VIBRATION ANALYSIS OF CENTRIFUGAL BLOWER IMPELLER

Ms. Vidya A. Takale[1]
Department of Mechanical Engineering,
Savitribai Phule Pune University, Pune.
Maharashtra, India.
Email – vidyatakale19@gmail.com

Mr. Avinash K. Mahale[2]
Assistant Professor, Department of Mechanical Engineering,
Savitribai Phule Pune University, Pune.
Maharashtra, India.
Email-akmahale@gmail.com

Abstract - The design of any machine or structure is an interdisciplinary process, involving aerodynamics, vibration analysis, fluid dynamics, stress analysis, thermodynamics the selection of materials, and the requirements for manufacturing. The operation of mechanical system will always produce some vibration. The main goal of this project is to minimize the effect of these vibrations, because while vibration is undesirable, vibration is unavoidable. The result of excess vibrations varies from nuisance disturbance to a catastrophic failure. All fans generate some vibration. They continuously rotate and since nothing is perfect, cyclic forces are generated. It's only when vibration reaches a certain amplitude that we call it bad. Vibration is an indicator of problems with a mechanism, or it may be a cause of problems. At the end, vibration can transmit into nearby areas and interfere with precision processes, or creates an annoyance for people. Hence the objective of this paper is to present vibration analysis of centrifugal blower impeller. Presently centrifugal blower is made of MS material, model is created in CATIAV5, meshing is done in HYPERMESH and analysis is done using ANSYS. Re-analysis will be done using Glass fiber (epoxy) material to know the response of blower. Once get desired results model will be fabricated and testing will be done using FFT analyzer.

Keywords— Centrifugal blower, impeller, vibration, CATIA V5 R19, ANSYS 14.5.7.

I. INTRODUCTION

Centrifugal pumps, compressors, and blowers utilize various impeller designs that are an essential component for bulk transport of any fluids. Typically, a motor is used to spin a shaft that is connected to a housed impeller, which draws fluid along a rotating axis. The fluid is accelerated and whirled radially and tangentially outward through the impeller vanes and where it exits through a casing designed to increase fluid pressure and decelerate the fluid velocity.

Impeller's Basic Theory:

The impeller rotates, it creates vacuum at its inlet suction side through centrifugal force and the impeller creates a positive pressure, inducing a force of air on the discharge side. Impeller is the important part of the blower components because of its performance inadvertently determines the blower's performance. An impeller is a disk shaped structure with vanes that create the actual suction in a blower. The impeller is always placed directly on the shaft of the electric motor so that it spins at a very high speed.

The effects of centrifugal force acting on the spinning air within the impeller create the suction. Von Cube and Steimle (1981) confirms as the impeller rotates that the spinning air moves outward away from the hub, which is creating a partial vacuum causes more air to flow into the impeller.

Most important impeller parameters can be grouped into three categories:

1. Geometrical Parameters: hub diameter, tip diameter and tip width.
2. Operating conditions: Inlet total temperature, Inlet total pressure and fluid density.
3. Performance characteristics: mass flow parameter, pressure ratio and specific speed.

II. LITRATURE REVIEW

Adekunle Taofeek Oyelami, Olawale Oluwadare Olaniyan, Dalyop Iliya and Abimbola Samson Idowu [1] has presented the blower was specifically designed to ensure a near-complete standardization in the design of EMR500. The suction conditions and other application data are used to calculate parameters such as the suction specific speed, specific speed, required shaft power, required impeller dimension and volute dimensions. The blower was designed to convert 'driver' energy to kinetic energy in the fluid by accelerating it to the outer rim of the revolving device known as the impeller. The impeller, driven by the blower shaft adds the velocity component to the fluid by centrifugally casting the fluid away from the impeller vane tips. The amount of energy given to the fluid corresponds to the velocity at the edge or vane tip of the impeller.

Shalini rai, Prabha chan [2] This paper gives redesigning a centrifugal impeller and its inlet duct. The double-discharge volute casing is a structural constraint and is maintained for its shape. To reducing the power required to operate the fan, redesign effort was geared towards meeting the design volute exit pressure. Given the high performance of the baseline impeller, the redesign adopted a high-fidelity CFD-based computational approach capable of calculated to the all aerodynamic losses. This papers effort utilized a numerical optimization with experiential steering techniques to redesign the fan blades, inlet duct, and shroud of the impeller. The resulting flow path modifications not only met the pressure requirement, but also reduced the fan power by 8.8% over the baseline. A refined CFD-based assessment of the impeller/volute coupling and the gap between the stationary duct and the rotating shroud revealed a reduction in efficiency due to the volute and the gap.

Y Srinath, K.Monhar Reddy[3] The present work aims at observing the choice of E-Glass as an alternative to metal for better vibration control. E-Glass, known for their superior damping characteristics are more promising in vibration reduction compared to metals. The modeling of the blower was done by CATIA V5 R19. The blower is meshed with a three dimensional hex8 mesh is done using HYPERMESH 10. It is proposed to design blower with Epoxy glass, analyze its strength and deformation using FEM technique. In order to evaluate the effectiveness of E-Glass and metal blower using FEA packaged (ANSYS). Modal analysis is performed on both Aluminum and E-Glass blower to find out first five natural frequencies.

Kusekar S.K., Lavnis A.K[4] The present work aims at examining the choice of material as an alternative for better vibration control. SS316L is well known for their superior damping characteristics are more promising in vibration reduction compared to metals. The modeling of the blower was done by using solid modeling software, CATIA V5 R20. The blower is meshed with a three dimensional hex8 mesh is done using HYPERMESH 10 and analysis using ANSYS14.5.

Kay Thi Myaing, Htay Win[5] In this paper, backward-curved impeller was simulated and compared with theoretical result by using Solid Works Software. Flow Analysis is also based on the computational fluid dynamic and can obtain the results for the estimation of the outlet flow velocity components, pressure distribution and temperature distribution for impeller.

Robert Paul. M[6] In this paper, 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 modeled using Pro-E and after simplification the modeled blower is meshed in Gambit CFD.

Adgale Tushar Balkrishna, P.D.Darade, Govind Raiphale[7] Hence the objective of this study is to present vibration analysis of centrifugal blower for materials such as steel, aluminum and composite (glass/epoxy).

III. OBJECTIVE

The main objective in this project is to find a response of centrifugal blower impeller under modal analysis.

- Improve the structural strength.
- Reduce Vibrations.
- Reduce Noise.

IV. METHODOLGY

1. Literature Study
2. Preparing the CAD model of blower impeller in CATIA by reverse Engineering from part parametric data.
3. Calculation of boundary conditions
4. Modeling the Part in hypermesh and applying loading conditions
5. Post-processing on Ansys.
6. Re-analysis similar process in hypermesh and Ansys using composite material.
7. Comparing the results with the conventional model.
8. Fabrication of final model.
9. Testing on FFT analyzer.
10. Result Validation with Ansys results.

V. DESIGN OF BLOWER IMPELLER

Much research has gone into more and more systematic design of centrifugal blower. Different authors have been suggested different procedure; It has a slightly different method of calculation, the broad underling principles all are similar. The other factors needed for selection of blower are the static pressure the blower must overcome, the shape and direction of the desired air flow, the average air flow volume required, space limitations, available power, audible noise allowances, efficiency, air density, and cost. The first two of these, static pressure and air flow, along with available power considerations are generally the most critical for system designers. For design of casing must be first required design of impeller and finally design of casing is done.

Selection of Centrifugal Blowers is based on following:

1. Air flow rate required by the process in m^3/Hr. or CFM (cubic feet/ min.)
2. Static pressure as offered by the ducting. In inches/ mm of water column.
3. Temperature at which Air enters into the blower.
4. Application for which centrifugal fans & blower is required

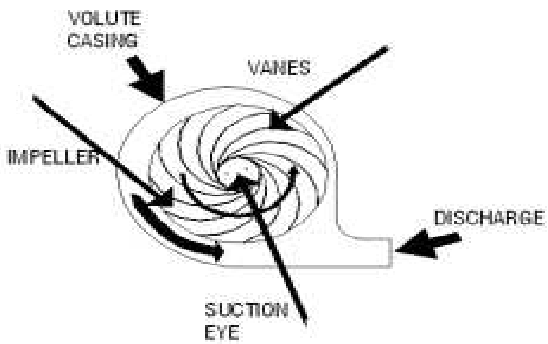

Fig 1: Section drawing of a blower

Fig 1 shows a cross-section of the blower designed. Fluid enters the inlet port at the center of the rotating impeller, or the suction eye. The impeller spins in a counter-clockwise direction, it thrusts the fluid outward radially, causing centrifugal acceleration. Which is creates a vacuum in its wake, drawing even more fluid into the inlet. Centrifugal acceleration creates energy is proportional to the speed of the impeller. The faster the impeller rotates, the faster the fluid movement and the stronger its force. Impellers are the rotating blades that actually move the fluid. They are connected to the drive shaft that rotates within the blower casing. The impeller is designed to impart a whirling to the air in the blower.

Input parameters:
Flow Discharge $Q = 0.5\ m^3/s$
Static Delivery Pressure = 784.8 N/m^2
Static Suction Pressure = -196.4 N/m^2
Static Pressure Gradient ΔPs = 981.2 Pa
Air Density = 1.165 kg/m^3
Speed of impeller rotation N = 2800 rpm
Optimized number of blades z = 16
Outlet Blade Angle $\beta 2 = 90°$
Suction Temperature Ts = 30ºC = 303º K
Atmospheric Pressure Patm = 1.01325×10^5 Pa
Atmospheric Temperature Tatm = 30ºC = 303ºK
Design of Impeller:

- Impeller eye and inlet duct size: Let inlet duct size is to be 10% higher than impeller inlet diameter or impeller eye size. This will make conical insertion of inlet duct and flow acceleration at impeller eye or inlet.

$$D_{duct} = 1.1D_{eye} = 1.1D_1$$

Assuming no loss during 90º turning from eye inlet to impeller inlet, the eye inlet velocity vector will be remain same as absolute velocity vector at the entry of impeller.

$$V_{eyet} = V_1 = V_{ml}$$

Further the tangential velocity component is to be 10% higher than axial velocity component for better induction of flow.
So, Inlet Tip velocity
$U_1 = 1.1V_1 = 1.1V_{ml}$ $U_1 = 1.1V_1 = 1.1V_{ml}$
$Q = \frac{\pi}{4} X\ D_{eye}^2\ X\ V_1$
$Q = \frac{\pi}{4} X\ D_1^2\ X\ V_1$
$V_1 = \frac{(4 X Q)}{\pi X D1^2}$
$U_1 = \frac{(\pi X D1 X N)}{60} = 1.1\ V_1$
$\frac{(\pi X D1 X N)}{60} = 1.1 \frac{(4 X Q)}{\pi X D1^2}$
Here Q=0.5 m^3/s and speed of impeller rotation N=2800 rpm,
∴Impeller Inlet Diameter
$D1 = 0.168\ m = D_{eye}$
∴ Peripheral speed at inlet
$U_1 = \frac{(\pi X D1 X N)}{60} = 24.63\ m/s = 1.1V_1$
$V_1 = 22.45\ m/s = Vm_1 = V_{eye}$
$D_{duct} = 1.1D_1 = 185$ mm
$W_1 = \sqrt{U1^2 + V1^2} = 33.37$ m/ s

- Impeller inlet blade angle
  $\tan\beta_1 = \frac{V1}{U1}$
  $\beta_1 = 42.35^0$
- Impeller width at inlet
  Here Z=16 and assumed blade thickness t = 2 mm

$Q = [\pi D_1 - zt]\ X\ b_1\ X\ V_{m1}$
$b_1 = 45$ mm

- Impeller outlet parameters:

The Fan power = ΔP X Q = 490.6 W

Considering 10% extra to accommodate flow recirculation and impeller exit

Hydraulic losses.
So, 1.1 X Fan power = 539.66 W
Power, $P = \dot{m}\ X\ W_s$
Specific work done, W_s = 926.45 W/(kg/s)
Euler power = $\dot{m}\ X\ V_{u2}\ X\ U_2$
Taking $V_{u2} = 0.8U_2$
$U_2 = 34.03$ m/s
$V_{u2} = 27.22$ m/s
And $U_2 = \frac{(\pi X D2 X N)}{60}$
$D_2 = 0.232$ m
Taking width of blade at inlet = outlet blade width
$b_1 = b_2$
$Q = [\pi D_2 - zt]\ X\ b_2\ X\ V_{m2}$
$V_{m2} = 16$ m/ s
$W'_2 = \sqrt{Wu2^2 + Vm2^2} = 17.39$ m / s
$V'_2 = \sqrt{Vu2^2 + Vm2^2} = 31.58$ m / s
$\tan \alpha'_2 = \frac{Vm2}{Vu2}$
$\alpha'_2 = 30.45^0$

- **Design of Volute Casing**
  Analyzing steady flow energy equation at inlet and exit:

$$\frac{P1}{\rho 1} + \frac{1}{2}V1^2 + gz1 + Ws = \frac{P2}{\rho 2} + \frac{1}{2}V4^2 + gz2$$

Neglecting potential difference,

$$V4^2 = \frac{-2\ [P2-p1]}{\rho f} + V_1^2 + 2W_s$$

Hence casing outlet velocity, V4 = 25.93 m/s
$Q = A_v V_4$
Where Av is Exit area of volute casing = $A_v = b_v (r_4 - r_3)$
Allowing for 5 mm radial clearance between impeller and volute tongue,
$r_3 = \frac{D2}{2} + 5 = 121$ mm
$D_3 = 2\ X\ 121 = 242$ mm
$b_v = 2.5\ X\ b_2 = 112.5$ mm
$Q = A_v V_4$
$0.5 = b_v (r_4 - r_3)\ X\ 25.93$
$r_4 = 292$ mm
$D_4 = 584$ mm

Now incremental volute angle with respect to increase in radius of casing
$r_\Theta = r_3 + \frac{\Theta}{360} X\ \Delta r$
The calculated volute radiuses at different volute angles are given in below table:

θ in Degree	Volute Radius r in m
0	0.121
60	0.150
120	0.178
180	0.207
240	0.235
300	0.264
360	0.292

Radius of Volute Tongue $r_t = 1.075r_2 = 1.075 \text{ X } 0.116 = 0.125$m
Angle of Volute Tongue
$\Theta_t = \frac{132\log10(rt/r2)}{\tan\alpha 2} = 7.26^0$

Hydraulic, leakage and power Losses:

Leakage loss:

$Q_L = c_d \text{ X } \pi \text{ X } D_1 \text{ X } \delta \text{ X } \sqrt{\frac{2 \text{ X Ps}}{\rho}} = 0.0213 \text{ m}^3/\text{s}$

Suction pressure loss:

$dp_{suc} = \frac{1}{2} \text{ X } k_i \text{X } \rho \text{ X } V_{eye}^{\ 2} = 190.76$ Pa

Impeller pressure loss:

$dp_{imp} = k_{iii} \text{ X } \frac{1}{2} \text{ X } \rho \text{ X } (W_1 - W'_2)^2 = 37.18$ Pa

Volute pressure loss:

$dp_{vc} = k_{iii} \text{ X } \frac{1}{2} \text{ X } \rho \text{ X } (V'_2 - V_4)^2 = 7.23$ Pa

Disc friction loss:

$T_{df} = \pi \text{ X } f \text{ X } \rho \text{ X } \omega_2^{\ 2} \text{ X } \frac{(r2)^5}{5} = \pi \text{ X } f \text{ X } \rho \text{ X } (U2 / r_2)^2 \text{ X } \frac{(r2)^5}{5}$

Where, f is material friction factor in order of 0.005 for mild steel sheet metal.

$T_{df} = 0.0066$ Nm

Hence Power loss due to disc friction,

$P_{df} = \frac{(2 \text{ X } \pi \text{ X N X T})}{60} = 1.94$ W

Efficiencies:

Hydraulic efficiency

$\eta_{hy} = \Delta p/(\Delta p + d_{pimp} + d_{pvc}) = 0.8065$ = **80.65 %**

Volumetric efficiency

$\eta_{vol} = Q/(Q+Q_L) = 0.959$ = **95.9 %**

Total efficiency

$\eta_{Total} = \eta_{hy} + \eta_{vol} = 0.7736$ = **77.36 %**

Ideal shaft power required to run the fan

$= \frac{\Delta P + dpsuc + dpimp + dpvc)(Q+QL)}{\eta Total} +$

Power loss due to disk friction

= 821.7 W

So, Torque = 2.804 Nm

Shaft diameter:

Ds = **= 11.9 mm**

Table 2: Impeller inlet dimension

Parameters	Symbol	Unit	Value
Peripheral Velocity	U1	m/s	24.63
Relative Velocity	W1	m/s	33.37
Meridian Velocity	Vm1	m/s	22.45
Absolute Velocity	V1	m/s	22.45
Impeller Diameter	D1	Mm	168
Width Of Blade	b1	Mm	45
Blade Angle	β1	Degree	42.35
Inlet duct diameter	Dduct	Mm	185
Eye Diameter	Deye	Mm	168
Eye velocity	Veye	m/s	22.45

Table no 3: Impeller Outlet Dimensions

Parameters	Symbol	Unit	Value
Peripheral Velocity	U2	m/s	34.03
Relative Velocity	W2’	m/s	17.39
Swirl velocity	VU2’	m/s	27.22
Meridian Velocity	Vm2	m/s	16.00
Absolute Velocity	V2’	m/s	31.58
Impeller Diameter	D2	Mm	232
Width Of Blade	b2	Mm	45
Blade Angle	β2	Degree	90º

Table no 4: Volute Casing

Parameters	Symbol	Unit	Value
Width Of Casing	Bv	Mm	112.5
Outlet Velocity Of Casing	V4	m/s	25.93
Scroll Radius at Inlet	r3	Mm	121
Scroll Radius at Outlet	r4	mm	292
Scroll Height	Hs	mm	172
Volute Tongue Angle	Θt	Degree	7.26
Radius of Tongue	Rt	mm	125

Considering various Losses efficiencies are calculated:

Table no 5: Efficiencies

Parameters	Symbol	Unit	Value
Hydraulic Efficiency	η_{hy}	%	80.65
Volumetric Efficiency	η_{vol}	%	95.92
Total Efficiency	η_{total}	%	77.36

VI. MODAL ANALYSIS:

It is the study of the dynamic properties of structures under vibration excitation. Modal analysis uses the overall masses and stiffness of a structure to find the various periods at which it will naturally resonate. That periods of vibration are very important to note in vibration of any machine, as it is imperative that a components or nearby system's natural frequency does not match the frequency of machine. If a structure's natural frequency matches a component's frequency, the structure may continue to resonate and experience structural damage.

The goal of modal analysis in a structural mechanics is to determine the natural mode shapes and frequencies of an object or structure during free vibration. This is common to use the finite element method (FEM) to perform this analysis because, like other calculations using the FEM and the object being analyzed can have arbitrary shape and the results of the calculations are acceptable. Detailed modal analysis determines the fundamental vibration mode shapes and corresponding frequencies. It can be relatively simple for basic components of a simple system, and extremely complicated when qualifying a complex mechanical device exposed to periodic wind loading. These systems require accurate determination of mode shapes and mode shapes natural frequencies using techniques such as Finite Element Analysis.

Today, modal analysis is the procedures of finding the mode shapes & natural frequency of a machine or structure. In the general meaning, the modal analysis is a process of determining the dynamic characteristic of a system in form of natural frequency, mode shapes and damping factors and from this we can generate a mathematical model for its dynamic behavior (Jimin, 1998). We can design the structural noise as well as vibration applications if we understand better on natural frequency and mode shape. A mode shape is a pattern of vibration executed by a mechanical system at a specific frequency.The response of the structure is different at the different natural frequencies. These deformation patterns are called mode shapes.

Results for modal analysis of MS:

Mode 1:

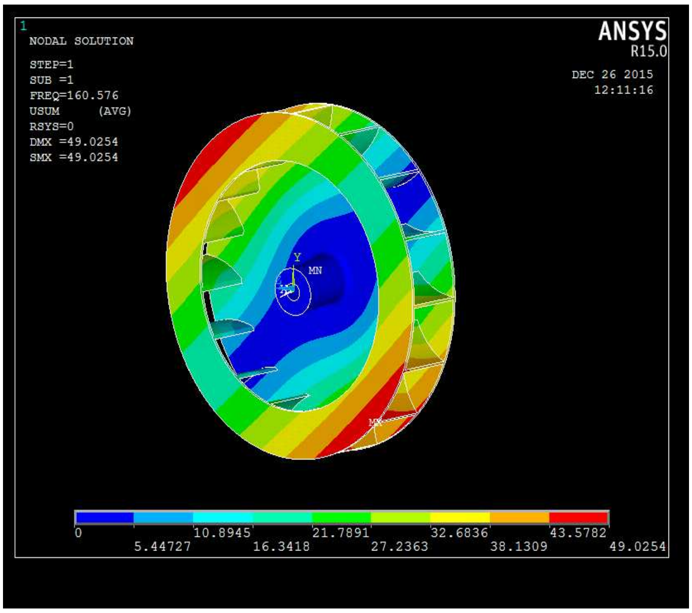

Fig: 1st mode frequency of blower impeller

The frequency of 1st mode is **160.57** hz.

Mode 2:

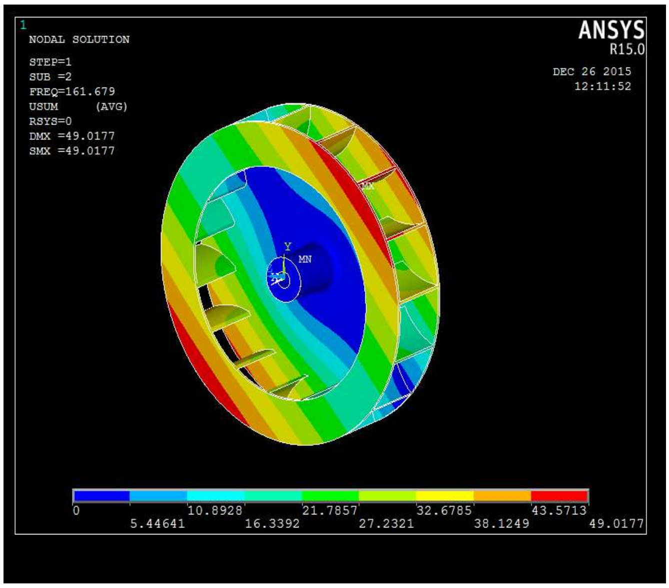

Fig: 2nd mode frequency of blower impeller

The frequency of 2nd mode is **161.67** hz.

Mode 3:

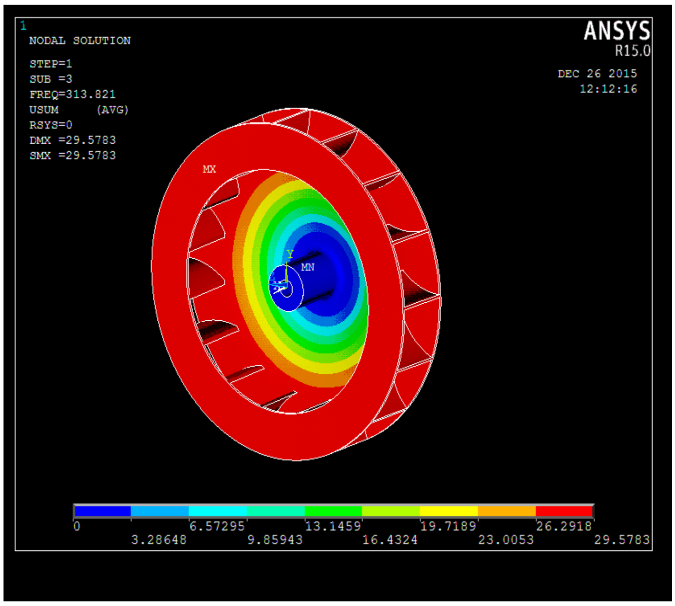

Fig: 3rd mode frequency of blower impeller

The frequency of 3rd mode is **313.8**hz.

Mode 4:

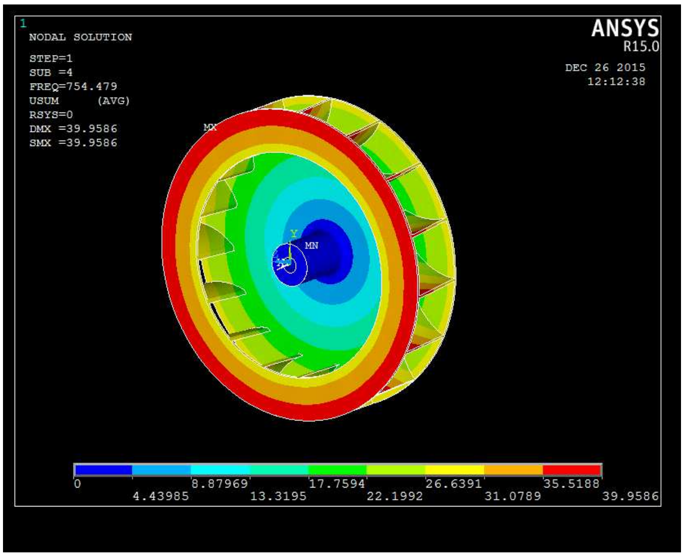

Fig: 4th mode frequency of blower impeller
The frequency of 4th mode is **754.47** hz.

Mode 5:

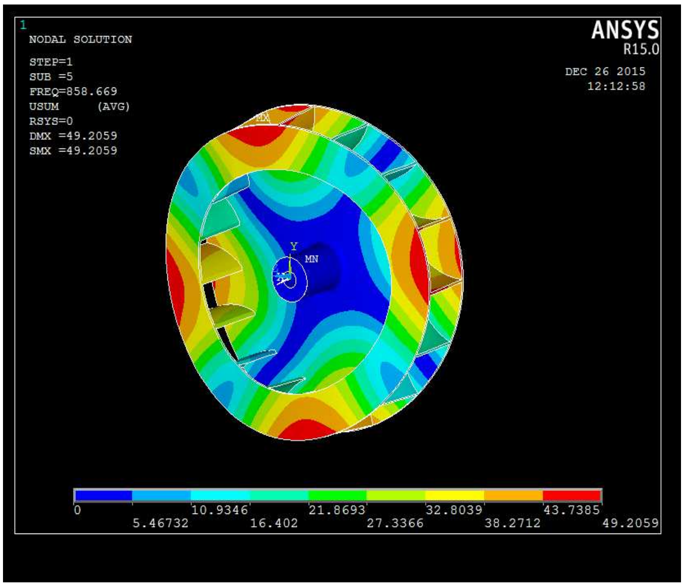

Fig: 5th mode frequency of blower impeller
The frequency of 5th mode is **858.66** hz**.**

Mode 6:

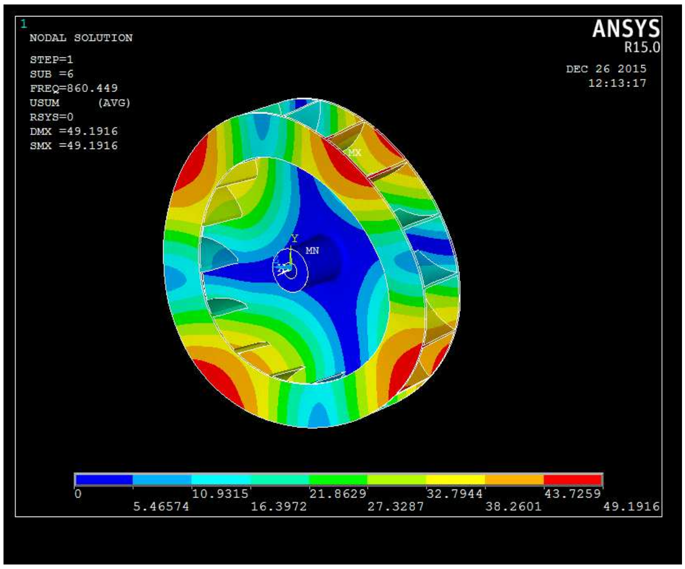

Fig: 6th mode frequency of blower impeller
The frequency of 6th mode is **860.44** hz.

Results for modal analysis of Glass Fiber:

Mode 1:

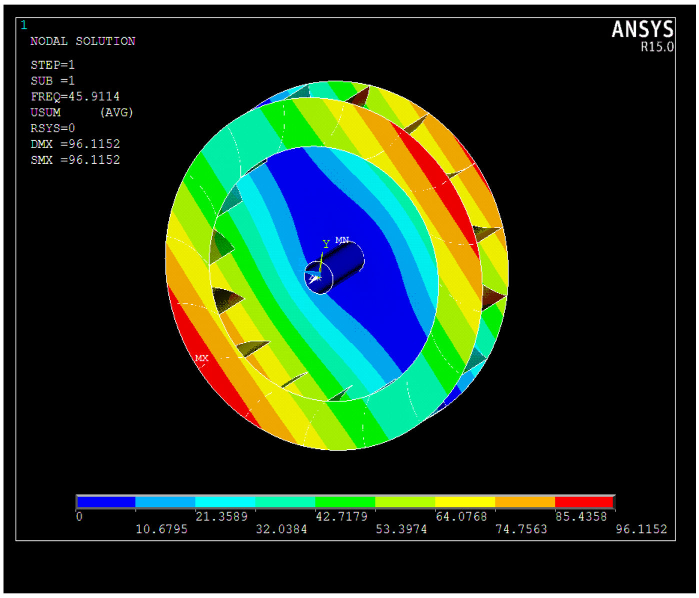

Fig: 1st mode frequency of blower impeller
The frequency of 1st mode is **45.9** hz.

Mode 2:

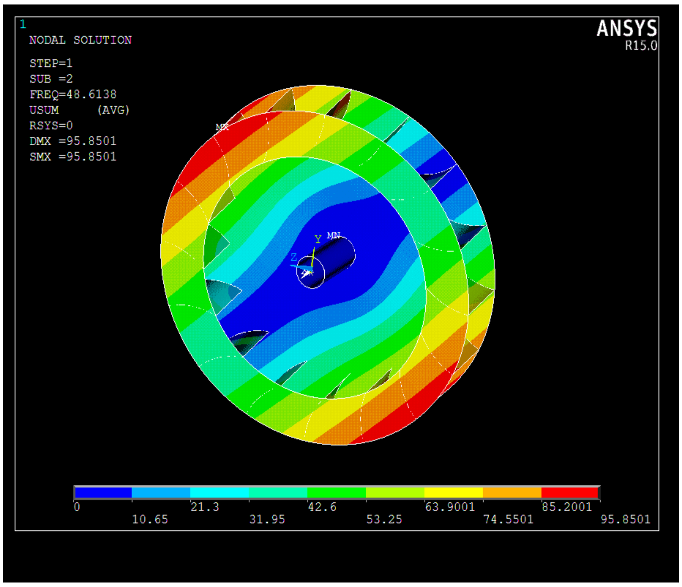

Fig: 2^{nd} mode frequency of blower impeller
The frequency of 2^{nd} mode is **48.61** hz.

Mode 3:

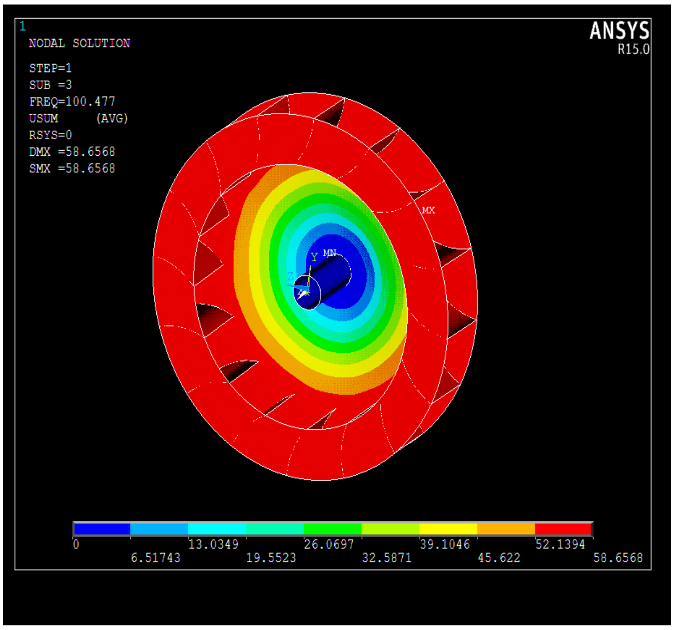

Fig: 3^{rd} mode frequency of blower impeller
The frequency of 3^{rd} mode is **100.47** hz**.**

Mode 4:

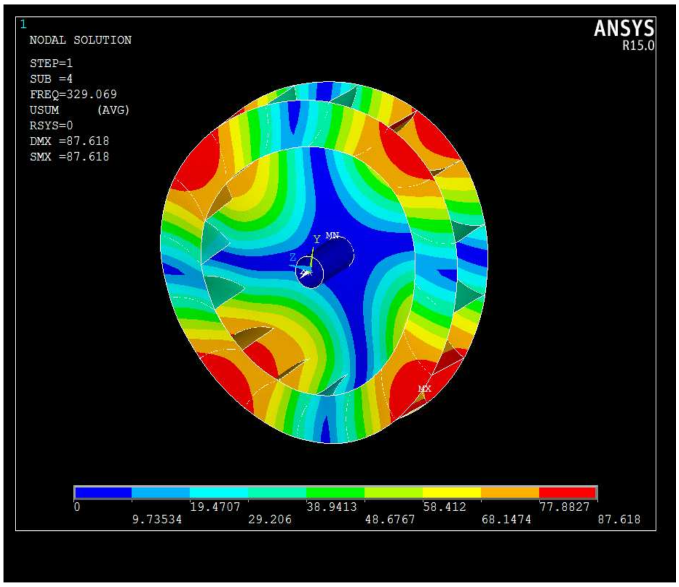

Fig: 4^{th} mode frequency of blower impeller
The frequency of 4^{th} mode is **329.06** hz.

Mode 5:

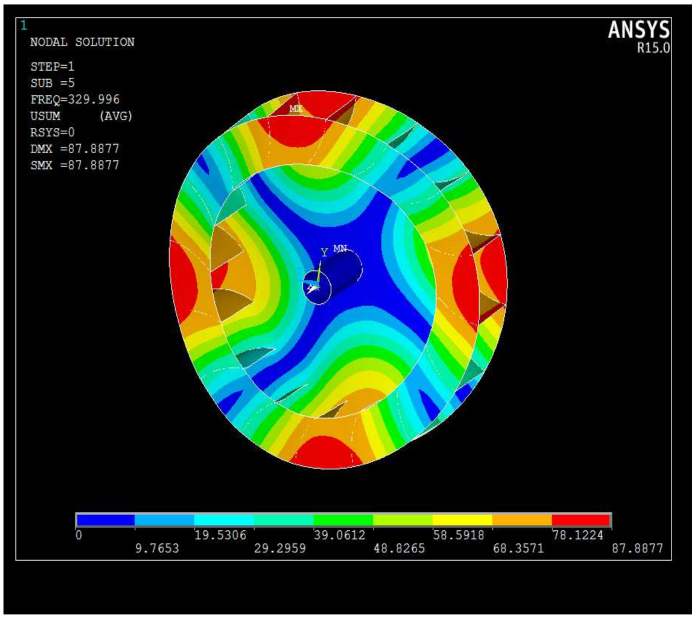

Fig: 5^{th} mode frequency of blower impeller
The frequency of 5^{th} mode is **329.9** hz**.**

Mode 6:

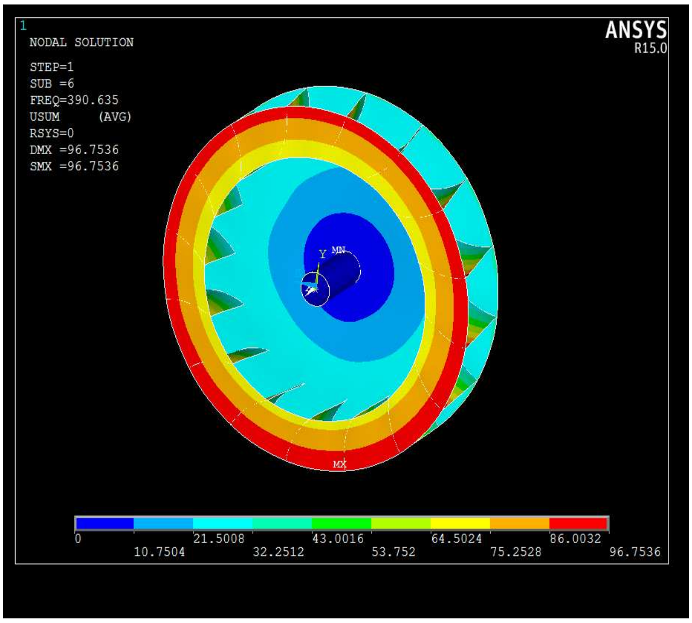

Fig: 6th mode frequency of blower impeller
The frequency of 6th mode is **390.6** hz.

Comparison of Modal Analysis:

Sr.No.	Natural frequency of blower impeller For MS	Natural frequency of blower impeller For Glass fiber
1	160.57	45.9
2	161.67	48.61
3	313.8	100.47
4	754.47	329.06
5	858.66	329.9
6	860.44	390.6

Conclusion:

Centrifugal blower impeller was studied thoroughly. Design calculations were done based on which 3D model was drawn in CATIAV5 software. Meshing was done in Hypermesh.

Modal analysis on the blower impeller with MS and EPOXY material is done. Different mode shapes and their frequency have to be found. Mode shapes and frequency shows the response of the system in natural condition. Modal Analysis result shows the natural frequency of blower impeller for MS material is high as compared to natural frequency of blower impeller for Glass fiber.

Reference:

1. Samson Idowu, “The Design of a Closed-Type-Impeller Blower for a 500kg Capacity Rotary Furnace”, Engineering Materials Development Institute Akure, Ondo State, Nigeria, AU J.T. 12(1): 50-56 (Jul. 2008)
2. Shalinirai, Prabhachand, “Centrifugal Fan Impeller Design with Optimization of Blade”, International Journal of Applied Engineering Research, ISSN 0973-4562 Vol.7 No.11 (2012)
3. Y Srinath, K.Monhar Reddy, “Modeling & Analysis of Centrifugal Blower using Composite Material”, Journal of Mechanical and Civil Engineering e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 9, Issue 6 (Nov. - Dec. 2013), PP 17-25
4. Kusekar S.K., Lavnis A.K, “Optimization of critical parts of centrifugal blower by Modal & CFD Analysis” International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163 Volume 1 Issue 12 (December 2014)
5. Kay ThiMyaing, HtayHtay Win, “Design and Analysis of Impeller for Centrifugal Blower using Solid Works”, International Journal of Scientific Engineering and technology research, ISSN 2319-8885 Vol.03,Issue.10 May-2014, Pages:2138-2142
6. Robert Paul. M, “Analysis and Optimization of Centrifugal Blower Using CFD”,International Journal of Innovative Research in Science, Engineering and Technology ISSN (Online) : 2319 – 8753 ISSN (Print) : 2347 – 6710
7. Adgale Tushar Balkrishna ,P.D.Darade, Govind Raiphale,“Vibration Analysis Of Centrifugal Blower Impeller For Various Materials Using FEA” International Journal of Research in Engineering and Technology eISSN: 2319-1163 pISSN: 2321-7308
8. C. N. Jayapragasan, Sumedh J. Suryawanshi and K. Janardhan Reddy, “Design Optimization Of Centrifugal Fan Of Travelling Cleaner”, Journal of Engineering and Applied Sciences ISSN 1819-6608
9. M.Sampathkumar,.DsvsraVaraprasad,Vijaykumar, “Static Analysis of Centrifugal Blower Using Composite Material”, The International Journal Of Engineering And Science ISSN (e): 2319 – 1813 ISSN : 2319 – 1805