Stress Analysis of Axial Flow Fan Impeller

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ABSTRACT

In this work, stresses and natural frequencies of axial flow fan are evaluated. Various combinations of hub thickness and ring thickness are considered to calculate stresses and frequencies. It is observed that in case of solid hub the maximum stresses are induced at root of the blade and if the thickness of the hub reduces the stresses at the root of the blade increases and natural frequency decreases. Finite element analysis is done on impeller for investigation of stresses and natural frequency.

Keywords: ***Axial fan, Stress, Natural Frequency, Ring.***

1. INTRODUCTION

A Fan is a machine used to create flow within a fluid, typically a gas such as air. A fan consists of a rotating arrangement of vanes or blades which act on the air. The axial flow fans have blades that force air to move parallel to the shaft about which the blades rotate. Axial fans flow air along the axis of the fan, linearly, hence their name.

Fans produce air flows with high volume and low pressure, as opposed to compressors which produce high pressures at a comparatively low volume. A fan blade will often rotate when exposed to an air stream, and devices that take advantage of this, such as anemometers and wind turbines, often have designs similar to that of a fan. An impeller of axial flow fan comprises a hub which carries blades installed thereon with the aid of attachment fitting in the form of a swiveling base with an extension. The blades installed on a single base are rigidly secured thereto at one end and joined to each other by a connector at the other end, thus forming a rigid system.

For the purpose of analysis blade is treated as a free fan with no air restriction. To determine analytically the stresses along the blade length, geometrical model of axial flow fan impeller is developed. Stress analysis of axial flow fan impeller is carried out. The effect of ring on axial flow fan impeller by varying hub thickness is investigated by considering various geometrical parameters of fan.

NOTATION

d Diameter
r_H Hub Radius
r_t Tip Radius
p Pressure
u Tangential Velocity
A Area
C_d Coefficient Of Discharge
C_L Coefficient Of Lift
E Modulus Of Elasticity
α Angle Of Attack
β Blade Angle
ρ Density
ω Angular Velocity
ψ Pressure Coefficient

Fig1.shows the axial flow fan of tip radius r_t and hub radius r_H. Referring to this figure, the fan data considered in this study are,

Diameter of hub (D_h)	= 0.3 m
Diameter of tip (D_t)	= 0.6 m
Hub height	= 0.1 m
Blade chord at hub	= 0.105 m
Blade chord at tip	= 0.075 m
Angular velocity (ω)	= 100.53 rad/sec
Fan total pressure (P_t)	= 125 Pa
Speed of fan	=16 Rev/sec
Frequency	= 50 Hz

The thickness of Hub is varied as 5 mm, 10 mm, 20 mm, 30 mm, 40 mm and 50 mm and thickness of Ring is varied as 5 mm, 6 mm, 7 mm, 8 mm, 9 mm and 10 mm. Fan is made up of aluminium. To design the fan blade Gottingen 436 aerofoil has been considered.

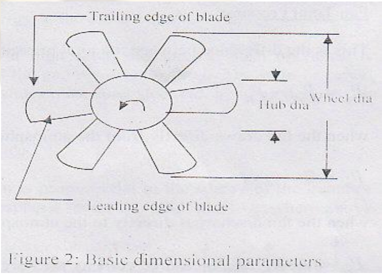

Fig. 1: Fan Geometry

Analytical stress calculations are carried out using the equation,

$$\text{Stress } (\sigma) = \rho\omega^2 / A_1 \int_{r1}^{r2} Ar\, dr$$

2. MODELING AND ANALYSIS OF AXIAL FLOW FAN IMPELLER

Fig. 2 shows the model of axial flow fan impeller.

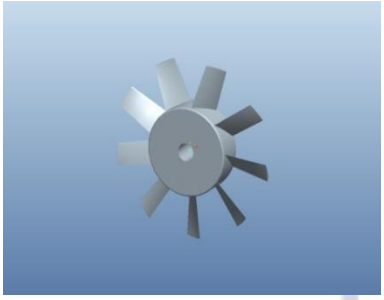

Fig. 2: Axial flow fan without ring

The maximum Von mises stresses induced at blade are shown in fig. 3 and stresses are shown in table 1.

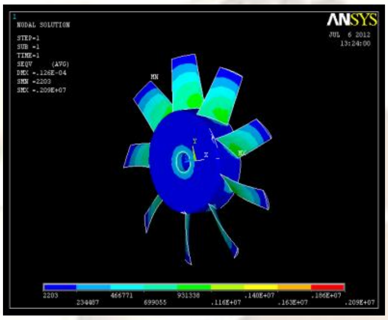

Fig. 3: Maximum Von mises stress contour for axial flow fan impeller

Table 1: Maximum Von mises stresses on axial flow fan impeller

Part	Von mises stresses (Mpa)
Hub	0.44
Blade Root	1.76
Blade Middle	0.66
Blade Tip	$2.208 * 10^{-3}$

The von mises stresses are also determined by varying hub thickness are shown in table 2.

Table 2: Von mises stresses on axial flow fan impeller with varying Hub thickness

Hub thickness (mm)	Von mises stress at Blade Root (Mpa)	Von mises stress at Blade Middle (Mpa)	Von mises stress at Blade Tip (Mpa)
5	15.1	$2.193x10^{-3}$	$2.193x10^{-3}$
10	7.54	$2.202x10^{-3}$	$2.202x10^{-3}$
20	4.96	0.62	$2.190x10^{-3}$
30	3.21	0.403	$2.192x10^{-3}$
40	2.65	0.66	$2.190x10^{-3}$
50	2.20	0.55	$2.191x10^{-3}$

3. STRESS ANALYSIS OF IMPELLER WITH RING AT BLADE TIP

In this study, the stresses on axial flow fan impeller with ring at blade tip are evaluated. These cases are described as follows.

CASE 1: RING OF 5 MM THICK AND VARYING HUB THICKNESS

In this case 5 mm ring and varying hub thickness is considered. The finite element analysis of axial flow fan with ring as per loading and boundary conditions revealed the stress distribution in the form of stress contour. The representative Von mises stress contours are shown in fig. 4 and stresses are shown in table 3.

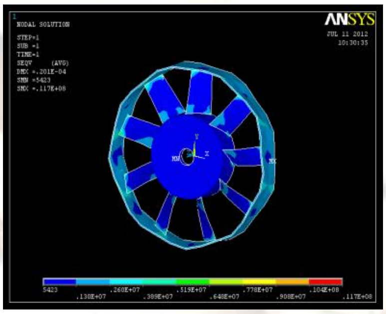

Fig. 4: Von mises stress contour of fan of 5 mm ring and 20 mm hub thickness

Table 3: Von mises Stresses On Fan having 5mm Ring Thickness and Varying Hub Thickness

Hub Thickness (mm)	Von mises Stress at Root (Mpa)	Von mises Stress at Tip (Mpa)
5	15.3	3.83
10	10.6	7.92
20	5.19	10.4
30	2.83	7.07
40	2.38	7.13
50	2.58	10.3

CASE 2: RING OF 6 MM THICK AND VARYING HUB THICKNESS

In this case 6 mm ring and varying hub thickness is considered. The finite element analysis of axial flow fan with ring as per loading and boundary conditions revealed the stress distribution in the form of stress contour. The representative Von mises stress contours are shown in fig. 5 and stresses are shown in table 4.

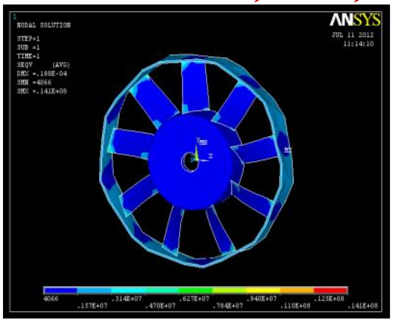

Fig. 5: Von mises stress contour of fan of 6 mm ring and 20 mm hub thickness

Table 4: Von mises Stresses On Fan having 6 mm Ring Thickness and Varying Hub Thickness

Hub Thickness (mm)	Von mises Stress at Root (Mpa)	Von mises Stress at Tip (Mpa)
5	15.9	4.00
10	9.41	9.41
20	4.70	11.0
30	4.31	11.5
40	2.79	11.1
50	3.01	12.0

CASE 3: RING OF 7 MM THICK AND VARYING HUB THICKNESS

In this case 7 mm ring and varying hub thickness is considered. The finite element analysis of axial flow fan with ring as per loading and boundary conditions revealed the stress distribution in the form of stress contour. The representative Von mises stress contours are shown in fig. 6 and stresses are shown in table 5.

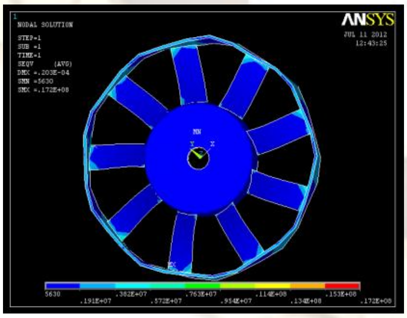

Fig. 6: Von mises stress contour of fan of 7 mm ring and 20 mm hub thickness

Table 5: Von mises Stresses On Fan having 7 mm Ring Thickness and Varying Hub Thickness

Hub Thickness (mm)	Von mises Stress at Root (Mpa)	Von mises Stress at Tip (Mpa)
5	16.2	4.06
10	8.26	8.26
20	3.82	9.54
30	2.77	11.1
40	2.67	10.7
50	2.27	11.3

CASE 4: RING OF 8 MM THICK AND VARYING HUB THICKNESS

In this case 8 mm ring and varying hub thickness is considered. The finite element analysis of axial flow fan with ring as per loading and boundary conditions revealed the stress distribution in the form of stress contour. The representative Von mises stress contours are shown in fig. 7 and stresses are shown in table 6.

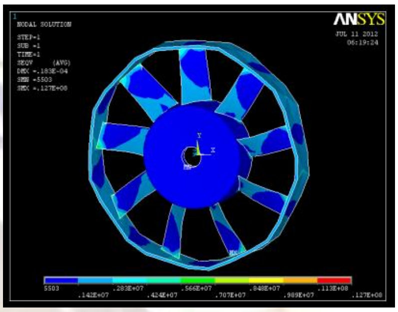

Fig. 7: Von mises stress contour of fan of 8 mm ring and 20 mm hub thickness

Table 6: Von mises Stresses On Fan having 8 mm Ring Thickness and Varying Hub Thickness

Hub Thickness (mm)	Von mises Stress at Root (Mpa)	Von mises Stress at Tip (Mpa)
5	16.4	4.10
10	10.8	8.09
20	5.66	9.89
30	2.88	8.64
40	2.95	11.8
50	1.86	9.23

CASE 5: RING OF 9 MM THICK AND VARYING HUB THICKNESS

In this case 9 mm ring and varying hub thickness is considered. The finite element analysis of axial flow fan with ring as per loading and boundary conditions revealed the stress distribution in the form of stress contour. The representative Von mises stress contours are shown in fig. 8 and stresses are shown in table 7.

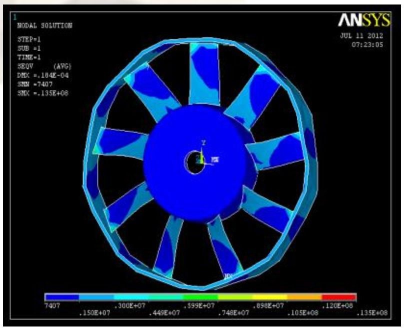

Fig. 8 Von mises stress contour of fan of 9 mm ring and 20 mm hub thickness

Table 7: Von mises Stresses On Fan having 9 mm Ring Thickness and Varying Hub Thickness

Hub Thickness (mm)	Von mises Stress at Root (Mpa)	Von mises Stress at Tip (Mpa)
5	16.5	4.13
10	11.2	6.97
20	5.99	10.5
30	3.12	10.9
40	3.22	11.2
50	1.79	12.4

CASE 6: RING OF 10 MM THICK AND VARYING HUB THICKNESS

In this case 10 mm ring and varying hub thickness is considered. The finite element analysis of axial flow fan with ring as per loading and boundary conditions revealed the stress distribution in the form of stress contour. The representative Von mises stress contours are shown in fig. 9 and stresses are shown in table 8.

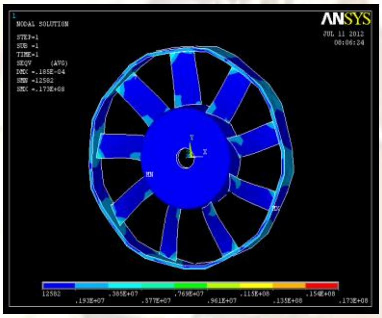

Fig. 9 Von mises stress contour of fan of 10 mm ring and 20 mm hub thickness

Table 8: Von mises Stresses On Fan having 10 mm Ring Thickness and Varying Hub Thickness

Hub Thickness (mm)	Von mises Stress at Root (Mpa)	Von mises Stress at Tip (Mpa)
5	16.8	6.13
10	10.7	6.67
20	5.77	7.69
30	6.06	8.08
40	5.13	8.56
50	4.12	9.60

4. NATURAL FREQUENCY ANALYSIS

Natural frequency is the frequency at which a system naturally vibrates once it has been set into motion. In other words, natural frequency is the number of times a system will oscillate (move back and forth) between its original position and its displaced position,if there is no outside interference.

In this section the natural frequency analysis of fan with solid and hollow hub and varying ring thickness is carried out. First ten modes are determined and modal shape of fan with respective frequency is shown in fig 10.

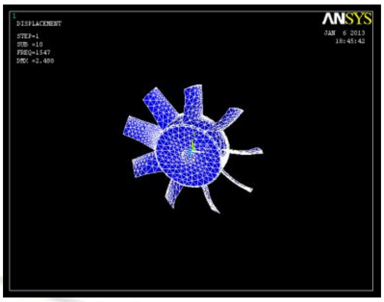

Fig.10 Natural frequency of axial flow fan impeller

Table 9: Natural Frequency Analysis

Sr. no.	Set no.	Frequency (Hz)
1	1	414.71
2	2	419.44
3	3	420.44
4	4	420.93
5	5	421.29
6	6	421.42
7	7	421.86
8	8	422.67
9	9	422.87
10	10	1547.0

The natural frequencies of fan by varying hub thickness are shown in table 10.

Table 10: Fundamental Natural Frequency of Impeller for Hub Thickness and Ring Thickness

Ring Thikness (mm)	Frequency (Hz)					
	5 mm Hub	10 mm Hub	20 mm Hub	30mm Hub	40mm Hub	50mm Hub
5	45.232	116.44	209.16	212.56	215.04	214.48
6	42.679	110.22	196.15	199.62	200.67	201.31
7	41.089	106.39	188.16	191.48	192.63	193.12
8	39.159	101.60	178.97	181.91	183.24	183.75
9	37.458	97.384	171.02	174.14	175.11	175.65
10	35.949	93.598	164.14	167.09	168.31	168.82

CONCLUSION

It is observed that in case of solid hub the maximum stresses are induced at root of the blade with the magnitude 1.76 N/mm^2. The Von mises stress decreases from root to tip of the blade with the magnitude of 0.66 N/mm^2 at the middle and $2.208*10^{-3}$ N/mm^2 at the tip respectively. The analysis is also carried by varying the thickness of the hub, it is seen that as the thickness of the hub reduces the stresses at the root of the blade increases. The natural frequency analysis revealed that, as the hub thickness decreases the natural frequencies also decreases.

With reference to above discussion, the stresses are least in case of impeller without ring, but it is observed in practice that, the ring is provided over the blades.

The natural frequency analysis revealed that the provision of ring drastically alters the natural frequency of the impeller. This shift in the natural frequency is maximum when the ring is placed at the tip of the blade. Thus the structural design of the impeller with the ring needs to be based also on natural frequency response.

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