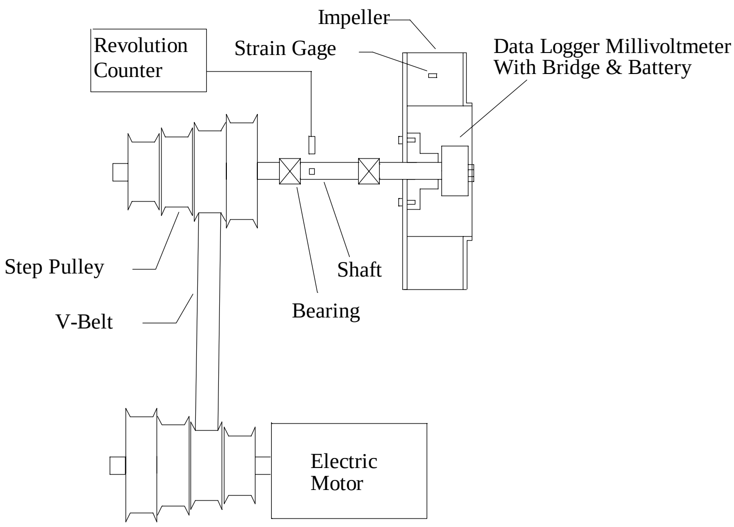

Fig. 1 - Set-up for Strain Measurement

EXPERIMENTAL INVESTIGATION OF FLOW & NOISE OF FAN WITHOUT STIFFENING RING

The impeller is rotated in the volute casing by means of the electric motor through V-belt drive. The flow, total pressure, static pressure & efficiency are measured by fabricating the set-up as shown in Fig. 2.

The set-up has been fabricated as per AMCA & NAFM [15] standards. The outlet of the volute casing is connected to the test duct, through the transformation piece & flow straightner. The thermometers are used to determine the air temperature in the duct and also to note the wet & dry bulb room temperature of air. The atmospheric pressure is also determined and the density of the air is calculated. Two pitot tubes are placed along the duct diameter, at an angle of 90 degrees with each other, to measure the total pressure & static pressure. The difference between total pressure (TP) and static pressure (SP) gives the velocity pressure(VP). These pressures are measured by the inclined tube manometers. The pressures are determined at 10 transverse point along the duct diameter, by each pitot tube and then they are averaged, to determine the velocity of the flow & hence the discharge of the fan. The discharge of the fan is varied by means of the orifices mounted at the end of the duct.

The power input to the 3-phase electric motor is measured by using the two wattmeter method [22], a voltmeter, ammeter & power factor meter. The power input to the fan shaft is calculated by determining the efficiency of the motor and the belt drive. For this purpose the test were conducted on no load conditions.

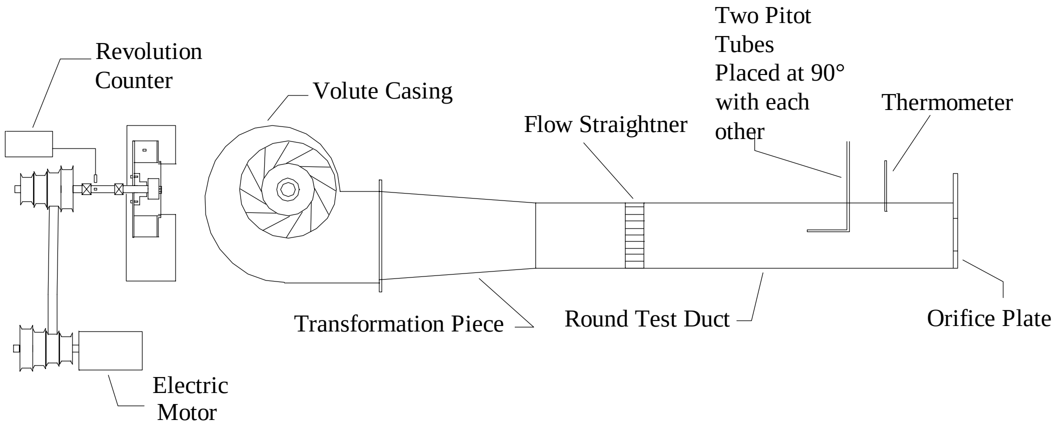

Fig. 2 - Set-up for Flow Measurement

It is seen that, the static pressure, total pressure, discharge & efficiency of the fan determined experimentally, are as per the impeller specifications. The noise generated by the fan is measured by the sound level meter and it is found to be 80 db.

EFFECT OF STIFFENING RINGS ON THE FLUID FLOW BY CFD

The stiffening ring provided on the blade, disturb the flow around the ring and hence affects the flow performance of the impeller. This flow has been investigated by CFD analysis. It is seen that, the air is entering axially in the impeller through the shroud eye. This flow changes it's direction gradually and becomes the radial flow. It is also seen that, the incoming air flow interacts with the stiffening ring, and the flow gets separated at the ring. The eddies & vortices are formed at both the ends of the ring. It is shown in Fig – 3. It is seen that, the cylindrically shaped stiffening ring leads to more flow separation. So, for minimum flow separation, it is felt to place a ring in the direction of the flow. So, conical shaped ring is considered for the analysis. The CFD analysis reveals that, the flow separation is reduced, by using the stiffening ring of conical shape, as shown in Fig. 4. This separation is still reduced by rounding the inlet of the ring.

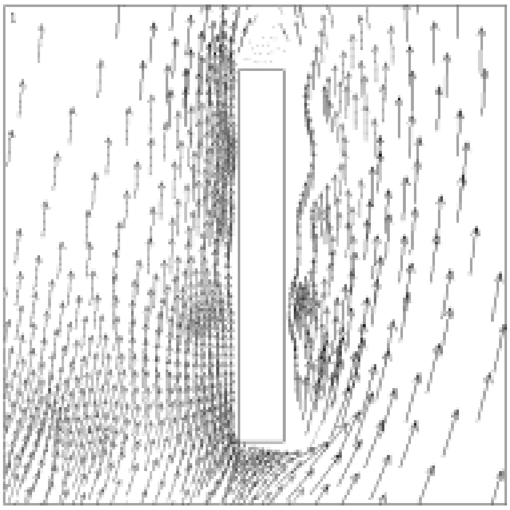

Fig. 3 - Flow pattern around cylindrical Stiffening ring

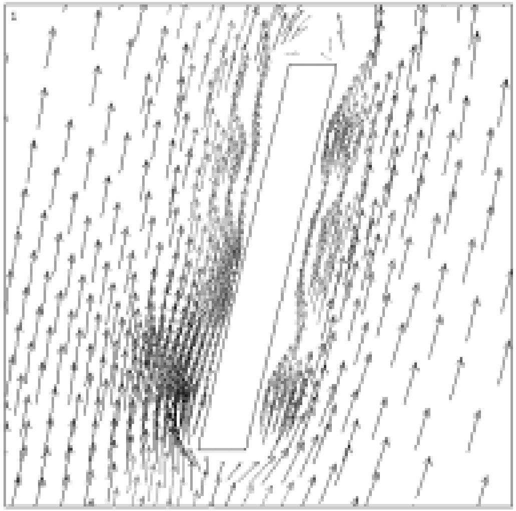

Fig. 4 – Flow pattern around Conical Stiffening ring

INVESTIGATION OF STRESSES IN IMPELLER USING CONICAL SHAPED STIFFENING RING BY FINITE ELEMENT METHOD

The stresses in the impeller components are investigated by FEM, for conical shape of stiffening ring at different locations & for different thickness and given in Table 2

Table 2 – Comparison of Stresses for different shapes & thickness of Stiffening Ring.

Details	Vonmises Stress (MPa)		
Location of Ring	At centre of blade span	At 40% of span distance from shroud	At 40% of span distance from shroud
Size & Shape of Ring	2 mm thick – conical shape	2 mm thick – conical shape	2.2 mm thick – conical shape
Stresses in Shroud	15.73	13.28	13.11
Stresses in Blade	33.24	35.17	34.89
Stresses in Backsheet	12.87	14.98	14.84
Stresses in Ring	50.77	43.20	38.79

It is seen that, the stresses in backsheet, shroud and blades are not greatly affected by the ring 2 mm thick, placed at the center of the blade span & at the nose of the blade. But the stresses in the ring are increased by 66% than the cylindrical shaped ring. Later, the ring is located at a distance of 40% of the blade span from the shroud. It is seen that, this arrangement has reduced the stresses in the ring from 50.77 MPa to 43.20 MPa. Next, the thickness of the ring is increased from 2 mm to 2.2 mm and it is seen that, the stresses in the ring are further reduced to 38.79 MPa. Thus due to the conical shaped ring of 2.2 mm thick, the stresses in the impeller components are reduced by more than 50% as compared to the impeller without stiffening ring.

DISCUSSION & CONCLUSION

The present analysis reveals that, the stiffening rings plays very important role in the reduction of stresses in impeller components. The conical shaped ring, located at 40% of the blade span from the shroud, has decreased the stresses by more than 50% as compared with the impeller without stiffening ring. The CFD analysis also reveals that, the flow is disturbed to a lesser extent with the use of conical shaped ring, than the cylindrical ring. For proper performance of the impeller, the strength of impeller component is very important, along with it's fluidic efficiency. The location & shape of the stiffening ring plays very important role in strength of the impeller & the fluid flow. The extensive experimentation on location and shape of the stiffening ring is in progress & will be communicated in future.

REFERENCES

1. Haerle H., The strength of rotating discs, Engineering, 106, 131-134, 1918.
2. Glessner J.W., A method for analysing stresses in centrifugal impellers, ASME paper no. 54-A-167, 1967.
3. Deutsch E.J., Method of stress analysis for shrouded discs, Aerospace Engg., 21(3), 24 – 30, 1962.
4. Ho B.P.C., Procedure for calculating stresses in centrifugal impeller with cover disc, J. Engg. & Power, Trans. of Am. Soc. Mech. Engrs.,88, 395, 1966.
5. Thurgood D.A., Stresses in asymmetric discs, J. of Strain analysis, 4(1), 65-73, 1969.
6. Patton R.G., Stresses in centrifugal fan impellers, Proc. Instn. of Mech. Engrs., 187(28), 309-315, 1973.

7. Bell R. and Benham P.P., Theoretical and experimental stress analysis of centrifugal fan impeller, J. of Strain analysis,13(3), 141-147, 1978.

8. Ramamurti V. and Balasubramanian P., Steady state stress analysis of centrifugal fan impeller, Computers & Structures, 25(1), 129-155, 1987.

9. Bhope D.V. and Bhat M.G., Stress analysis of centrifugal fan impeller by finite element method., J. Inst. of Engrs.(Mech. Engg. Division), 70, 111-113, 1990

10. Nabi M.S. and Ganeshan N., Stress analysis of composite centrifugal fan impeller using the cyclic symmetric approach, Computers & structures, 48(5), 781-785, 1993.

11. Bhope D.V., and Padole P.M., Effect of Stiffening Rings on the Stress distribution in centrifugal fan impeller, International conference CCM'98, Lyon, France, July 1998.

12. Bhope D.V. and Padole P.M., Effect of location & size of stiffening rings on the stress distribution in centrifugal fan impeller, International conference ECCM’99, Munich, Germany, Aug-Sept 1999.

13. Desai G.R. and Badve S.A., FEM analysis of centrifugal fan impeller, Nisa User’s Conference, Banglore, India, 1997.

14. Bhope D.V. and Padole P.M., Proposed experimental techniques for determination of stresses in centrifugal fan impeller, National Conference on Machines & Mechanisms, I.I.T. Bombay, 52-63, December 1999.

15. Bleier F.P., Fan Handbook – Selection, Application& Design, 1st ed., McGraw-Hill, 1998.

16. Osborne W.C., Fans, 2nd ed., Pergamon Press, 1977.

17. Bruno Eck, Fans, 5th ed., Pergamon Press, 1972.

18. Baumeister T., Fans, 1st ed., McGraw-Hill, 1935.

19. Zienkiwicz O.C., The Finite Element Method, 3rd ed., Tata Mc-graw Hill India, 1979.

20. CSA/NASTRAN user manuals ver. 97, Computational Structural Analysis & Research Inc. USA.

21. FEMAP user manuals, ver. 5.0, Enterprise software Products Inc., USA.

22. Edwin P. Anderson, Rex Miller, Electric Motors, D.B. Taraporewala, India, 1983.