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Design and Analysis of Centrifugal Pump Impeller for Optimizing Strength & Weight of Impeller

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Abstract: - The pump is mechanical device which conveys liquid from one place to another place. It can be defined as a hydraulic machine which converts the mechanical energy into hydraulic energy. If mechanical energy is converted into pressure energy by means of centrifugal force acting on the fluid, for conveying liquid from one place to another then that pump is called centrifugal pump. It is a similar to a reversed of an inward radial flow reaction turbine. In this pump flow of liquid is in radial outward direction. The impeller increases kinetic energy of liquid which is coming from sump. Our project is industrial defined project. Shreeji diesel is the industry which gives us a project for optimizing the strength and the weight of centrifugal pump impeller. In our project, we are doing analysis on Mild Steel & Stainless steel pump impeller in order to optimize strength of centrifugal pump. Our Project gives the static & Modal analysis of Mild Steel & Stainless steel Pump Impeller to check strength of Pump & vibrations produced by pump.

Key Words:— *Pump Impeller , Optimization , Strength , Weight, ANSYS Workbench.*

I. INTRODUCTION

A pump is a device that moves fluids (liquids or gases), or sometimes slurries, by mechanical action. Pumps are classified into three major groups according to the method they use to move the fluid:

- Direct lift pumps,
- Displacement pumps &
- Gravity pumps.

Pumps operation is by some mechanism (typically reciprocating or rotary), and consume energy to perform mechanical work by moving the fluid. Pumps operate via many energy sources, including manual operation, electricity, engines, or wind power, come in many sizes, from microscopic for use in medical applications to large industrial pumps. Mechanical pumps are used in a wide range of applications such as pumping water from wells, aquarium filtering, pond filtering and aeration etc. Below Figure:1 Shows the working principle of the Pump.

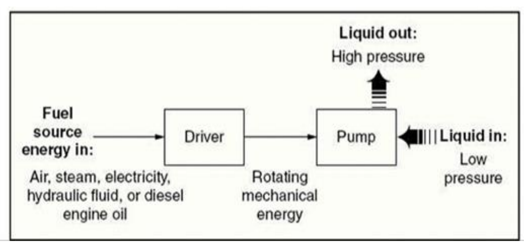

Fig.1. Working Principle of a Pump

II. LITERATURE SURVEY

Our project deals with the optimization and analysis in design of centrifugal pump so in related to these following research papers have been studied:

- Sumit N. Gavande, Prashant D. Deshmukh , Swapnil S. Kulkarni [2014] the objective of the study is in-depth analysis of various methodologies to increase the discharge of the pump. In this research paper for increasing the discharge of the pump some methodologies were given. Some relate to change in design of pump whereas some methodologies relate to change in design of suction side.
- Pramod J. Bachche, R.M.Tayade [2013] have analysed the shaft by using finite element analysis

technique for stresses and deflections. The total work is carried out in two stages. First stage is static analysis and second stage is dynamic analysis.

- Bin Cheng al. [2012] have proposed a study to analyse the flow characteristics of the lateral diversion and intake pumping stations. The main conclusion of this research paper is the inlet flow pattern is more complex than single lateral division & the flow pattern in the lateral diversion is similar with the bend flow.
- S.P.Asok al. [2011] have shown the 3D analysis in prediction of pressure drop taking place in helical-grooved labyrinth seals & having a good agreement with the experimental results. Helical-grooved labyrinth seals bring in additional energy losses due to flow bending effects.
- HSIAO Shih-Chun al. [2011] the main aim of study is to examine the hydrodynamics of a pump sump. The numerical results of stream wise velocity profiles and flow patterns are discussed and compared with experimental data.

III. Problem Definition

Our Industry Shreeji Diesels is small scale Industry they are manufacturing the centrifugal pump impeller for small specific speed application. Hence, the impeller used for it not needed too robust such as impellers which are needed for high specific speed application pumps. According to the requirement of the customers they are manufacturing the impeller. Generally, customer needed semi - open impeller because semi-open impeller is the most suitable for small specific speed application. Following are the reason why Shreeji diesels are using Mild Steel for Pump Impeller:

- It is recyclable.
- It is weldable.
- It is cost - effective.

Following are the problem they are facing by using mild steel

- Mild steel is having very less tensile strength.
- It has high corrosion
- It has less fatigue strength
- It has less stiffness

Weight of the pump is also very high. Due to this frequent customer complaint are arrived & they need problem of the solution. Here, we decide to search another material which is most appropriate to use in the pump impeller. According to research paper " Centrifugal pump design materials and specifications " published by Mertin Guner & Mehmet Melih Ozbsyer Following are the materials which are the most appropriate in using centrifugal pump impeller:

- Mild steel
- Cast iron
- Stainless steel
- Titanium-Nickel alloy
- Super duplex stainless steel
- Duplex stainless steel
- 316 stainless steel
- Nickel aluminium bronze
- Gunmetals.

One of the most important thing telling us by industry is their profit margin is less so that whatever you want to improvement needed should be less costly to the industry. Now after talking with various material suppliers we finally reached to the conclusion that cost of using the material is increases as follows:

Material options	Increasing cost
Titanium	↑
Nickel alloy	
Super duplex stainless steel	
Duplex stainless steel	
316 stainless steel	
Nickel aluminium bronze	
Gunmetals	
Austenitic cast iron	
Stainless steel	
Mild Steel	

From about table it is clear that after the mild steel stainless steel is second cheapest material used for the pump impeller.

Now, we have to prove how the stainless steel is more good as compared to mild steel by doing the static and the dynamic analysis mild steel and stainless steel pump impeller.

IV. Objective Of Study

Our objective of study is as follows:

- To provide the best suitable material to the industry for Centrifugal pump impeller in their budget.
- To inspect strength of pump impeller by static analysis using various material like Mild steel, Stainless steel.
- To decrease the weight of pump impeller by keeping the same dimensions and changing the material
- To determine natural frequency by modal analysis of Mild Steel, Stainless Steel.

V. Methodology

A. Assembly

There is the various modelling software available in the market. Computer-Aided Design (CAD) software allows building 3D models of parts and assemblies. CAD software has a drafting component that allows you to create 2D drawings of your parts that can be manufactured. CAD tools also have direct integration into an FEA (Finite Element Analysis) package so you can iterate seamlessly between design and analysis. Examples of 3D CAD software: SolidWorks, Unigraphics NX, CATIA, and Autodesk Inventor. Here by using AutoCAD software we are creating the 3D model of centrifugal pump and then import to the ANSYS 18.1 for further analysis. It is shown in following figure.2.

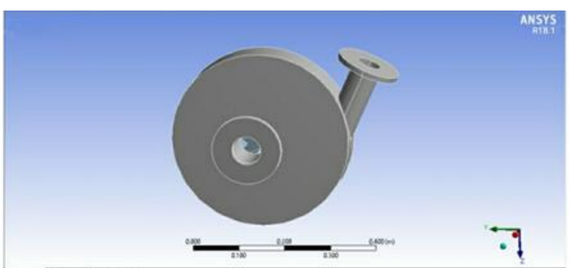

Fig.2. Assembly of Centrifugal Pump

B. Geometry

- A numerical description of impeller's geometry is transferred into a 3D CAD software.
- Below figure shows the geometry of impeller which is to be considered for all further analysis.

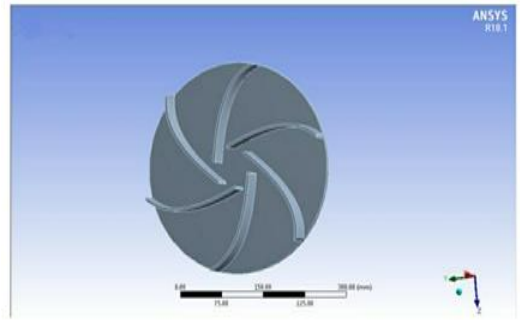

Fig.3. Geometry of Centrifugal Pump

C. FEA Model of Centrifugal Pump Impeller

- Structural analysis can be done with Finite Element Analysis (FEA). The Finite Element Analysis software allows you to analyse stresses and deflections in complex structures. A structure is typically modelled in a 3D CAD program, its geometry is built, a mesh is created to discretise the structure into elements, forces and constraints are applied, and the model can then be solved. From the solved model, you can interrogate stresses and deflections in the structure.
- Examples: ANSYS and NASTRAN.
- FEA model of centrifugal pump impeller is shown in the following figure.4.

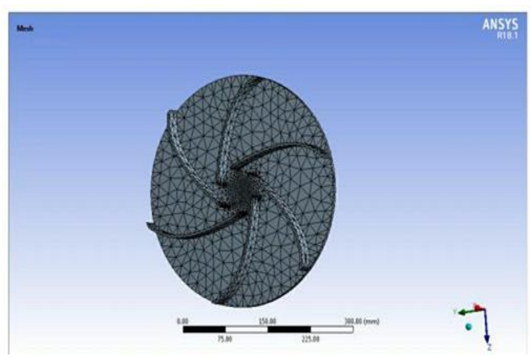

Fig.4. FEA Model of Centrifugal Pump Impeller

Statistics	
Nodes	14775
Elements	7636
Mesh Metric	None

Fig.5. Table of Nodes & Elements

Above Table shows the number of the nodes & elements in mesh generated for a centrifugal pump impeller. Now, for the static analysis of the Centrifugal Pump impeller It is necessary to fix the support. Generally according to the C.G. of the body place of fixed support as decided Here also we are doing the same. According to the C.G. of them centrifugal pump impeller we are fixing the support It is shown in following figure.6.

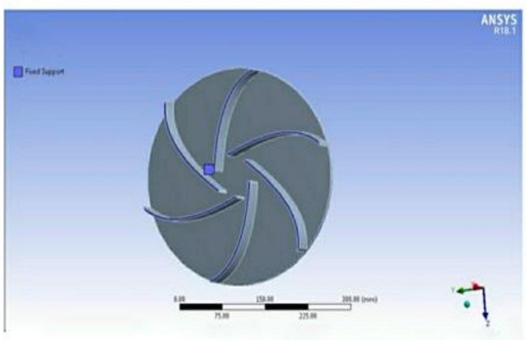

Fig.6. Fixed Support

VI. STATIC ANALYSIS OF CENTRIFUGAL PUMP IMPELLER

A. Procedure for Static Analysis in ANSYS

Following are the steps which are performed for static analysis in ANSYS:

- Build the FE model as explained in previous slides,
- Define the material properties such as young's modulus and density etc.,
- Apply boundary condition and pressures,
- Solve the problem using current LS command from the tool bar.

B. ANSYS 18.1

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.

C. Static Analysis for Equivalent Stress (Von - Misses Stress)

Static analysis of critical part of centrifugal Pump i.e. static analysis of fan is done by using FEA. Impeller is core part of centrifugal pump and all the performance of blower is totally depending upon impeller, so Impeller 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.

D. Static Analysis of Mild Steel Pump Impeller:

1. TOTAL DEFORMATION

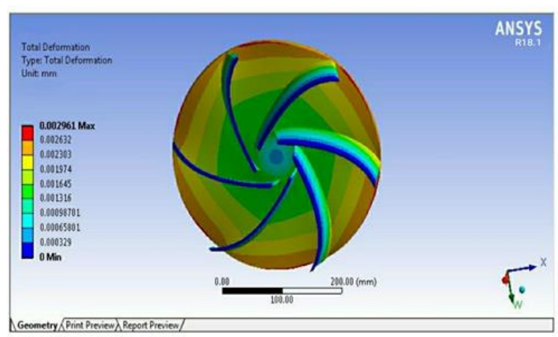

Fig.7. Total deformation in mild steel pump impeller

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2. Equivalent Stress:

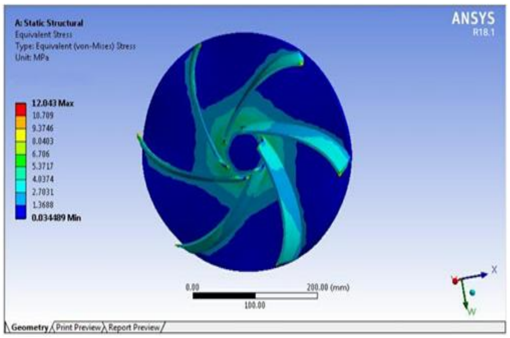

Fig.8. Equivalent stress in mild steel pump impeller

3. Equivalent Strain:

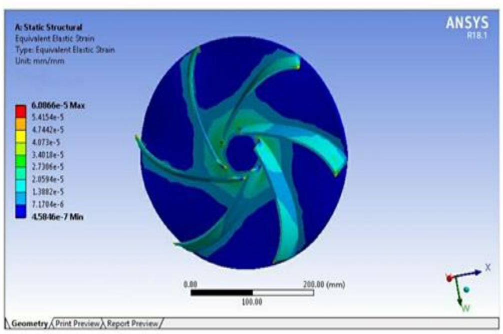

Fig.9. Equivalent strain in mild steel pump impeller

E. Static Analysis of Stainless Steel Pump Impeller

1. Total Deformation:

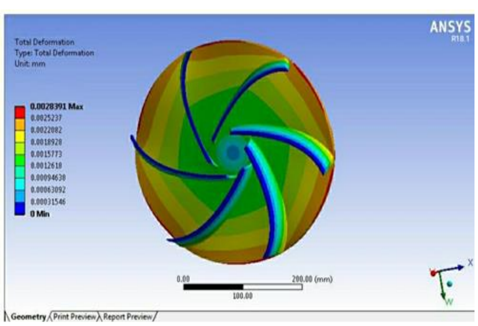

Fig.10. Total deformation in Stainless steel pump impeller

2. Equivalent Stress:

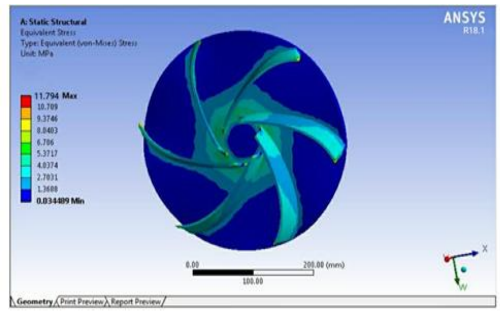

Fig.11. Equivalent stress in Stainless steel pump impeller

3. Equivalent Strain:

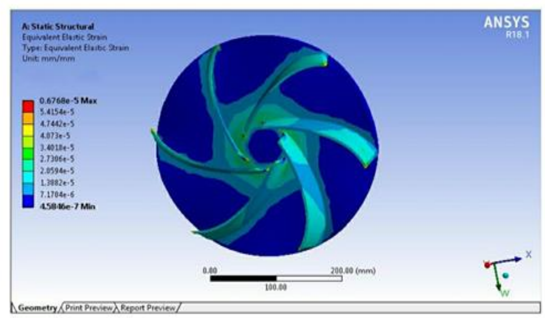

Fig.12. Equivalent strain in Stainless steel pump impeller

VII. RESULT & ANALYSIS

S.No.	Material	Stress (MPa)	Deformation (mm)	Weight (Kg)
1	Mild Steel	12.043	0.002961	29.202
2	Stainless Steel	11.974	0.0028391	28.83

- The maximum deflection induced in Mild Steel Pump Impeller i.e. MS material is 0.002961 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 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 Impeller 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) impeller material is minimum as compared to MS (29.202Kg) material, hence weight of the pump Impeller reduced (optimized).

VIII. Model Analysis Of Centrifugal Pump Impeller

A. Procedure for Modal Analysis in ANSYS

Following are the steps which are performed for static analysis in ANSYS

- Build the FE model as explained in previous slides,
- Define the material properties such as young's modulus and density etc,
- Apply boundary conditions,
- 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 / Direct method.
- Solve the problem using current LS command from the tool bar.

B. Material Properties of Pump

The analysis is performed on

- Mild Steel Pump Impeller
- Stainless Steel Pump Impeller

Material properties of Mild steel pump:

- Young's modulus E= 210 GPa
- Poisson's ratio =0.303
- Mass density =7860 kg/m³
- Damping co-efficient =0.008

Material properties of Stainless Steel pump:

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

C. Model Analysis for Mild Steel Pump Impeller

The frequencies of MS pump impeller for different modes are shown in following table

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

Different mode shape of MS pump impeller is shown in the following figures:

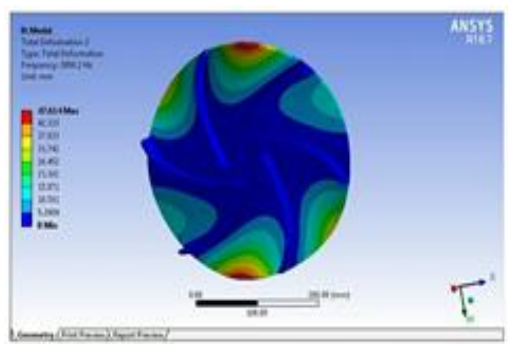

Fig.13. 1st mode shape of MS Pump Impeller

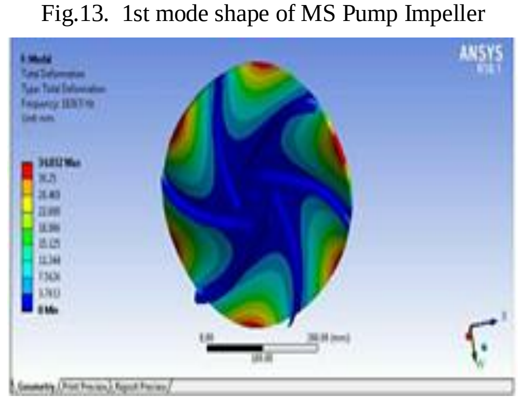

Fig.14. 2nd mode shape of MS Pump Impeller

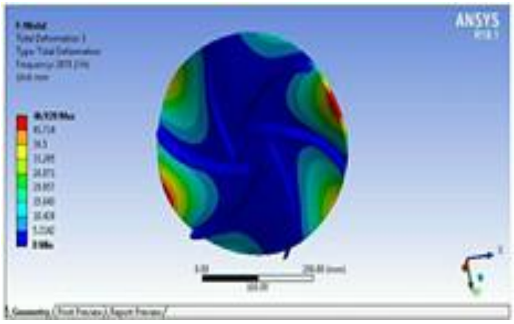

Fig.15. 3rd mode shape of MS Pump Impeller

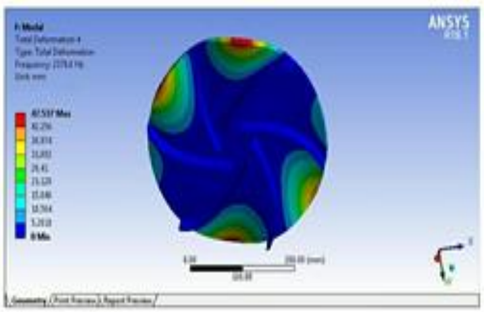

Fig.16. 4th mode shape of MS Pump Impeller

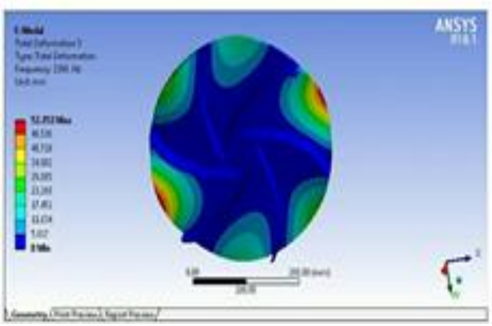

Fig.17. 5th mode shape of MS Pump Impeller

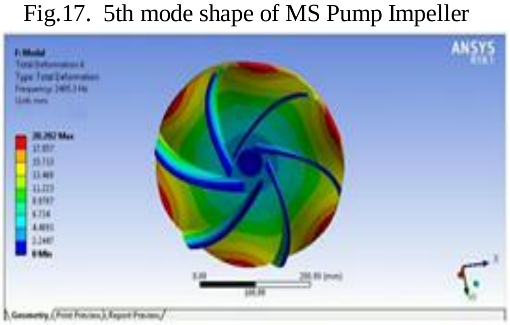

Fig.19. 6th mode of MS Pump Impeller

D. Model Analysis for Centrifugal Steel Pump Impeller

The frequencies of SS pump impeller for different modes are shown in following table:

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

Different mode shape of SS pump impeller is shown in the following figures

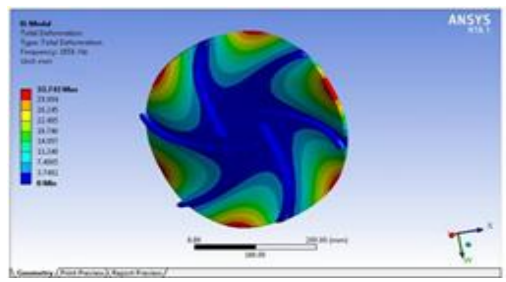

Figure.19. 1st mode shape of SS Pump Impeller

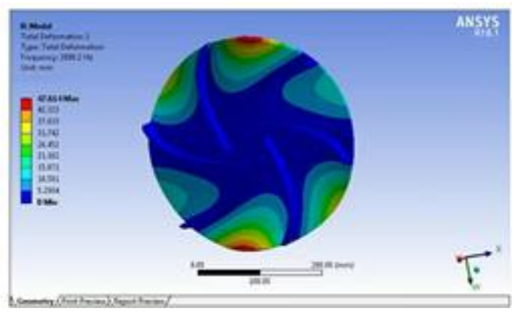

Fig.20. 2nd mode shape of SS Pump Impeller

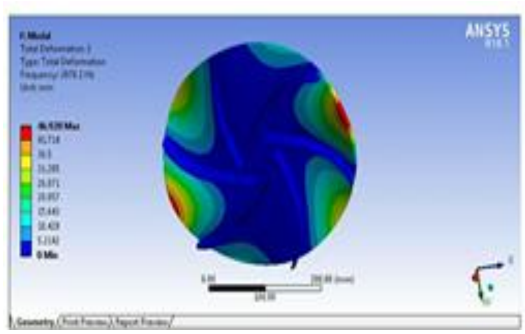

Fig.21. 3rd mode shape of SS Pump Impeller

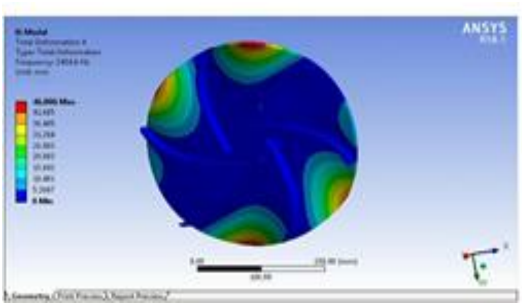

Fig.22. 4th mode shape of SS Pump Impeller

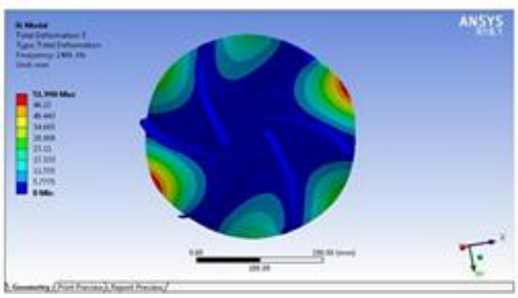

Fig.23. 5th mode shape of SS Pump Impeller

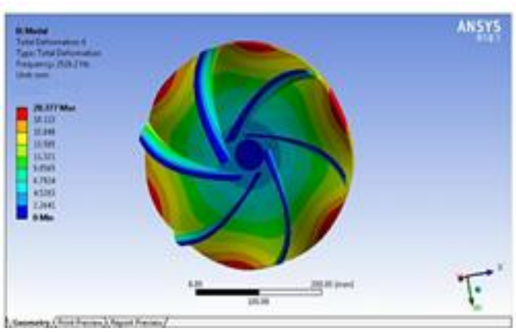

Fig.24. 6th mode of SS Pump Impeller

IX. Comparison Of Natural Frequencies

- From this table it is clear that natural frequencies of a stainless steel pump impeller is higher than mild steel pump impeller.
- It means that we can operate at a higher speed without encountering resonance by using stainless steel pump impeller.
- In this way, for getting higher speed stainless steel pump impeller are better as compared to mild steel pump impeller.

Number of Modes	Natural frequencies of Mild Steel Pump Impeller in Hz	Natural frequencies of Stainless Steel Pump Impeller in Hz
1	1978.5	1959.
2	2076 .	2098.2
3	2078.1	2100.2
4	2378.6	2402.6
5	2380.	2406.
6	2495.3	2526.2

X. Conclusion

By doing Static and model analysis of centrifugal pump impeller it is a clear that mild steel pump impeller induced maximum deflection as compared to stainless steel pump. 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 impeller as compare to MS materials. Hence, the strength of pump gets increased because of the stainless steel material. From the table 2, it is clear that weight of stainless steel pump impeller (28.83 kg) is lesser then mild steel pump impeller (29.202 kg) .In this way , the weight of centrifugal pump impeller is minimized (Optimized).

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