Design & Analysis of Centrifugal Pump Impeller by FEA

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Abstract - A centrifugal pump is a rot dynamic pump that uses a rotating impeller to increase the pressure of a fluid. Centrifugal pumps are commonly used to move liquids through a piping system. The fluid enters the pump impeller along or near to the rotating axis and is accelerated by the impeller, flowing radially outward into a diffuser or volute chamber (casing), from where it exits into the downstream piping system. Its purpose is to convert energy of a prime mover (a electric motor or turbine) first into velocity or kinetic energy and then into pressure energy of a fluid that is being pumped. Centrifugal pumps are used for large discharge through smaller heads. centrifugal pumps converts mechanical energy from a motor to energy of a moving fluid; some of the energy goes into kinetic energy of fluid motion, and some into potential energy, represented by a fluid pressure or by lifting the fluid against gravity to a higher level. The transfer of energy from the mechanical rotation of the impeller to the motion and pressure of the fluid is usually described in terms of centrifugal force, especially in older sources written before the modern concept of centrifugal force as a fictitious force in a rotating reference frame was well articulated. The concept of centrifugal force is not actually required to describe the action of the centrifugal pump. In this paper analysis on MS & SS pump impeller is done in order to optimize strength of centrifugal pump. This paper gives the static & Modal analysis of MS & SS Pump Impeller to check strength of Pump & vibrations produced by pump.

Key Words: *Analysis, Pump Impeller, Optimization, MS, SS, etc.*

1. PROBLEM IDENTIFICATION:

Most of the centrifugal pump impellers are made up with Mild Steel which has more density. This is main cause of high weight of pump. In addition to this it has high corrosion and less fatigue strength.

The mild steel can be replaced with alloy material (e.g. SS, Inconel, Aluminum alloys) to reduce the weight, improve corrosion resistance and fatigue strength is more as compare to different alloys material and composite material. Due to less stiffness, deformations produced for the same material is more as compared to composite material and different alloys.

2. LITERATURE SURVEY :

[1]. A Syam Prasad, BVVV Lakshmipathi Rao, A Babji, Dr P Kumar Babu , "Static and Dynamic Analysis of a Centrifugal Pump Impeller" Alloys are playing major role in many engineering applications. They offer outstanding mechanical properties, flexibility in design capabilities, and ease of fabrication. Additional advantages include light weight and corrosion resistance, impact resistance, and excellent fatigue strength. In this paper study of static and modal analysis of a centrifugal pump impeller which is made of three different alloy materials. (viz., Inconel alloy 740, Incoloy alloy 803, Warpaloy) The best material for design of impeller is Inconel 740. Specific modulus of Inconel 740 obtained in static analysis is 10 % higher than other material. The natural frequency in modal analysis is 6% higher than other material. The deformation of Inconel 740 in static analysis is reduce by 12%.

[2] Karthik Matta, Kode Srividya, Inturi Prakash , "Static and Dynamic Response of an Impeller at Varying Effects"

An impeller is a rotating component of a centrifugal pump, usually made of iron, steel, bronze, brass, aluminum or plastic. The modeling of the impeller was done by using solid modeling software, CATIA V5 R18. It is proposed to design a blower with composite material, analyze its strength and deformation using FEM software. In order to evaluate the effectiveness of composites and metal blower and impeller using FEA packaged (ANSYS). Modal analysis is performed on both Aluminum and composite centrifugal blower impeller to find out first 5 natural frequencies. If number of blade and outer diameter increases stresses and deformation also increases all are allowable limit. Total analysis result compares and found that composite materials are having less deformation and stresses.

[3]. G. Kalyan, K.L.N. Murty. "Design and Optimization of Centrifugal Pump Guide Vanes" In this paper an impeller of a centrifugal pump is designed and modeled in 3D modeling software Pro/Engineer.. Materials used are steel and aluminum. The optimization of the impeller design is done by observing the results obtained from the analysis performed. The results considered are stress frequency velocity pressure flow rates. Analysis is done in ANSYS.

By observing the structural analysis result the stresses by increasing number of blades andincreasing the angle of blade. When Aluminum material is used the stresses are less than that of steel. By observing modal analysis results the frequencies are reducing by increasing the number of blade .

[4]. Pramod J. Bachche1, R.M.Tayade "Finite Element Analysis of Shaft of Centrifugal Pump" Centrifugal pump is world one of the oldest water pumping devises. In this paper study Shaft of centrifugal pump for static and dynamic analysis. The shaft is analyzed by using finite element analysis technique for stresses and deflections. The total work is carried out in two stages first stage is static analysis. In this stage pump shaft is analyzed for stresses and deflection and same results are verified using graphical integration method. And second for dynamic analysis, in this stage result obtained by static analysis are used to calculate dynamic forces coming in pump shaft. Again shaft is analyzed in dynamic input condition and results are verified by using graphical integration method. Maximum deflection and stress are generated to minimum flow condition. Maximum dynamic deflection is obtained 11% less than allowable deflection and Maximum stresses for dynamic is obtained 18% less than allowable tensile strength.

[5] S.Rajendran and Dr. K Purushothaman "Analysis of centrifugal pump impeller using ANSYS-CFX"

In this paper analysis of centrifugal pump impeller design is carried out using ANSYS-CFX. It is most common pump used in industries and domestic application. The complex internal flow in centrifugal pump impeller can predicted by ANSYS-CFX. A centrifugal pump is kinetic device. Liquid entering the pump receives kinetic energy from the rotating impeller. The centrifugal action of impeller accelerates the liquid to high velocity, transferring mechanical (rotational) energy to the liquid. The flow pattern, pressure distribution in blade passage and blade loading of centrifugal pump impeller are discussed in this paper. Centrifugal pump impeller without volute casing is solved at designed mass flow rate is high. Total efficiency of pump is 30% increases.

[6].Static Analysis of Centrifugal Blower Using Composite Material 1Mr M.Sampathkumar, 2Mr.Dsvsra Varaprasad, 3Mr.Vijaykumar

This paper is static and model analysis of centrifugal blowers using composite materials Centrifugal blowers are used in naval applications and motors which have high noise levels. The noise generated by a rotating component is mainly due to random loading force on the blades and periodic iteration of incoming air with the blades of the rotor. The Contemporary blades in naval applications are made up of Aluminum or Steel and generate noise that causes disturbance to the people working near the blower. 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 stresses of E-Glass/Epoxy blower obtained in static analysis are within the allowable stress limit. The natural frequency of E glass blower is reducing by 16.6% to 27.7% because of high stiffness.

3. OBJECTIVES OF STUDY:

[1] To check strength of pump by static analysis using various material like MS, SS.

[2] To reduce weight of pump by using different material.

[3] To determine natural frequency by modal analysis of MS, SS.

4. METHODOLOGY:

4.1 Modeling of pump impeller by using CATIA V5R20

- **ASSEMBLY**

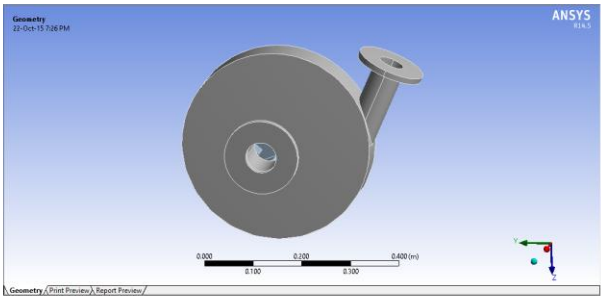


Fig. 1 Assembly of Centrifugal Pump

- **GEOMETRY**

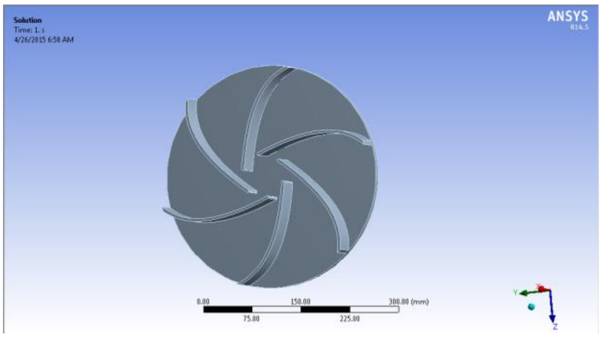


Fig. 2 Geometry of Centrifugal Pump Impeller

4.2 FEA MODEL:

- MESH GENERATION:

In order to carry out a finite element analysis, the model we are using must be divided into a number of small pieces known as finite elements. Since the model is divided into a number of discrete parts, FEA can be described as a discretization technique. In simple terms, a mathematical net or "mesh" is required to carry out a finite element analysis. If the system under investigation is 1D in nature, we may use line elements to represent our geometry and to carry out our analysis. If the problem can be described in two dimensions, then a 2D mesh is required. Correspondingly, if the problem is complex and a 3D representation of the continuum is required, then we use a 3D mesh. Area elements can be triangular or quadrilateral in shape. The selection of the element shape and order is based on considerations relating to the complexity of the geometry and the nature of the problem being modeled. Membrane elements don't have any thickness. As a consequence they have no bending stiffness; loads can only be carried in the element plane. Plate & shell elements are used to model thin walled regions in 3D space. The plate element is formulated around plate theory, which assumes that the load is carried via bending. Shell elements are used to model shells, where there is combination of flexure & membrane action. Plate elements are considered applicable where the out of plane distortion is little more than the plate thickness. There are also special elements, which facilitate accurate modeling of thick plates. If the deflection is greater than the plate thickness, membrane action should be considered, and so shell elements should be used. Shell element nodes have five degrees of freedom; the missing is the in-plane rotational freedom (sometimes referred to as the drilling freedom). Solid elements come in different varieties. Axisymmetric elements are used to describe the cross-section of an axially symmetric part. Plane strain elements are used to describe section of long objects (such as a shaft or wall cross-section). The strain in the out-of-plane direction is taken to be zero, reflecting the assumption that the strain is in one Plane stress elements are used to describe sections of thin objects (such as a wrench). The stress in the out-of-plane direction is taken to be zero, reflecting the assumption that the stress is in one plane

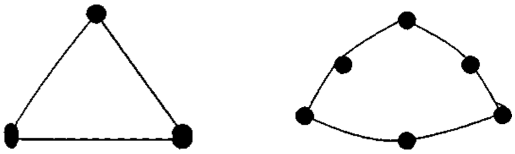
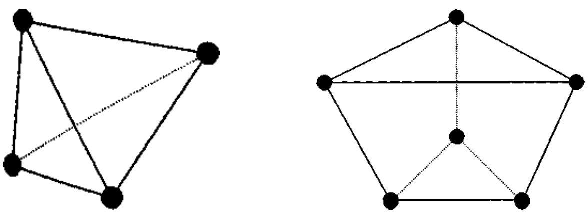


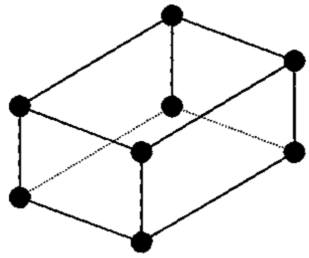
Fig. 3 Two dimensional elements

➢ VOLUME MESHING:

3D elements take the form of cubes called hexahedrons (hexes), 3D triangles called tetrahedrons (test) and 3D wedges known as pentahedrons. Decisions on element selection hinge on understanding the role of the element shape and order of interpolation. Modeling with 3D-Elements is the most flexible approach. These types of elements are used for thick structures that have neither a constant cross section nor an axis of symmetry. Solid modeling will nearly always make analysis preparation easier. Meshing and solving can take a long time; particularly if the structure is thin-walled (large numbers of elements are required to produce a mesh). The three dimensional element are shown in Fig.4



Tetrahedral Hexahedral



Prismatic

Fig. 4 Three dimensional elements

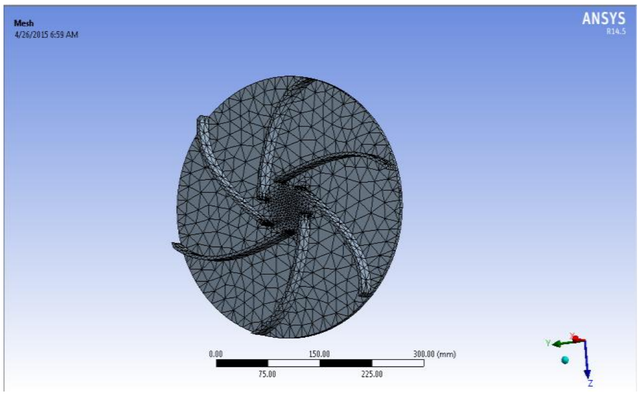


Fig. 5 FEA Model of Centrifugal Pump Impeller

Table -1: Number of Node & Elements

Statistics	
Nodes	14775
Elements	7636
Mesh Metric	None

➢ **SUPPORT**

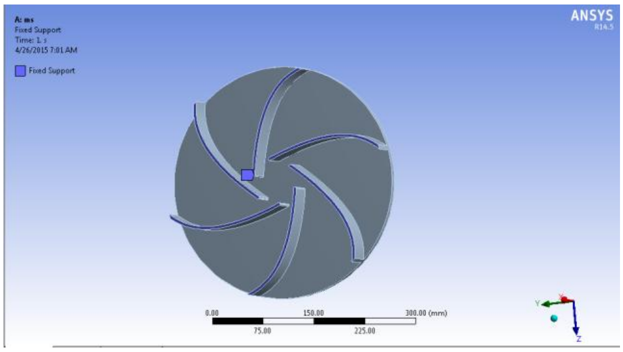


Fig. 6 Fixed Support of Pump Impeller

➢ **MOMENT**

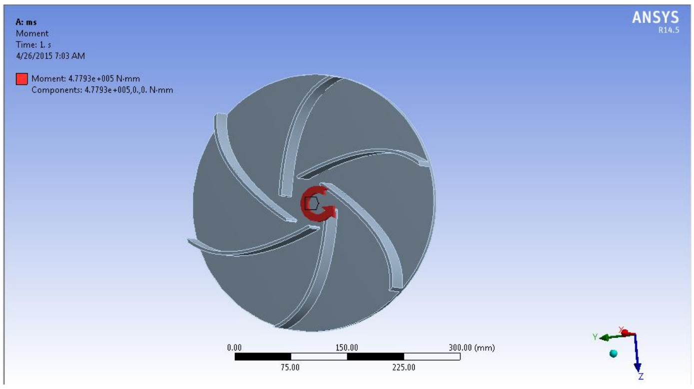


Fig. 7 Moment Applied at Pump Impeller

5. STATIC ANALYSIS OF CENTRIFUGAL PUMP IMPELLER:

➢ Procedure For Static Analysis In Ansys:

1. Build the FE model as explained in chapter 4.2
2. Define the material properties such as young's modulus and density etc.,
3. Apply boundary condition and pressures.
4. Solve the problem using current LS command from the tool bar

ANSYS 14.5:

ANSYS Work bench can be thought of as a software platform or framework where you perform your analysis (Finite Element Analysis) activities. In other words, workbench allows you to organize all your related analysis files and databases under same frame work. Among other things, this means that you can use the same material property set for all your analyses.

The ANSYS Workbench platform allows users to create new, faster processes and to efficiently interact with other tools like CAD systems. In this platform working on Metaphysics simulation is easy. Those performing a structural simulation use a graphical interface (called the ANSYS Workbench Mechanical application) that employs a tree-like navigation structure to define all parts of their simulation: geometry, connections, mesh, loads, boundary conditions and results. By using ANSYS workbench the user can save time in many of the tasks performed during simulation. The bidirectional links with all major CAD systems offer a very efficient way to update CAD geometries along with the design parameters.

➢ Static Analysis For Equivalent (Von-Misses) Stress:

Static analysis of critical part of centrifugal Pump i.e. static analysis of fan is done by using FEA. Fan is core part of centrifugal pump and all the performance of blower is totally depends upon fan, so fan is chosen critical part of centrifugal pump for the static analysis. Analysis is done for the material MS, SS, respectively, in order to check Equivalent stresses and its corresponding deformations induced in each material.

5.1 STATIC ANALYSIS OF MS PUMP IMPELLER:

➢ TOTAL DEFORMATION:

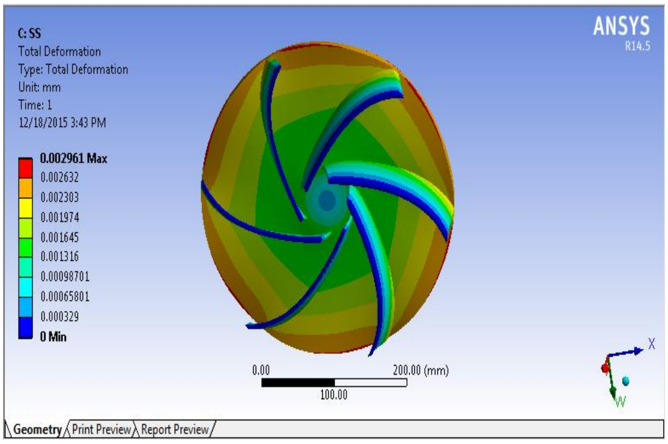


Fig. 8 Total Deformation of MS Pump Impeller

➢ EQUIVALENT STRESS:

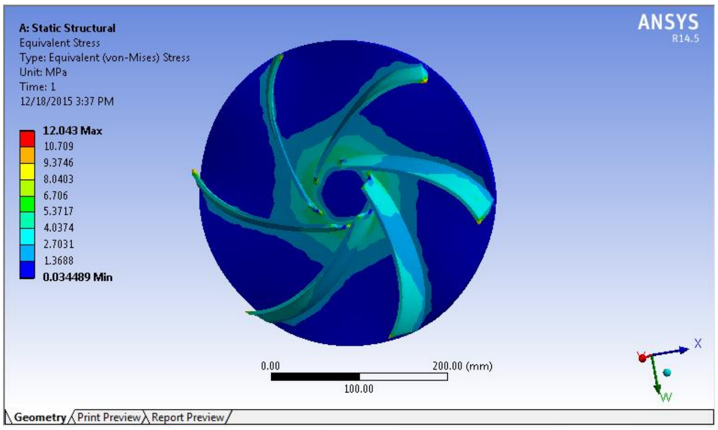


Fig. 9 Maximum Stress induced in MS Pump Impeller

➢ EQUIVALENT STRAIN:

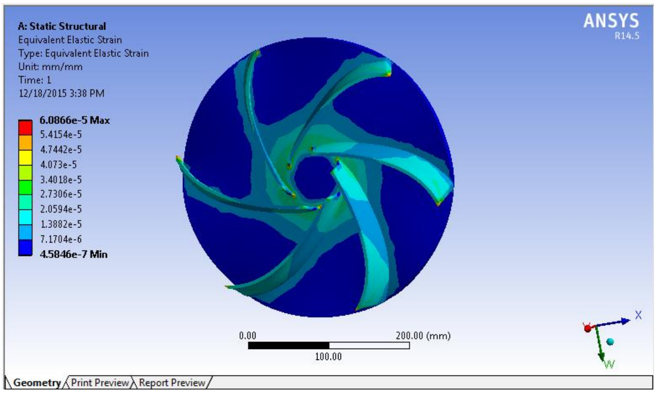


Fig. 10 Maximum Strain for MS Pump Impeller

5.2 STATIC ANALYSIS OF SS PUMP IMPELLER:

➢ **TOTAL DEFORMATION:**

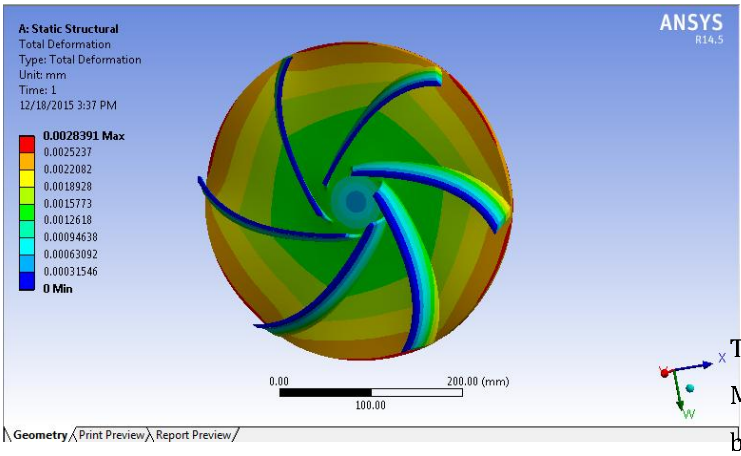


Fig. 11 Total Deformation of SS Pump Impeller

➢ **EQUIVALENT STRESS:**

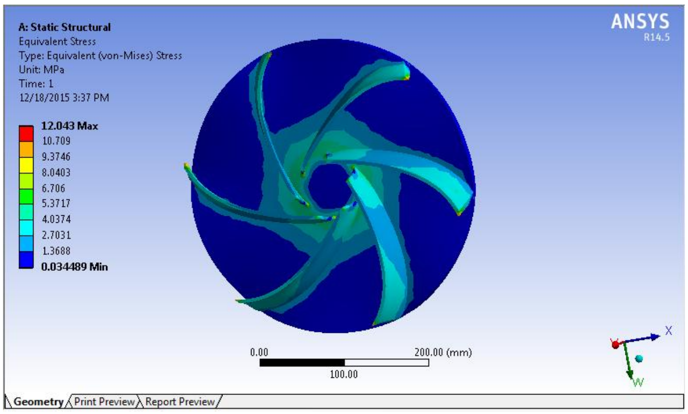


Fig. 12 Maximum Stress induced in SS Pump Impeller

➢ **EQUIVALENT STRAIN:**

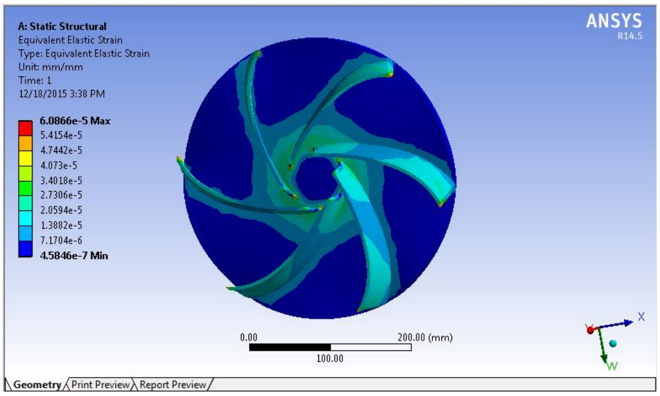


Fig. 13 Maximum Strain for SS Pump Impeller

6. RESULTS & DISCUSSIONS:

Table -2: Result and Discussion

Sr. No.	Material	Stress (MPa)	Deformation (mm)	Weight (Kg)
1	MS	12.043	0.0028391	29.202
2	SS	11.974	0.002961	28.83

The maximum deflection induced in metallic pump fan i.e. MS material is 0.002839 mm, which is in safe limits. Hence based on rigidity the design is safe. The maximum induced stress for the same material is 12.043 Mpa which is less than the allowable stress i.e working sress by considering factor of safety (160Gpa).Hence the design is safe based on strength. If we compare corresponding deformation of the material SS on above results MS material, SS having minimum deformation therefore there are less chances of failure of the pump fan as compare to MS materials. Hence the strength of pump gets increased because of the SS material. From the above result table it is clear that weight of the SS pump (28.83Kg) fan material is minimum as compared to MS (29.202Kg) material, hence weight of the pump fan reduced (optimized).

7. MODAL ANALYSIS OF CENTRIFUGAL PUMP FAN:

➢ **Procedure For Modal Analysis In ANSYS:**

1. Build the FE model explained in chapter 6
2. Define the material properties such as young's modulus and density etc
3. Apply boundary conditions
4. Enter the ANSYS solution processor in which analysis type is taken as modal analysis, and 'by taking mode extraction method, by defining number of modes to be extracted. Solution method is chosen as Block lanczos method.
5. Solve the problem using current LS command from the tool bar.

➢ **MATERIAL PROPERTIES OF THE PUMP:**

The analysis is performed on (i) MS pump Impeller (ii) SS pump Impeller

➢ **Material properties of MS pump:**

1. Young's modulus E= 210 GPa
2. Poisson's ratio NUXY=0.303
3. Mass density =7860 kg/m3
4. Damping co-efficient =0.008

➢ **Material properties of SS pump:**

1. Yield stress 0.2 % proof minimum- 170
2. Elastic modulus- 193 GPa
3. Mass density-8000 kg/m3
4. Hardness B (HRB) max- 217
5. Elongation (%)- 40 minimum

➢ **Modal Analysis of MS Pump Fan:**

Tabular Data

	Mode	Frequency [Hz]
1	1.	1959.
2	2.	2098.2
3	3.	2100.2
4	4.	2404.6
5	5.	2406.
6	6.	2526.2

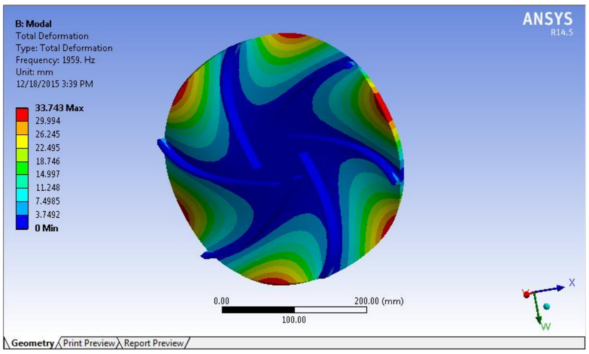


Fig. 14 First Mode Shape of MS Pump Impeller

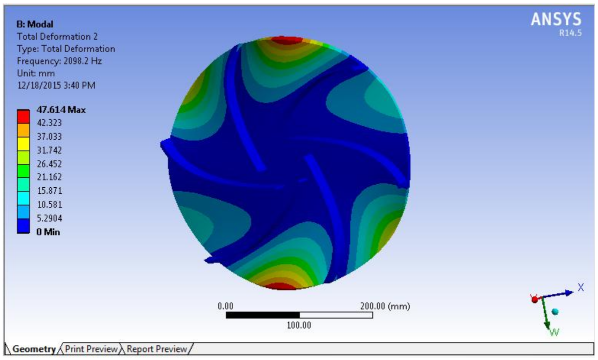


Fig. 15 Second Mode Shape of MS Pump Impeller

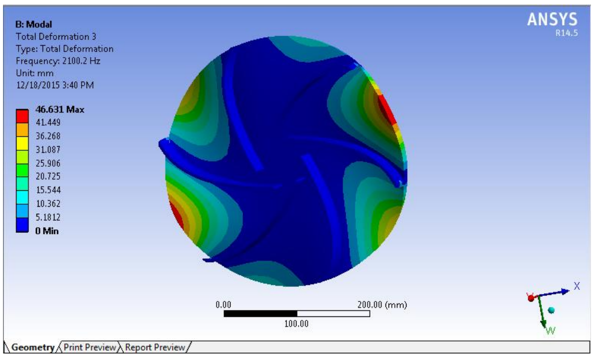


Fig. 16 Third Mode Shape of MS Pump Impeller

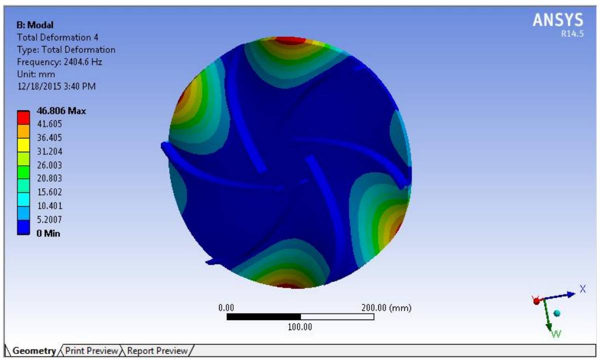


Fig. 17 Fourth Mode Shape of MS Pump Impeller

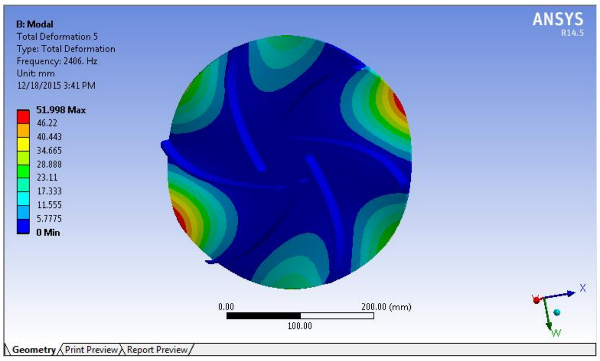


Fig. 18 Fifth Mode Shape of MS Pump Impeller

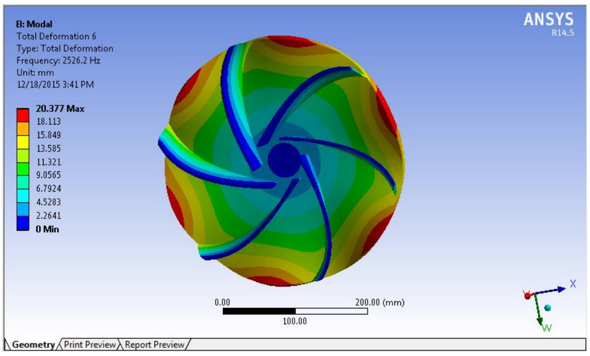


Fig. 19 Sixth Mode Shape of MS Pump Impeller

- **Modal Analysis of SS Pump Impeller:**

Tabular Data

	Mode	Frequency [Hz]
1	1.	1938.5
2	2.	2076.
3	3.	2078.1
4	4.	2378.6
5	5.	2380.
6	6.	2495.3

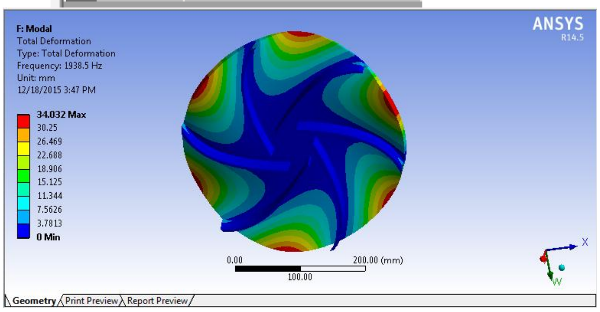


Fig. 20 First Mode Shape of SS Pump Impeller

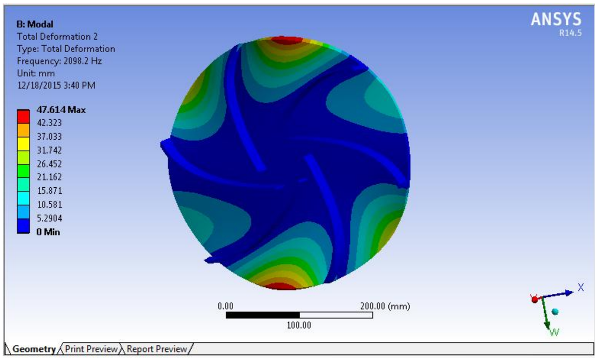


Fig. 21 Second Mode Shape of SS Pump Impeller

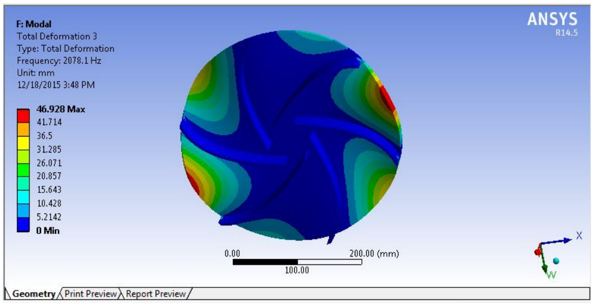


Fig. 22 Third Mode Shape of SS Pump Impeller

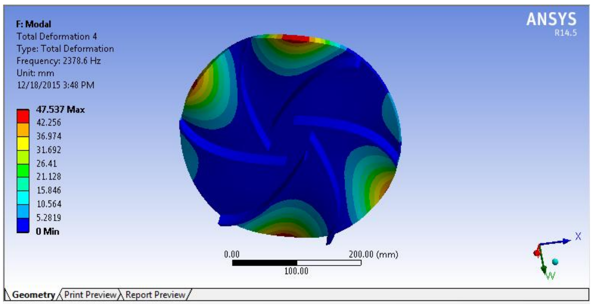


Fig. 23 Fourth Mode Shape of SS Pump Impeller

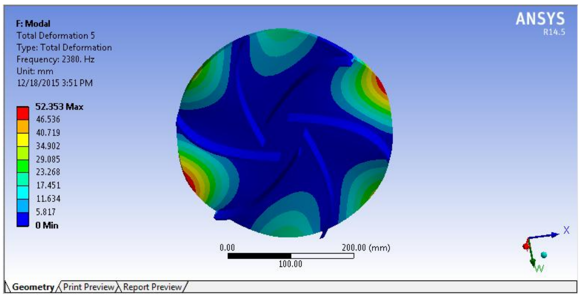


Fig. 24 Fifth Mode Shape of SS Pump Impeller

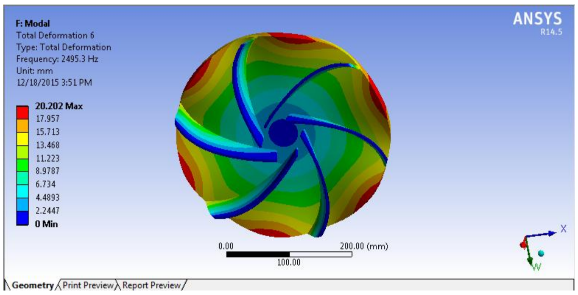


Fig. 25 Sixth Mode Shape of SS Pump Impeller

Table-3: Comparison of first six natural frequencies Of MS, SS, Pump Fan

No. of Modes	Natural frequencies of MS pump fan in Hz	Natural frequencies of SS pump fan in Hz
1	543.42	538.27
2	543.86	538.73
3	564.45	559.7
4	675.86	667.93
5	675.99	668.07
6	1094.1	1080.05

The minimum and maximum deformation of MS, SS, pump fan for six different modes is as shown in above table. By doing static and dynamic analysis of centrifugal pump fan it is clear that weight of the weight SS fan is high as compared to MS. The deformations induced in pump fan are also high which leads to lower the strength of the pump. Due to lower strength there may be possibility to fail the material. From the above table it is clear that natural frequency of MS pump fan is high as compared to SS.

8. CONCLUSION:

On doing static & modal analysis of pump impeller it is clear that, the maximum deflection induced in metallic pump fan i.e. MS material is 0.002839 mm, which is in safe limits. The maximum induced stress for the same material is 12.043 Mpa which is less than the allowable stress i.e working stress by considering factor of safety (160Gpa).Hence the design is safe based on strength. If we compare corresponding deformation of the material SS on above results MS material, SS having minimum deformation therefore there are less chances of failure of the pump fan as compare to MS materials. Hence the strength of pump gets increased because of the SS material. From the above result table-2 it is clear that weight of the SS pump (28.83Kg) fan material is minimum as compared to MS (29.202Kg) material, hence weight of the pump fan reduced (optimized). The natural frequencies of MS pump fan are more than SS pump impeller.

9. REFERENCES:

[1] A Syam Prasad, BVVV Lakshmipathi Rao, A Babji, Dr P Kumar Babu , "Static and Dynamic Analysis of a Centrifugal Pump Impeller" International Journal of Scientific & Engineering Research, Volume 4, Issue 10, October-2013, pp966-971

[2] Karthik Matta, Kode Srividya, Inturi Prakash , "Static and Dynamic Response of an Impeller at Varying Effects" IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 11, Issue 1 Ver. III pp 101-106 (Jan. 2014),

[4] Pramod J. Bachche1, R.M.Tayade " Finite Element Analysis of Shaft of Centrifugal Pump" IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 7, Issue 3 (Jul. - Aug. 2013), pp 37-42

[5] S.Rajendran and Dr. K Purushothaman "Analysis of centrifugal pump impeller using ANSYS-CFX" International Journal of Engineering Research & Technology (IJERT) Vol. 1 Issue 3, May - 2012 pp 1-6

[6].Static Analysis of Centrifugal Blower Using Composite Material 1Mr M.Sampathkumar, 2Mr.Dsvsra Varaprasad, 3Mr.Vijaykumar The International Journal Of Engineering And Science (IJES) , Volume 3 Issue 9, 2014 , pp 25-31 ,