Material Optimization and Static Analysis of Centrifugal Pump Impeller Using FEA

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Abstract: Main attention in Centrifugal pumps is an impeller, rotational one which rotates with motor speed and introduces centrifugal forces to the making fluid and the another one is diffuser the static which is the fixed part guiding the flow to the ejection. Profile of the impeller is the most affecting factor in the performance of the pump. The area of importance to the pump design is only the impeller's geometric parameters for accomplish pump performance. Reduced pump routine may upset the plant operation such as repairs cost, loss of invention, and increase in operating cost.Impellers blades have numerous technical programs. Regarding their aerodynamic overall performance, they may be nicely optimized now a days, this work changed into therefore involved with analysing the waft systems inside the casing of the centrifugal pump. Numerical and optimization strategies have been going to apply in an effort to observe the effect of various wrap angle, inlet perspective and outlet perspective. Here we've taken readings of five different impellers of same capability centrifugal pumps a good way to calculate the wrap perspective. Considering the distribution of static pressure is the maximum uniform and relative pace surprising modifications do now not exist. Distribution of turbulent kinetic energy is the smallest. Based on performance experiment transport head and efficiency of centrifugal pump of great impeller gets elevated. Centrifugal pump with the fine impeller has better hydraulic overall performance than the everyday centrifugal pump. The favoured top one centrifugal impeller can be obtained with given layout parameters through using this technique. Additionally ultimate another 5 impellers using the equal parameters had been also designed following to the preceding one.

Keywords: *Centrifugal pump, impeller, blade wrap angle*

I. INTRODUCTION

An impeller is a rotating thing of a centrifugal pump, commonly product of solid iron, metal, bronze, brass, aluminum or plastic, which transfers strength from the motor that drives the pump to the fluid being pumped by using accelerating the fluid outwards from the middle of rotation. The velocity achieved by using the impeller transfers into stress when the outward movement of the fluid is confined by the pump casing. Impellers are typically quick cylinders with an open inlet (known as an eye fixed) to just accept incoming fluid, vanes to push the fluid radially, and a splined, keyed or threaded bore to just accept a pressure-shaft. The modeling of the impeller become performed through using parametric modeling software program CREO 5.0. The boundary condition application and analysis has been executed through using ANSYS. ANSYS is dedicated finite detail package used for determining the variation of stresses, strains and deformation throughout profile of the impeller.

A structural evaluation has been completed to investigate the stresses, lines and displacements of the impeller. Evaluation is carried out on diverse materials (C.I., metal, Aluminum and Composite) and the excellent cloth is recommended. Further, various parameters of the impeller can be changed like no. of blades, blade angle and velocity and so forth.

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 along with structure generates a mechanical loss which reduces the power transported from the motor shaft to the pumpor fan impeller.

Fig.1.Centrifugalpumpimpeller

A. Objectives

The main objective of the work project is to weight analysis of the impeller. This can be complete by comparative study in-between conventionally used SS material and CI material. For this subsequent objectives needs to be achieved:

- To study the existing 5 model combinations.
- Comparative study between two types of materials.
- Calculate forces and boundary conditions.
- Carryout analysis
- To carry out material optimization.

B. Scope

• Anaxial flow pump impeller 1.5HP rating may be taken as reference and it sparameters and loading parameters hence forth will be calculated.

- Literature Survey
- Design of pump impeller by using CREO 5.0, CAD Software
- Analysis of impeller for materials like SS, CI,etc.

C. Methodology

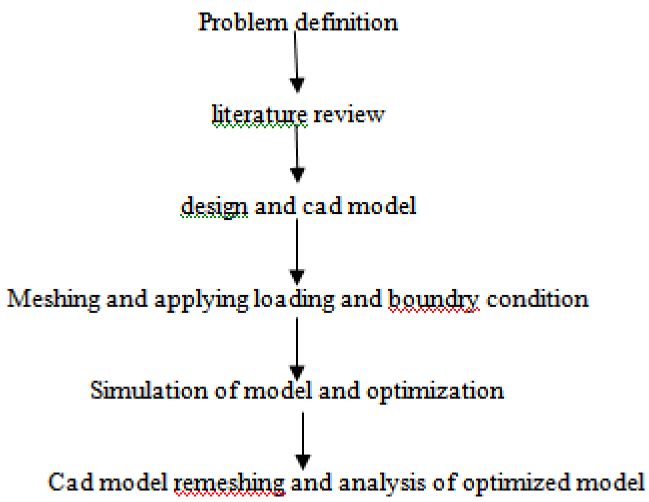


Fig. 2 flowchartof methodology

II. LITERATURE REVIEW

Mane Pranav Rajanand [1] had given the static & Modal analysis of MS & SS Pump Impeller to check strength of Pump & vibrations produced by pump.He studied that a centrifugal pump is a rot dynamic pump that uses a rotating impeller to increase the pressure of a fluid. They come to point that the concept of centrifugal force is not actually required to describe the action of the centrifugal pump. In this study, they done the analysis on MS and SS pump impeller is done in order to optimize strength of centrifugal pump. They come to problem in 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. They thought that the mild steel can be replaced with alloy material (e.g. SS, Inconel, Aluminium alloys) to reduce the weight, improve corrosion resistance and fatigue strength is more as compare to different alloys material and composite material. And due to less stiffness, deformations produced for the same material is more as compared to composite material and different alloys. He chose the objectives for their further work, are as follows: (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.

Ming Liu, Lei Tan, Yun Xu, Shuliang Cao [2] had studied, a novel method is proposed to optimize performance of multi-stage multiphase pump by theoretical prediction based on Oseen vortex. The velocity moment of flow field downstream diffuser can be predicted according to established theoretical model, and it is applied to optimize inlet blade angle of next impeller. In order to validate the proposed optimization method, case study has been done on a three-stage multiphase pump. They proposed that Multi-stage structure is necessary for helico-axial multiphase pump to obtain sufficient pump head, and the matching effect between rotating impeller and stationary diffuser can significantly influence the pump performance. Their proposed methodology consisting of theoretical prediction and optimization. Firstly they have, a theoretical prediction model for flow field downstream diffuser is established. With appropriate simplification to the governing equation, the analytical solution of flow field can be obtained. Secondly they found, the parameters in analytical solution are calculated based on pump geometry. Thirdly they determined, the inlet blade angle of next impeller is determined by the predicted flow field based on velocity triangles, and the optimization process can be accomplished.

Amit kumar Bhimrao Salunkhe, Ranjit Ganaptrao Todkar, Kedar Madanrao Relekar [3] have proposed a review on improvement of efficiency of centrifugal pump through modifications in suction manifold. They discusses the available material of performance improvement through various parameters and mainly focuses on the research related to manifold modifications. They studies all about that vortices and cavitation's present inefficiency on the operation of the centrifugal pump. The suction head and the delivery head has a bearing on the output of the pump in terms of discharge achieved per KW of pump power. As per their study, the intake pumping positions needs a desirable intake flow pattern in order to confirm the operation of pump units. They also told that the intake pumping positions needs a uniform flow distribution of the sumps in order to ensure the operation of pump units.

In the research work the main focus in towards comparative study of material with 5 different centrifugal pump impeller blade angle combinations.The cumulative weight of the impeller affects the overall performance of the pump. Therefore, the weight reduction of the impeller is the factual need of industry. Impeller is one of critical component of centrifugal pump. Typically, the finite element software like ANSYS is utilized to achieve this purpose. For optimization also, FEAANSYS is utilized..

III. METHODOLOGY

A. Finite Element Analysis:

The Finite Element Analysis (FEA) is the virtual reality of any given physical phenomenon using the numerical technique known as Finite Element Method (FEM). The finite element method (FEM), or finite element analysis (FEA), is also computational technique used to obtain approximate solutions of boundary value problems in engineering. Engineer's habit is to decrease the number of physical models and experiments and optimize components in their design phase to develop improved products, as faster as possible. It is necessary to use mathematics to comprehensively understand and quantify any physical phenomena such as structural or fluid behaviour, thermal transport, wave propagation, the growth of biological cells, etc. Most of these developments are described using Partial Differential Equations (PDEs). However, for a computer to solve these PDEs, numerical techniques have been developed over the last little decades and one of the prominent ones, today, is the Finite Element Analysis.

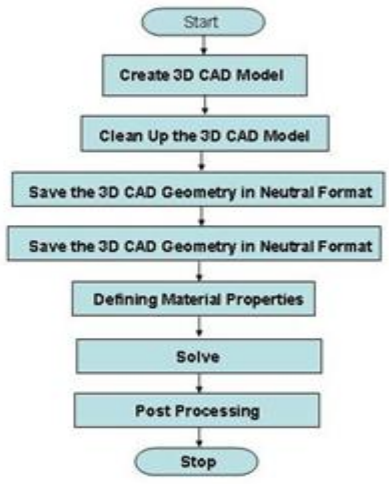


Fig.3: Typical flow chart of FEM analysis

Finite Element Analysis (FEA) is an influential tool to understand structural behavior. However, it has confident restrictions. FEA usually does not take defects from the manufacturing process into account, and failure criteria of composites are inaccurate particularly under non in-plane loading conditions. Failure criteria may be improved by taking fracture mechanical failure into account, but today it is unrealistic to include all types of interlaminar crack growth in an FEA of an entire wind turbine blade or a larger section, mainly due to computational limitations.

Furthermore, the inputs to fracture mechanics models, still need further development before they are reliable at all load conditions. Mixed mode opening problems, in particular, are not fully understood. As already mentioned, more systematized experimental testing should be used in connection with large numerical non-linear FE models, which do not necessarily take all potential kinds of failure into account, but which do take more combinations into consideration. The increasing complexity of FE models, including the non-linearity and the complex load cases, will enable designers to predict new elastic failure mechanisms, which at present do not receive much attention. FEA is used to predict the operating stresses and temperature that a component will experience in service.

B. Design Consideration:

To study the effect of frictional losses in the performance of centrifugal pump, we need to take some considerations and some standard values to calculate the frictional losses. The parameters considered are as given below:

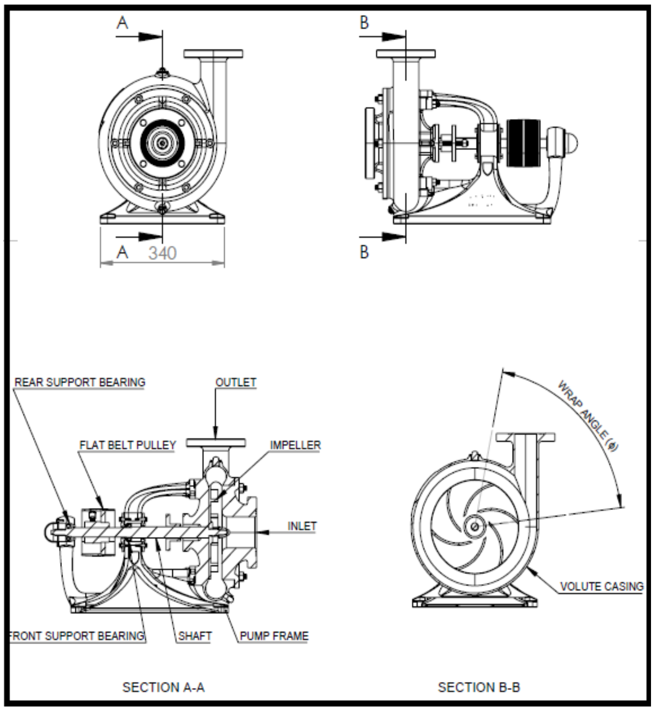
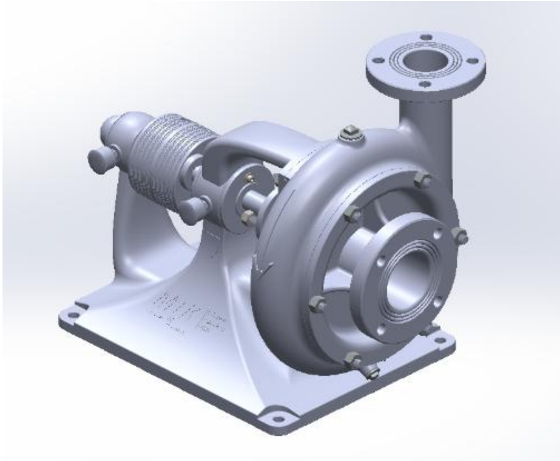


Fig.4: Parts of Centrifugal Pump

- Specification of Pump: For the study we have taken the volute casing type centrifugal pump with semi-closed impeller which is used for normal industrial purposes.

Capacity of pump: 1.5 HP (1.1 KW)
Delivery Head (h): 8 to 14 m
Material of Casing: Structural Steel
Material of Impeller: Structural Steel
Speed of Motor: 2880 RPM
Working fluid in pump: Water



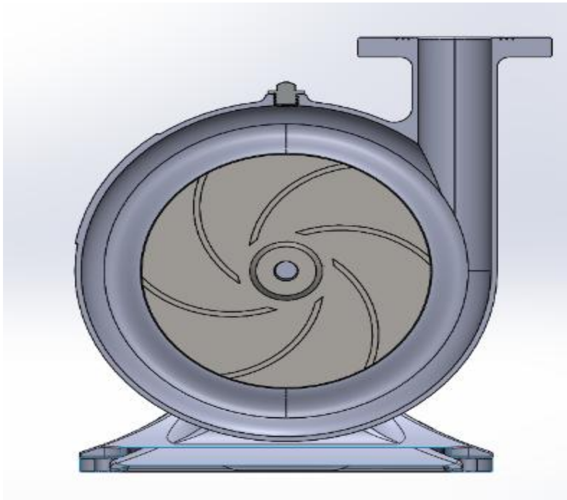


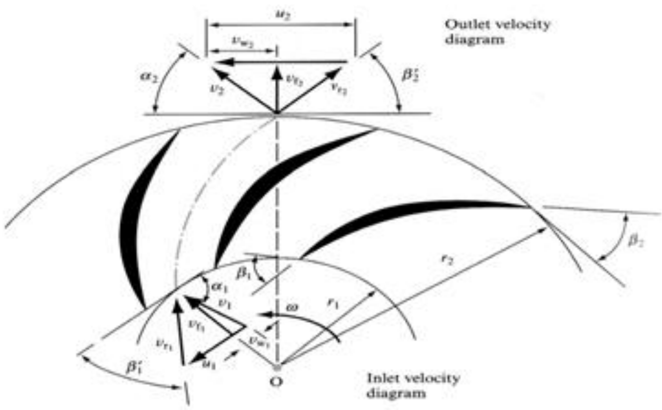
Fig.5 Isometric View of Centrifugal pumpFig.6: Cross Section of Centrifugal Pump at Impeller

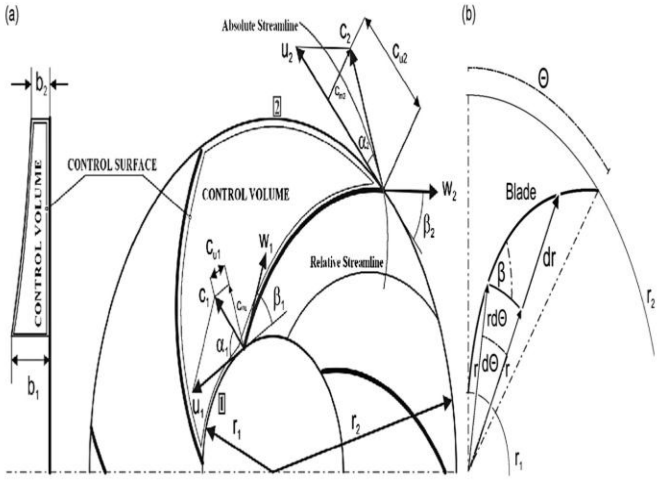
For study we have collected data of impeller blade wrap angle, impeller blade inlet angle and impeller blade outlet angle of 5 different pump of same capacity from different manufactures, as given below:

Table.1: Reading of inlet, outlet and Wrap angles for different Pumps

Pump No.	Wrap Angle(ϕ)	Inlet Angle(β_1)	Outlet Angle(β_2)
1	122^{o}	20^{o}	26^{o}
2	126^{o}	22^{o}	26^{o}
3	130^{o}	22^{o}	26^{o}
4	126^{o}	24^{o}	28^{o}
5	126^{o}	22^{o}	24^{o}

C. Analytical Calculations:





The shape of the blade was designed using a point by point method. The wrap angle is shown in Fig. 1. In case of an infinitesimal increase dɵ the tangents of the flow angle β at radial coordinator r is,

$$\tan(\beta(r)) = dr / r\, d\theta$$

Above equation can be rearranged and integrated in order to get the wrap angle ϕ:

$$\phi = \int_{r1}^{r2} \frac{1}{r \tan(\beta(r))} dr$$

This expression for calculation of wrap angle of blade which must need the blade angle β(r).

D. Reference Data for Calculations

β1=220 and β2=260
Do=238 mm
Di=112 mm
Dshaft= 18 mm
N= 2880 RPM
No of Blades: 6 nos

For mass calculation of single blade we have considered it as straight blade. To find, location of combined CG = CG of blade from bottom of blade + radius of hub.

Ȳ= (V1y1+V2y2+V3y3) / (V1+V2+V3) = 35.76 mm
And location of CG is from axis of rotation,
35.76+56.32=92.08 mm
FC = mrω2 (where r is the radial distance of CG from axis of rotation)
m = volume of blade X density
= 0.1 Kg (Single Blade)
r = 92.08 mm
ω = 2ՈN/ 60= 301.6 rad/sec

FC= (0.1) X (92.08/1000) X (301.6)2 =837.58 N
σTotal= σdirect tensile + σbending due to eccentricity of blade
σdirect= FC/Area= 837.58/(163.2/(1000)2) = 5.132x106 N/mm2
where area of cross section = (19.2X4)+(21.6X4)= 163.2 mm2
Now, σbending= M.y / I
I xx =8.148x 10-9 m4
y is the distance of extreme fiber from neutral axis, for this we need centroid of c/s
x̄=6.65 mm
ȳ=5.57 mm
y=21.6-6.65=14.95 mm (Maximum value of y is taken)
y=19.2-5.57=13.63 mm
σbending = M.y/I= 39.24x106 N/m2
σ = 39.24x106+5.132x106 =44.38 MPa

As per Ansys (simulation) analysis result for model 2 (SS) are σ=41.98MPa
Due to some assumptions, there is error in between Software and Analytical calculations:
%error= 5.71%

IV. RESULT

After analysis of all five model in ANSYS for two different most preferable materials used. From the data we have listed down from ANSYS results for SS and CI material for different combination of blade angles. After analysis, we come to know that, with SS material, given model No. 2 And Model No. 5 gives satisfactory results in terms of max. stress generated(41.9 Mpa and 37.04 Mpa) and deflection occurred (0.072 mm and 0.070 mm) and both are within the tolerable limits in case of centrifugal pump.

Hence from above results, for excellent efficiency as well as performance in terms of centrifugal pump impeller we got optimum inlet, outlet and wrap angle with SS material and will perform best along of all taken combinations, with less deformation and less stress concentration.

MODEL	MAX. DEFLECTION (m)		MAXIMUM STRESS VALUE (Pa)	
	CI	SS	CI	SS
1	0.00012518	0.000074865	39500000	43098000
2	0.00012192	0.000072929	38467000	41980000
3	0.00014893	0.000088974	59300000	64022000
4	0.00015433	0.0000922	51403000	55466000
5	0.00011839	0.000070898	34340000	37040000

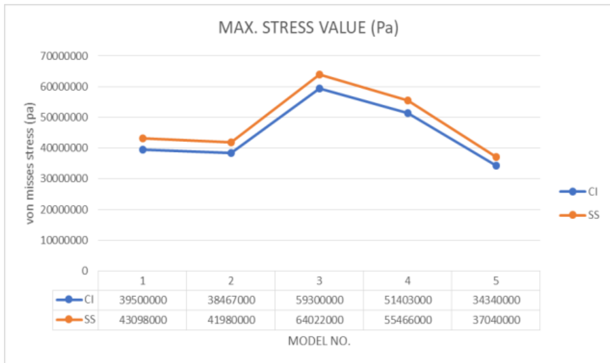


Fig.7. Comparative study of materials for Max Stress Value

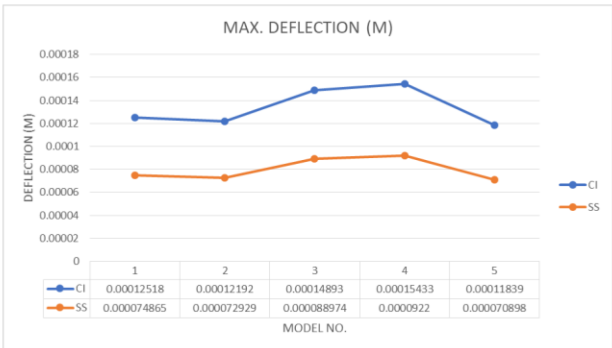
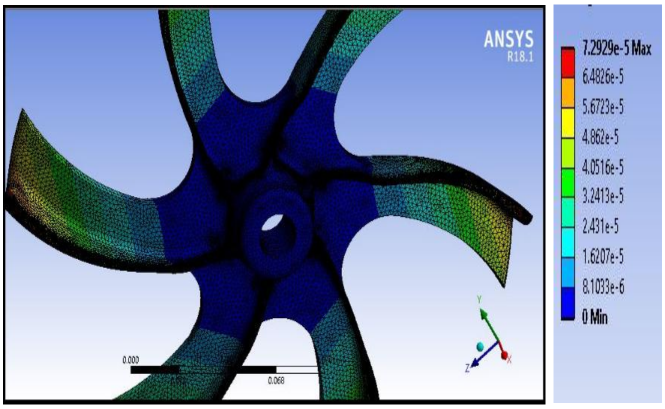
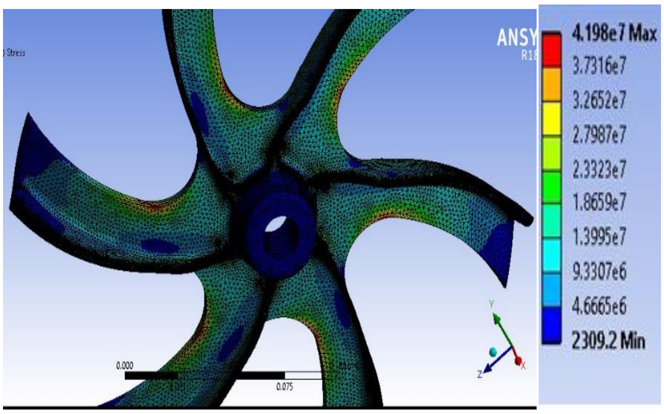


Fig.8. Comparative study of materials for Max Deflection Value

To measure the effects of blade wrap angle and blade exit angle on the performances of centrifugal pump, the impeller were analyzed under the typical boundary conditions like rotational force and fixed supporting force. And obtained results are shown below with reference to model no. 2

And here we have attached some of the analysis reports, which are representative of all of thoroughly analyzed results.





With reference to above calculations, all remaining calculations done for remaining four combinations of wrap angle, inlet angle and outlet angle and the corresponding methodology used is one of same kind.

CONCLUSION

In this paper, effects of blade exit angle and blade wrap angle on the optimized design of the impeller were comprehensively investigated.

1. The simulation results show that the pump with the largest wrap angle has wide area for high efficiency and stable operation. Both analytical and simulation results verify the design method and demonstrate that the blade wrap angle is a very important parameter in pump designing and has a great influence on pump performance.
2. The blade outlet angle has more obvious influence on the efficiency of centrifugal pump, and it has a little influence on the head.
3. The change trend of analytical approach and simulation is very similar, and the max error range is 5 to 10%.
4. As per the referred work, all the simulation results are concentric to the reference.

Acknowledgment

This work is supported by Gokhale Education Society's College of Engineering Nashik. In this research there is valuable contribution by our institute authorities, mentors, and coordinators. I am acknowledging the efforts of A. K Salve (prof., Mechanical engineering, GESCOE Nashik, Savitribai Phule University Pune)for such valuable contribution.

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