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Static Analysis And Material Optimization of Submersible Pump Impeller Using FEA

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Abstract : *In general, the Efficiency of a submersible pump (ηo) = Mechanical efficiency (ηm) × Volumetric efficiency (ηv). Most of the study has been done in the improvement of Hydraulic efficiency but overall efficiency depends on both factors Hydraulic and Mechanical. Mechanical components – for example, impeller weight and structure produce a mechanical loss that reduces the power transferred from the motor shaft to the pump or fan impeller. Also, the strength of the pump reduces due to stress corrosion problems in impeller which can be minimized using an alternate material having same/more strength. The modelling of the impeller will be done by using solid modelling software, CATIA. The meshing and boundary condition application will be carried using Hypermesh, it is also used to produce good and optimal meshing of the impeller to obtain accurate results and analysis has been done by using ANSYS. A static analysis on 3HP pump impeller has been carried out to examine the stresses and displacements of the submersible impeller. Conventional MS material is replaced with glass fiber composite material. After getting safe results from the analysis, the model will be fabricated and testing will be done on UTM.*
Keywords: *Submersible Pump Impeller, FEA, Static Analysis, Material Optimization, Glass Fiber.*

I. Introduction

Overall Efficiency of a centrifugal pump (ηo) = Mechanical efficiency (ηm) × Volumetric efficiency (ηv). Most of the analysis has been done in improvement of Hydraulic efficiency but overall efficiency depends on both factors Hydraulic and Mechanical (Mechanical Loss and Mechanical Efficiency). Mechanical components – such as impeller weight and structure generates a mechanical loss that reduces the power transferred from the motor shaft to the pump or fan impeller.

An impeller is a rotating component of a centrifugal pump, usually made of cast iron, steel, bronze, brass, aluminum or plastic, which transfers energy from the motor that drives the pump to the fluid being pumped by accelerating the fluid outwards from the center of rotation. The velocity achieved by the impeller transfers into pressure when the outward movement of the fluid is confined by the pump casing. Impellers are usually short cylinders with an open inlet (called an eye) to accept incoming fluid, vanes to push the fluid radially, and a splined, keyed or threaded bore to accept a drive-shaft. The modeling of the impeller was done by using parametric modeling software CATIA V5. The meshing and boundary condition application will be carried using Hypermesh, it is also used to generate good and optimum meshing of the impeller to obtain accurate results and analysis has been done by using ANSYS. ANSYS is dedicated finite element package used for determining the variation of stresses, strains and deformation across profile of the impeller.

A structural analysis has been carried out to investigate the stresses, strains and displacements of the impeller. Analysis is carried out on various materials (C.I., Steel, Aluminium and Composite) and the best material is suggested. In addition, various parameters of the impeller can be changed like no. of blades, blade angle and speed etc.

Fig.1. Submersible pump impeller

1.1 Problem Statement:
As the present submersible pump impeller is made up of material MS, the weight of the impeller is high because of material density. As the kinetic energy is converted to pressure/ hydraulic energy, stress generates in the impeller, therefore, it is necessary to do an analysis of the impeller strength which depends on the material used for the impeller. Also, the strength of the pump reduces due to stress corrosion problems in impeller which can be minimized using an alternate material having same/more strength.
Due to following conditions, mechanical efficiency reduces and power requirement of the pump increases.
• Non-optimized size of the impeller
• Weight of the pump impeller
• Impeller axial forces acting on side walls and internal blades
• Water head and pressure acting on impeller profile.

1.2 Objectives:
The main objective of the project is to weight optimize the impeller. This can be done by replacing conventionally used MS material with the glass fiber composite material. For this following objectives needs to be achieved:
• To study the existing model.
• Calculate forces and boundary conditions.
• Carryout meshing and analysis
• To carryout material optimization
• Testing on the fabricated model.

1.3. Scope
• An axial flow pump impeller 3 HP rating will be taken for reference and its parameters and loading parameters hence forth will be calculated.
• Literature Survey
• Design of pump impeller by using Solid works CAD Software
• Analysis of impeller for materials like MS, Glass fiber, etc.

1.4 Methodology

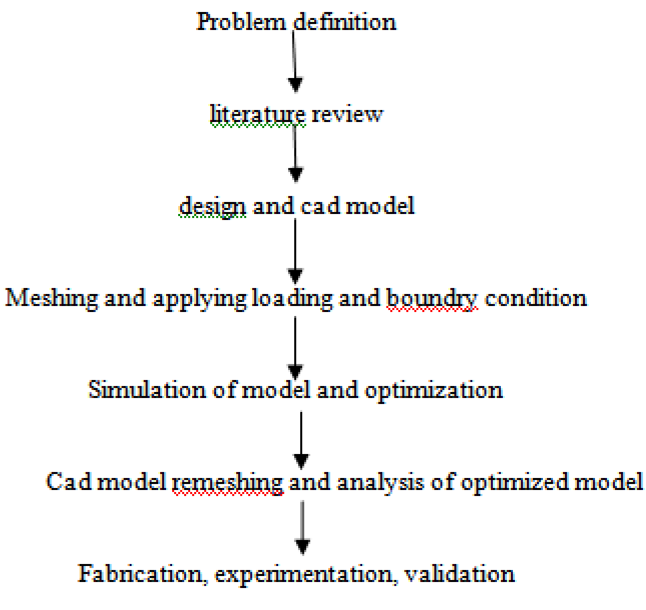

Fig.2 flow chart of methodology

II. Literature Review

Mohit Patil et. all In this study a low cost, light weight and high performance novel filament wound axial impeller of a multistage counter rotating axial compressor for compressing water vapor (R718) as refrigerant is investigated structurally. Three different fiber types were chosen as suitable materials for this study (Kevlar-49, S-Glass & Carbon fiber) with a standard epoxy resin for the composite matrix. Through means of FEA (Finite Element Analysis) method; stress, displacement and vibration analysis procedure is developed to assess the maximum stress, change in dimensions and natural frequencies of these impellers under constant operating conditions. The finite element modeling was performed on commercially avail- able software Abaqus. The modeling technique is explained in detail with regards to static structural and dynamic analysis of the impellers. Operating stresses, maximum shroud deflections, modal frequencies and effect of centrifugal stiffening is calculated and discussed in detail along with Campbell plots for each fiber material type. The study provides critical details about the structural behavior of the impellers and aims to provide a methodology to the compressor designer to support his decision in choosing the type of impeller and designing the housing.

In the research work the main focus in towards reduction of weight of the submersible pump impeller. The increasing weight of the impeller affects the overall performance of the pump. Therefore, the weight reduction of the impeller is the real need of industry. Impeller is one of critical component of submersible pump. There is scope to reduce the unsprung weight. Weight reduction of submersible pump is the objective of this exercise for optimization. Typically, the finite element software like OptiStruct (Hyper Works) is utilized to achieve this purpose. For optimization, FEA Ansys could also be utilized. The targeted weight or mass reduction for this exercise is about 10% without compromising on the structural strength.

III. Design And Properties

DIMENSION OF EXIST JOB:
D_{outer} = 97mm
D_{shaft} = 8mm
D_{hub} = 10mm
D_{eye} = 32 mm
Width = 7.25 ~ 8mm
No. of blade = 5 no.s
Radius of the blade = 141.6
Width of blade = 8 mm
$\beta_1 = 85^\circ$
$\beta_2 = 22.78^\circ$
Torque = 7.5 Nm

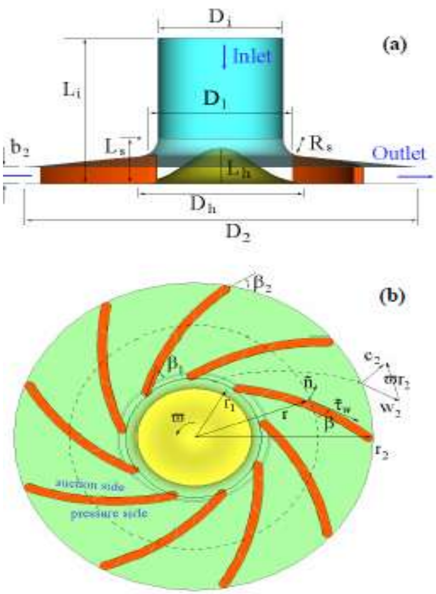

Fig:3 Details of impeller geometry

Boundary condition calculation:
$P = \rho g h$
Where,
P = Pressure of water, N/m2
ρ = mass of density of fluid = 10^3 Kg/m^3
H = height of fluid = 21 m
g = 9.81 m/s^2
∴ P = 206010 N/m2 = 0.21 mpa

IV. Analysis Of Impeller

4.1. Cad model

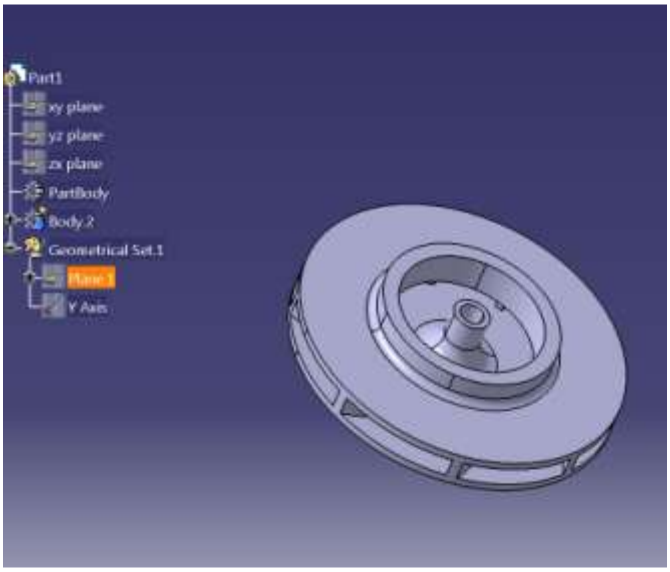

Fig 4. 3D CAD model of impeller

4.2.Meshing model
Number of nodes: 14041
Number of elements: 45439
Element size = 4 mm

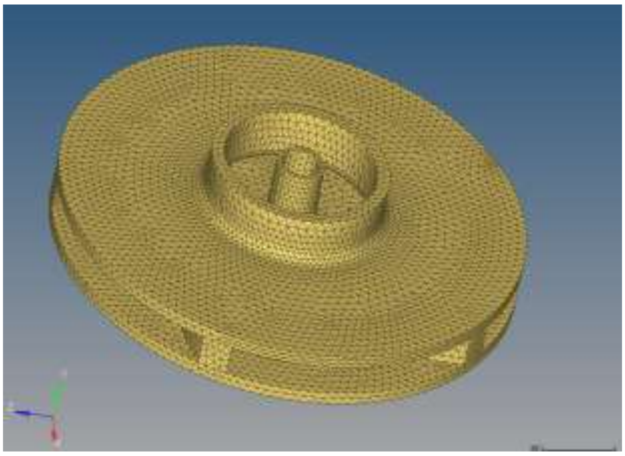

Fig:5 tetra-hedral meshing of pump impeller

4.3. Material Properties Of Steel
Youngs modulas =2$\times 10^{5} Mpa$
Poissons ratio = 0.3
Density =7.85$\times 10^{-6} kg/mm^{3}$
Thermal expansion= 1.2$\times 10^{-5}/0_{c}$
Tensile yield strength=250Mpa
Compressive yield strength=250Mpa
Tensile ultimate strength=460Mpa

4.4 Boundary Condition Application On Submersible Pump Impeller
The pump impeller is fixed as shown below

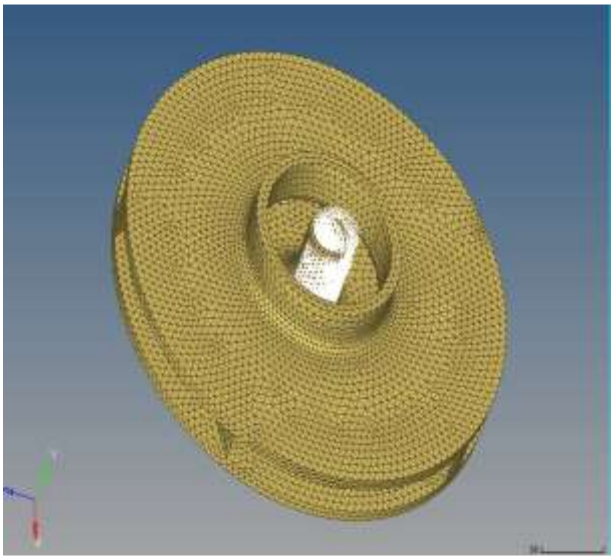

Fig.6 Fixed points in pump impeller

Loading conditions on submersible pump impeller when pressure applied on all blades

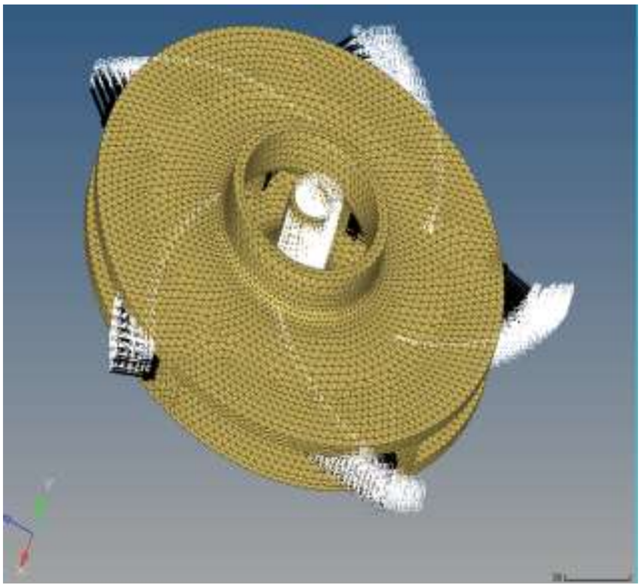

Fig.-7 Loading and boundary conditions

Deformation plot for steel impeller

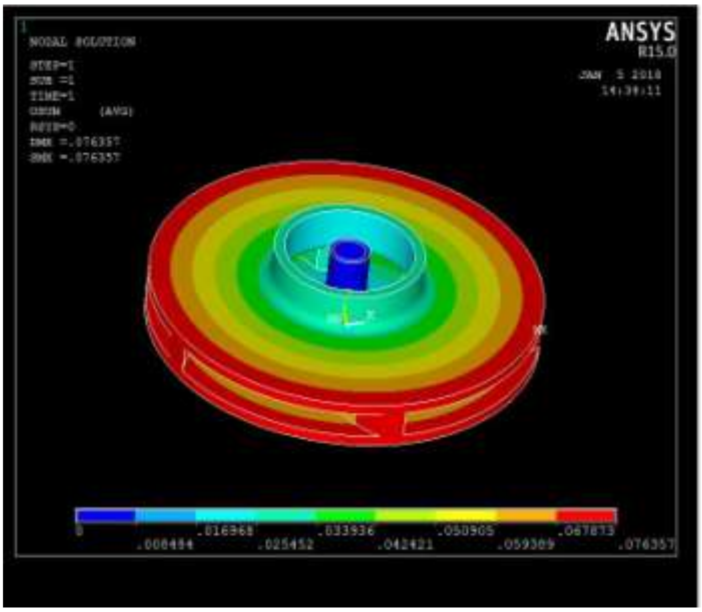

Fig.8 Deformation for steel impeller

The maximum deformation is found to be 0.076mm which is very less.

Stress plot for steel impeller

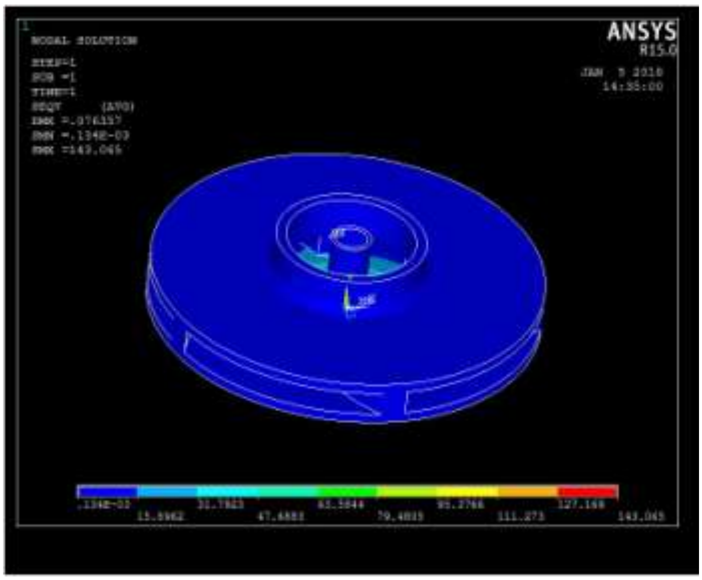

Fig.- 9 Stress distribution for steel impeller

The von mises stress obtained are 143.065 MPa which means the design is safe.
As the design is safe, means the stresses are well within the yield stress 250 MPa, and deformation is much less there is a scope for optimization.

4.5 Material Properties: Glass Fiber

Young's modulus in x-direction, Ex = 40300 MPa
Young's modulus in y-direction, Ey=6210 MPa
Young's modulus in z-direction, Ez=40300 MPa
Poisson's Ratio ,ν =0.2
Density, ρ=1.9 x 10^{-9}tonne/mm3
Shear modulus in XY plane, G_{xy} =3070 MPa
Shear modulus in YZ plane, G_{yz} =2390 MPa
Shear modulus in ZX plane,G_{zx}=1550 MPa

4.6. Boundary Condition Application on Composite Submersible Pump Impeller

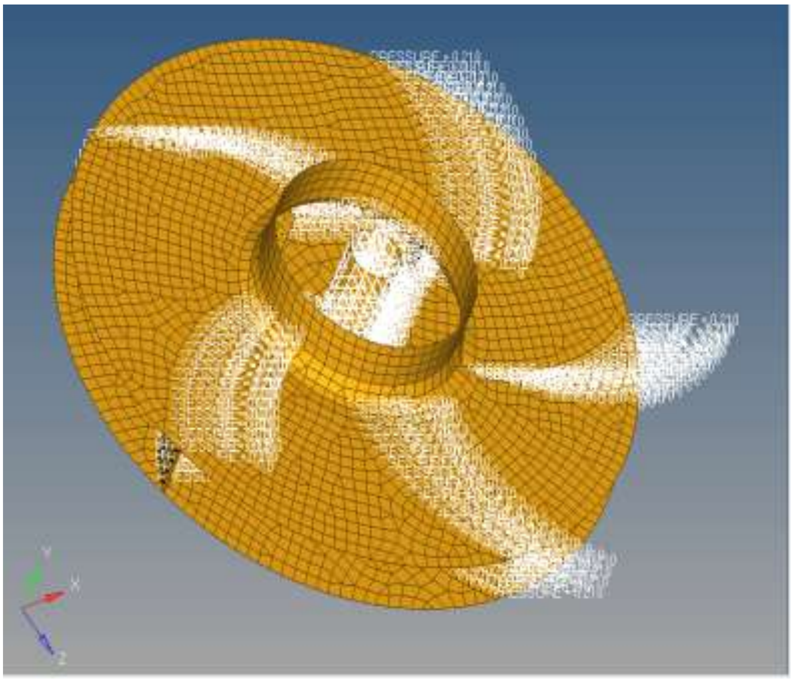

Fig.-10 Loading and boundary conditions when pressure applied on all blades

The plots obtained are as follows:
Deformation plot

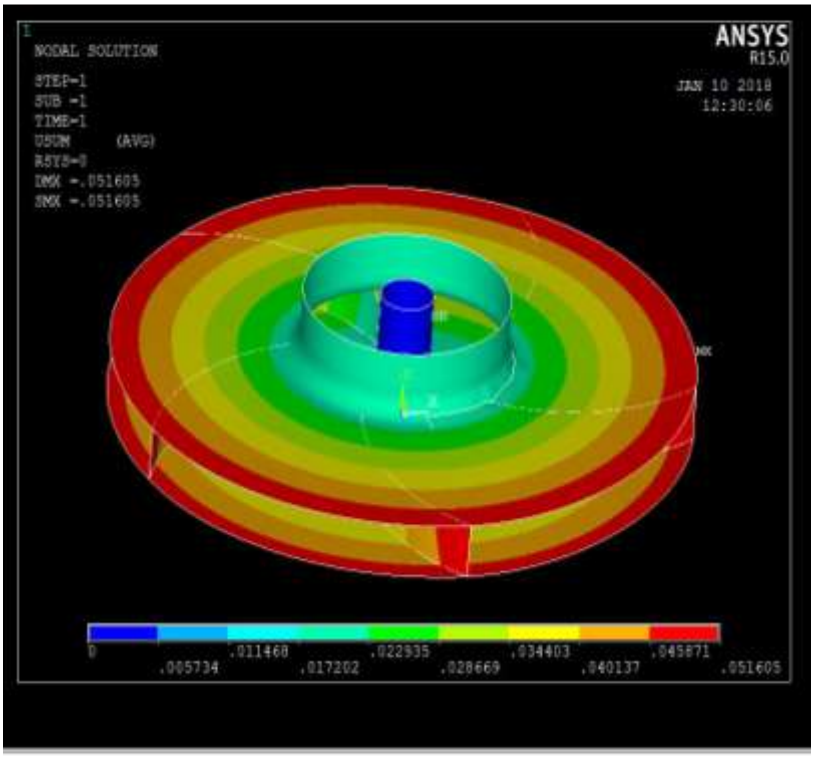

Fig 11 Deformation of composite impeller

Deformation produced is 0.051mm which is less than existing

Stress plot

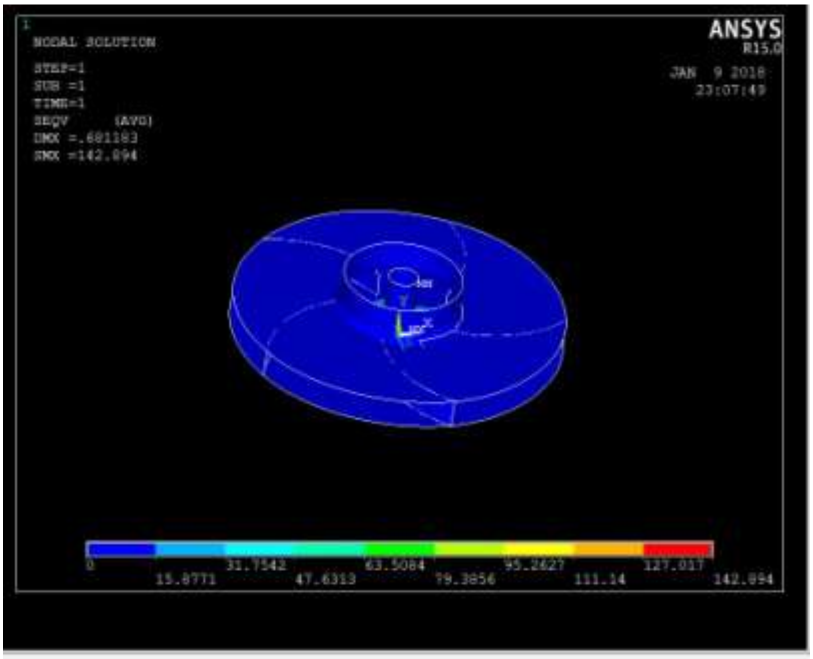

Fig.12 stress plot for composite impeller

Stress produced is 142.8 MPa

V. Results And Discussion

Table 1. Comparison of result for steel and composite impeller

Finite Element Analysis	Steel		Glass Fiber	
	Deformation (mm)	Stress (MPa)	Deformation (mm)	Stress (MPa)
In multiple blade	0.076	143	0.051	142.9

From the above comparison table it can be observed that maximum deformation in the existing submersible pump impeller pump for multiple blade is 0.076 mm for maximum permissible pressure of 0.021Mpa and in optimized glass fiber is 0.051 mm which is less than value for existing pump impeller for the same design whereas the equivalent stress generated in both the cases is near to 143Mpa.

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