Design Analysis of Radial Flow Pump Impeller by Varying Number of Blades, Their Shapes and Its Validation Using ANSYS

T.Manasa Priya
M.Tech (Machine Design)
Department of Mechanical
Engineering
Sankethika Vidhya Parishad,
PM Palem, Vizag.

S.Janardhana Rao
Associate Professor
Department of Mechanical
Engineering
Sankethika Vidhya Parishad,
PM Palem, Vizag.

Appala Narasimha Murthy.B
Assistant Professor
Department of Mechanical
Engineering
Sankethika Vidhya Parishad,
PM Palem, Vizag.

ABSTRACT

Pumps are used in the process of transferring fluids from one place to other and these pumps have a vital role in the domestic and industrial areas. This study deals with the application and need of Structural analysis in the pump industries. For this purpose, I have made a design and analysis of impeller used in Domestic Open well Radial flow water pumps. The impeller selected is of enclosed type, which is commonly used in domestic water pumps. The impeller for a domestic need is designed using formulas formulated by Dr. K.M Srinivasan, in the book Rotodynamic Pumps. The impeller is modeled using CATIA software and analyzed using ANSYS package. The ANSYS output is cross checked with theoretical values, so as to state the accuracy and need of ANSYS analysis.

In this study, the performance of impellers with the same outlet diameter having different blade numbers for radial flow pumps is thoroughly evaluated .The impeller outlet diameter, the blade angle and the blade numbers are the most critical parameters which affect the performance of centrifugal pumps. The model pump has a design rotation speed of 2880rpm and an impeller with 4, 8 & 12 numbers of blades has been considered. The inner flow fields and stresses of centrifugal pump with different blade number and shape are simulated and predicted by using ANSYS software. For each impeller, deformation and the changes in stresses as well as strains of radial flow pump is discussed. The blade's number and type was considered to improve the pressure distribution in the impellers channel. The pressure rise in turn increases the stresses induced in the blades.

Thus in this study by increasing the blade number on the type of blades like forward, backward and radial blade , the best blade type for the best design is predicted by correlating the theoretical with analytical and experimental results.

1. INTRODUCTION

A Pump is a hydraulic machine which converts the mechanical energy of the shaft into hydraulic energy (pressure energy).

A Radial flow Centrifugal pump is one such hydraulic machine where the fluid is being pumped radially i.e. at right angles to the pump shaft by means of centrifugal force acting on fluid.

The radial flow pumps operate at higher pressures and lower flow rates than axial and mixed-flow pumps.

Pumps enable a liquid to:

1. Flow from a region or low pressure to one of high pressure.

2. Flow from a low level to a higher level.
3. Flow at a faster rate.

1.1 There are two main categories of pump:

a.Positive-displacement Pumps:

A variety of positive-displacement pumps are also available, generally consisting of a rotating member with a number of lobes that move in a close-fitting casing. The liquid is trapped in the spaces between the lobes and then discharged into a region of higher pressure. A common device of this type is the gear pump, which consists of a pair of meshing gears. The lobes in this case are the gear teeth.

b.Rotodynamic pump(Kinetic Pumps):

A rotodynamic pump is a kinetic machine in which energy is continuously imparted to the pumped fluid by means of a rotating impeller, propeller or rotor.

1.2 Centrifugal Pumps:

centrifugal pumps have a rotating impeller, having a series of blades, that is immersed in the liquid. Liquid enters the pump near the axis of the impeller, and the rotating impeller sweeps the liquid out toward the ends of the impeller blades at high pressure.For low flows and high pressures, the action of the impeller is largely radial.
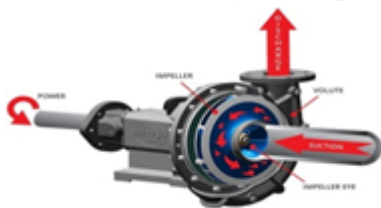
1.2.1 components of Centrifugal Pumps :

Fig:1.2 cut section of impeller and parts of pump

a.casing:

The volute pump is so called because of the shape of the casing. The object of the volute is gradually to reduce the velocity of the water after it leaves the impeller, and so convert part of its kinetic energy to pressure energy. For general purposes the volute pump is commonly used.

Fig: 1.3 volute casing

b.impeller:

An impeller is a rotating component , which transfers energy from the motor that drives the pump to the fluid being pumped by accelerating the fluid outwards from the centre of rotation. The blades are mounted to this base of impeller.

Fig: 1.4impeller with blades

2. LITERATURE REVIEW

S.Chakraborty and K.M.Pandey [1]done a study on the performance of impellers with the same outlet diameter having different blade numbers for centrifugal pumps is thoroughly evaluated. The impeller outlet diameter, the blade angle and the blade numbers are the most critical parameters which affect the performance of centrifugal pumps. They used Ansys software to simulate and predict the inner flow field and characteristic of centrifugal pump with different blade numbers. The simulation is steady and moving reference frame is applied to take into account the impeller-volute interaction. For each impeller, static pressure distribution, total pressure distribution and the changes in head as well as efficiencies of centrifugal pump are discussed. With the increase of blade number, the head and static pressure of the model increases, but the variable regulation of efficiency are complicated, but there are optimum values of blade number for each one.

Haridass Ramasamy and Prabhu Prakash[2] did a journal on CFD Approach in the Design of Radial

Flow Centrifugal Pump Impeller. This project deals with the application and need of CFD analysis in the pump industries by designing and analysing the impeller used in Domestic Open well Radial flow water pumps. The modelling and analysing of the impeller is done by CAD and CFD packages respectively. The CFD output is cross checked with desired requirements, so as to state the accuracy and need of CFD analysis.

Sambhrant Srivastava, Apurba Kumar Roy et al.,[3] have done work on Design analysis of Mixed Flow Pump Impeller Blades Using ANSYS and Prediction of its Parameters using Artificial Neural Network. The main aspect of designing an impeller blade for a mixed flow pump impeller is the root section which encounters the maximum stress. In this paper mixed flow pump impeller blades are designed having two different blade positioning in the meridional annulus. FEM analysis is used to evaluate the stress development in the pump blades. Artificial neural network (ANN) is used to optimize the thickness of the aero foil blade cross-section with respect to Von-misses stress. It is observed that the mixed flow pump impeller blade with inlet inclined blade position in the meridional annulus is more suitable with respect trapezoidal blade as predicted through ANN using RAPID MINER 5.3 software.

3. PROBLEM STATEMENT
3.1 Research need:
Centrifugal pumps are widely used in many applications, so the pump system may be required to operate over a wide flow range in some special applications. Thus, knowledge about off-design pump performance is a necessary. On the other hand, it was found that few researchers had compared flow and pressure fields among different types of pumps. Therefore, there is still a lot of work to be done in these fields. The centrifugal pump performance and its efficiency greatly rely on the components like impeller and casing. To achieve the better performance for a centrifugal pump ,design parameters of impeller such

as number of blades ,the blade angle, blade width etc have to be considered for the impeller.

The rise in head is done only by the impellers action with the help of the blades. The design and count of the blades will rise the pressure inside the casing, which in turn increases the head. This rise in head is used to discharge fluid for required high heads.

However, the large force of fluid can cause the failure of the blade when the fatigue stress exceeds the allowable stress. The impeller fraction is a very serious accident which is strictly prohibited in industries. The static stress in different medium is proportional to the pressure distribution because a large percentage of the total stress is caused by hydraulic pressure.so the study of stresses on impeller by varying its blades count and shape is very prominent to reduce and decide the best blade with best count for specific purposes.

3.2 Aspects of proposed work:
The proposed research work is intended to exploit the best impeller for centrifugal pump by varying the number of blades and its shape .This study is done in both theoretically and numerically .This provides the knowledge about the following aspects:

- Variations in the head developed by changing number of blades in series of 4,8,12 is studied on different types of blades like forward, backward and radial shapes.
- The deformations over impeller for all its considered blade number and shape
- Von-misses stress on each shape of blade with changes in blade number.
- von misses strain on each shape of blade with changes in blade number

4. IMPELLER DESIGN
Design is the application of scientific and mathematical principles to practical ends to form efficient and economical structures, machines, processes, and systems. Design of centrifugal impeller is done using K. M.Srinivasan method. Impeller design parameters are calculated using his procedure by

giving head, volume flow rate and pump speed as input as mentioned in specifications of pump.

4.1 Design approach:

The design of centrifugal pump impeller is done based on the method proposed by K.M.Srinivasan in his book ROTODYNAMIC PUMPS (Centrifugal and axial).

4.1.1 Specific speed:

The Specific speed for the pump is calculated from the following formula for the given values

$$n_s = 3.65 \frac{n\sqrt{Q}}{H^{3/4}}$$

4.1.2 Power input to pump:

The Power is given as:

$$P = \frac{\rho Q g H}{\eta_o}$$

4.1.3 Shaft diameter:

Shaft diameter can be found using the following formula

$$d_s = \sqrt[s]{\frac{16}{\pi} \frac{T}{\tau_t}}$$

4.1.4 Outer diameter of impeller:

The outer diameter D2can be calculated using:
The head coefficient (ψ)

$$\psi = \frac{gH}{U_2^2/2}$$

$$U_2 = \frac{\pi D_2 n}{60} = \sqrt{\frac{2gH}{\psi}}$$

$$D_2 = \frac{60}{\pi n}\sqrt{\frac{2gH}{\psi}}$$

4.1.5 Velocity of fluid at the impeller inlet:

Velocity of fluid at the impeller inlet is calculated by

$$C_{m1} = \left(\frac{\pi D1}{\pi D1 - ZS}\right) C_{m0}$$

4.1.6 Inner Diameter of impeller:

The eye diameter (D1) can be calculated by assuming inlet number. The radial velocity at the inlet is given by:

$$C_{m0} = \varepsilon\sqrt{2Y}$$

The volume flow rate at the suction end is given by:

$$\varrho' = C_{m0}\frac{\pi}{4}\left(D_1^2 - d_h^2\right),$$
$$where \varrho' = \frac{\varrho}{\eta_V}$$

Calculating for the eye diameter,

$$D_1 = \sqrt{\frac{4\varrho}{\pi \times C_{m0} \times \eta_V} + d_h^2}$$

The volumetric efficiency is given by:

$$\frac{1}{\eta_V} = 1 + \frac{0.287}{n_s^{2/3}}$$

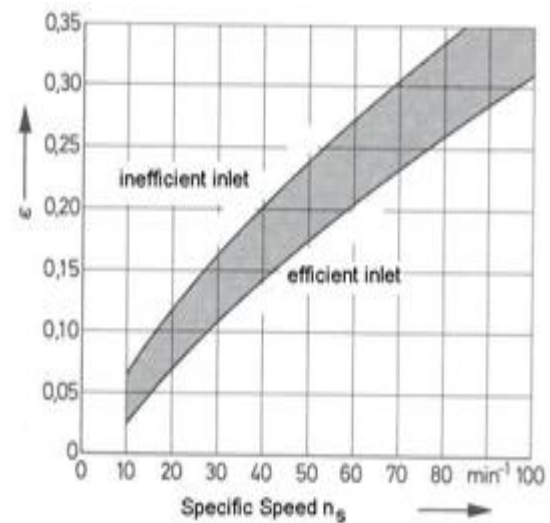The inlet number can be found from the following figure.

Figure 4.1 The inlet number values

4.1.7 Inlet blade angle:

Blade angle β_0

$$\beta_0 = tan^{-1}\left[\frac{C_{m0}}{U_1}\right] = tan^{-1}\left[\frac{C_{m0}}{\pi D_1 n}\right]$$

4.1.8 Impeller width at inlet:

$$Q_{th} = \pi D1 \; B1 \; Cm0$$

$$Or \quad B_1 = Q_{th}/ \pi D1 \; Cm0$$

4.1.9 Blade angle at outlet:

Blade angle β2can be estimated from the figure.
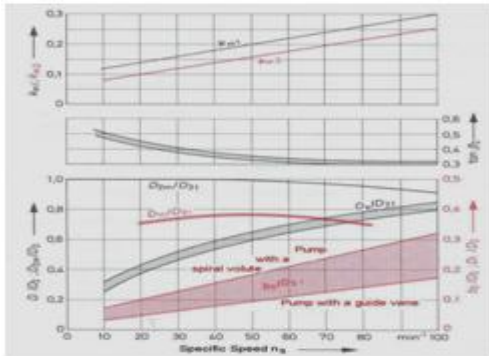
Figure:4.2 Blade angle β2values

4.1.10 Design for stresses on impeller:
Stress analysis of the impeller blades:

The calculation of stresses in a radial flow pump impeller blade is extremely complicated owing to number of reasons, the complex loading characteristics and the geometry of the blade is rather complicated. To get an accurate estimation of the stresses in the blades, validation of stress values are required to be compared with the calculated values. To accomplish the simplified method of stress validation among the calculated and numerically

Predicted values was carried out by replacing the twisted blades with an equivalent plate having rectangular cross-section, which acts like a cantilever. The material properties and the volume of both plate and blade were kept identical. The theoretical calculation of Von Misses stress was carried out using the following equations. It is assumed that each blade of the radial flow pump impeller acts as a cantilever fixed to the hub and due to torque applied on the impeller; a surface force acts on the blade.

4.1.10.1 Torque applied on the plate(T): N-m

4.1.10.1 Torque applied on the plate(T): N-m

$$T = \frac{P * 60}{2\pi N}$$

Or

$$T = \frac{WL^2 bn}{2}$$

Where P-Input power to the pump   watts
W-pressure force acted by fluid on impeller N/m²
L-span of each plate m
b-mean width of plate m
n-number of blades

4.1.10.2 Bending stress(σ_B): N/m²

$$\sigma_B = \frac{M}{I} y$$

Where M-Bending moment =W*b (N-m)
I-moment of inertia =b t³/12 m⁴
y-varying distance from neutral axis =t/2 mts
t-thickness of plate m

4.1.10.3 Shear stress(τ):N/m²

$$\tau = \frac{6WbI}{bt^3} \frac{t^2}{(4-y^2)}$$

4.1.10.4 Von Misses stress (σ):N/m$\sigma = \sqrt{\sigma_B^2 + 3\tau^2}$
4.1.10.5 Von Misses strain (ϵ):

$\epsilon = \frac{\sigma}{E}$ Where E-Young's Modulus of Elasticity N/m²

4.2 Specifications of pump:
The specifications of pump are directly taken from the reference(2).

S.no	Parameters	Values
1	Head H	24 m
2	Discharge Q	95 lpm=1.583 lps
3	Power Output P	1 hp=746W
4	Speed N	2880 rpm
5	Pipe size	25X25
6	Total pressure developed in the fluid (P)	141744.4773 Pa = 0.141744 MPA

Table 4.1 specifications of centrifugal pump

4.3 Material Properties:
For impeller and blades ,structural steels is the material selected. The below table shows the mechanical properties of structural steel.

Type of steel	Ultimate strength (MPa)	Yield strength (MPa)	Density (g/cm³)	Young's Modulus (GPa)
Structural steel ASTM A36 Steel	400	250	7.8	200

Table 4.2 material properties of centrifugal pump

## 4.4. MODELING USING CATIA V5 SOFTWARE

The above profile is then developed into a model using CATIA V5. Some considerations are made while developing the model. Considerations like, the impeller is without hub portion, the shrouds are flat, etc., this made because, in this work, we have concentrated in the analysis of impeller's vane profile. Hence the parameters associated with Casing are neglected. The following image is the model developed using CATIA V5.

Vane profile development:

K.M.Srinivasan method: Single curvature blade or plane vane development is adopted for pure radial blades, where the inlet and outlet edges lie parallel to axis. The specific speed 'ns' of such pump will be less than 100 i.e., ns < 100 and normally the diameter D2 < 70 to 100 mm.)Vane development is done either by single or by double arc method or by step by step method called as point by point method, must provide uniform variation in relative velocity 'w', meridional velocity Cm and angle of divergence from inlet to outlet along the flow passage .For smaller pumps the blade thickness will be 3 mm at inlet, 5 mm to 6 mm at the middle and 1 mm to 2 mm at the outlet. For larger pumps blade thickness is increased up to 10 to12 mm. Selection of minimum thickness provides a larger flow passage between blades. Nowthe profile is traced. The more number of points we employ, the tracing of the profile is made easy. In this case we have selected 7 trace points
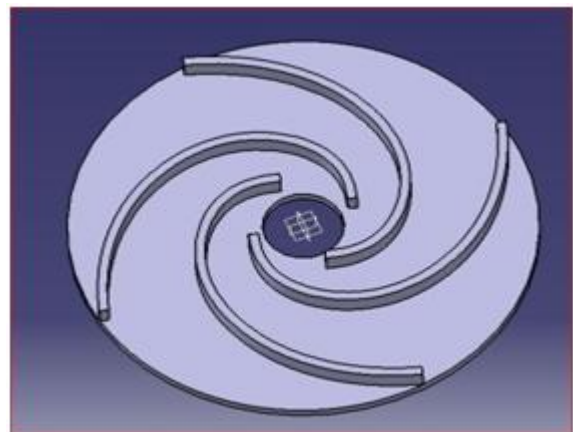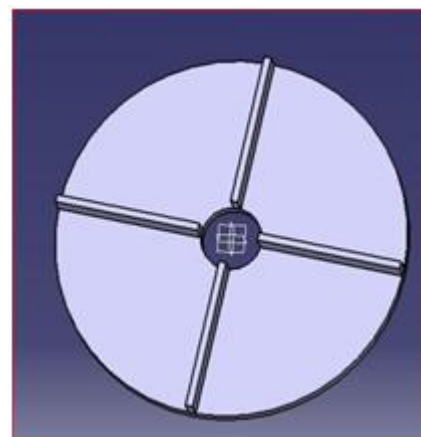
CATIA MODEL
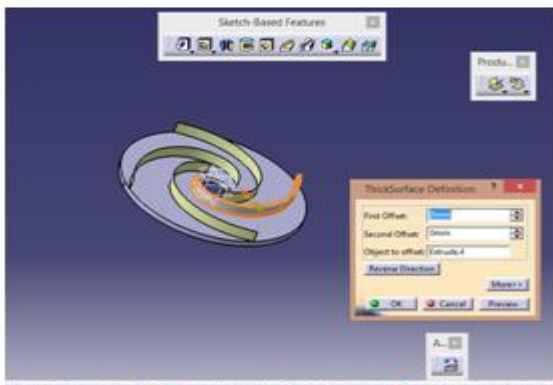
model of impeller

Forward blade:
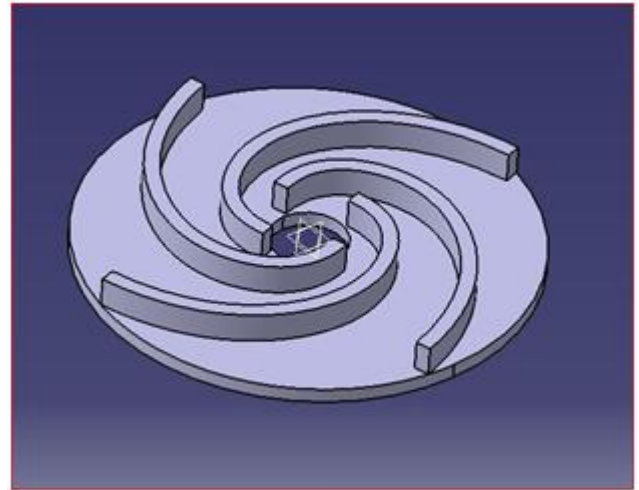
4 BLADE MODEL

Backward blades:

4 BLADE MODEL

RADIAL BLADES

4 BLADE MODEL

5. FINITE ELEMENT ANALYSIS

In mathematics, the finite element method (FEM) is a numerical technique for finding approximate solutions to boundary value problems for partial differential equations. It uses subdivision of a whole problem domain into simpler parts, called finite elements, and vibrational methods from the calculus of variations to solve the problem by minimizing an associated error function. Analogous to the idea that connecting many tiny straight lines can approximate a larger circle, FEM encompasses methods for connecting many simple element equations over many small sub domains, named finite elements, to approximate a more complex equation over a larger domain.

5.1 Principles of FEA:

The finite element method (FEM), or finite element analysis (FEA), is a computational technique used to obtain approximate solutions of boundary value problems in engineering. Boundary value problems are also called field problems. The field is the domain of interest and most often represents a physical structure.

The field variables are the dependent variables of interest governed by the differential equation. The boundary conditions are the specified values of the field variables (or related variables such as derivatives) on the boundaries of the field. For simplicity, at this point, we assume a two-dimensional case with a single field variable φ(x, y) to be determined at every point P(x, y) such that a known governing equation (or equations) is satisfied exactly at every such point. -A finite element is not a differential element of size dx × dy. - A node is a specific point in the finite element at which the value of the field variable is to be explicitly calculated.

5.2 Introduction to ANSYS:

ANSYS is a finite element analysis (FEA) software package. It uses a preprocessor software engine to create geometry. Then it uses a solution routine to apply loads to the meshed geometry. Finally it outputs desired results in post-processing.

ANSYS is used throughout industry in many engineering disciplines. This software package was even used by the engineers that investigated the World Trade Center collapse in 2001.

Models are imported into ANSYS 15.0 and Mesh model of Forward model
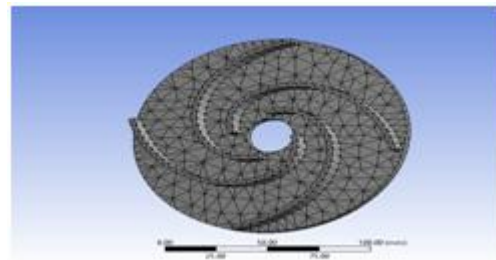

Fig.5.2 mesh model of impeller with blades

6. THEORETICAL CALCULATIONS

6.1 Theoretical calculations for impeller:

6.1.1 Specific speed N_s:

- The **Specific speed** for the pump is calculated from the following formula for the given values

$$N_s = 3.65 \frac{N\sqrt{Q}}{H^{3/4}} = 3.65 \frac{2880\sqrt{1.583}}{24^{3/4}} = 38.57$$

6.1.2 Power input to pump P : hp

- The Power is given as:

$$P = \frac{\rho Q g H}{\eta_o} = \frac{1000}{0.63} X 1.583 X 9.81 X 24 = 1.84 \, hp$$

6.1.3 Shaft diameter d_s : mm

- Shaft diameter can be found using the following formula

$$d_s = \sqrt[s]{\frac{16}{\pi} \frac{T}{\tau_t}} = \sqrt[s]{\frac{16}{\pi} \frac{4.6}{1.31 X 10^{-7}}} = 25mm$$

6.1.4 Outer diameter of impeller D_2 : mm

- The outer diameter D_2 can be calculated using:

The head coefficient (ψ)

$$\psi = \frac{gH}{U_2^2/2} = \frac{9.81 X 24}{(21.71)^2/2} = 2$$

$$U_2 = \frac{\pi D_2 N}{60} = \sqrt{\frac{2gH}{\psi}} = \sqrt{\frac{2 X 9.81 X 24}{2}} = 21.71 m/s$$

$$D_2 = \frac{60}{\pi N}\sqrt{\frac{2gH}{\psi}} = \frac{60 \, U_2}{\pi N} = \frac{60 X 21.71}{\pi X 2880} = 144mm$$

7 RESULTS & DISCUSSIONS

7.1 Results from Theoritical calculations:

| S.NO.	Number of blades	VON MISES STRESS (N/mm2)	VON MISES-STRAIN
1	4	$2.6 X 10^6$	$1.3 X 10^{-5}$

7.2 Results from ANSYS:

7.2.1Load and Boundary Conditions for Forward blade:

Load and Boundary Conditions for design is given below:

I. As shaft position all DOF is fixed

II. Angular Velocity = 2*phi*2880/60 = 300.00 Rad/sec

III. Pressures load P = 1.411 MPA

IV.

Load and Boundary Condition for Impeller blade for forward blade for all shapes are shown below:
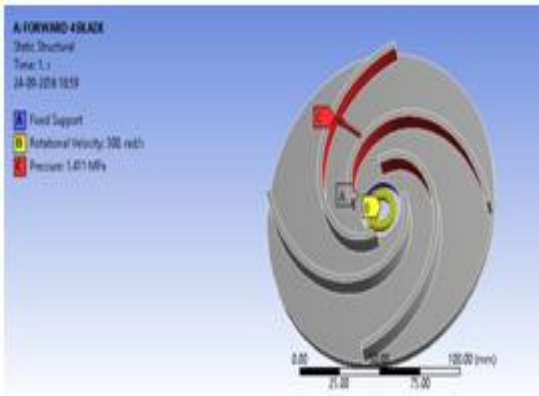
7.2.2 STRUCTURAL ANALYSIS FOR FORWARD BLADE ARE GIVEN BELOW RESULTS:

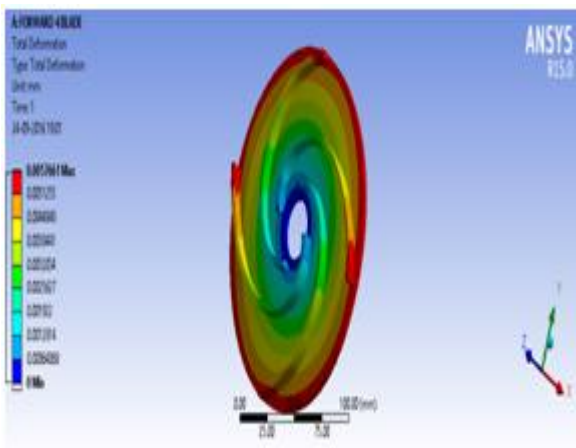### 7.2.2.1Total Deformation for all models forForward blades:

Fig 4 nos of blade deformartion andvalue of 0.005 mm(Max)

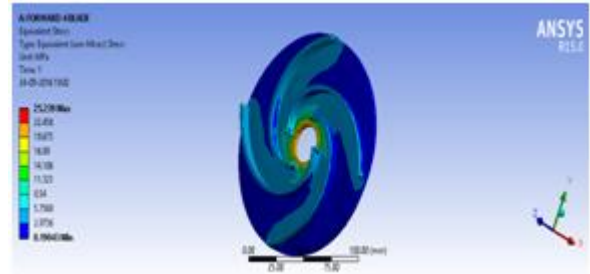### 7.2.2.2 Von Misses Stress for For Forward Blades:

Fig 4 nos of blade Stress andvalue of 25.23 MPA (Max)
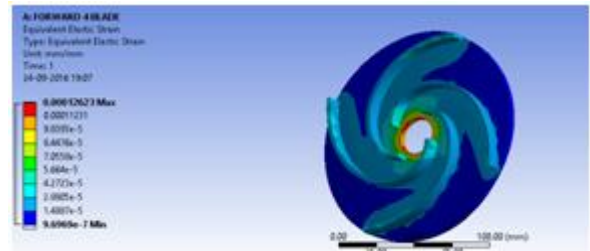
7.2.2.3 Von Misses Strain for For Forward Blades:

Fig 4 nos of blade Strain andvalue of 0.0001262 (Max)

7.3Resulttable from ANSYS:

From the above results from ANSYS ,it is concluded that the maximum values of von misses stresses is observed for 12 blades. Also the backward blade is experiencing less stress compared to the forward and radial blades. The following tables illustrate the results comparison from ANSYS.

Case1: 4 Blade Impeller Design Values:

7.4. GRAPHS FOR 4 BLADES FROM ANSYS RESULTS:

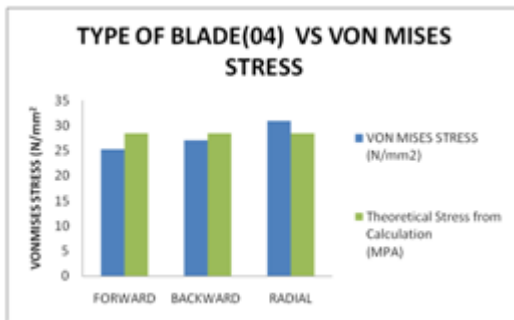Fig 7.4.1 shape of blades vs deformation

Fig 7.4.2 shape of blade vs von misses stress

8 Conclusions and Future Scope

Conclusion:

An impeller was designed for the input details using standard formulas and the vane profile was traced accordingly. Since the simulation is done only for the impeller's blade , the front and rear shrouds and hub portions are neglected in the modeling. The output of the simulation is close enough to the theoretical calculations. Hence it can be stated that, the usage of ANSYS structural analysis is worthy when compared to Forward, Backward and Radial are analyzed with changing no. of blades as 4,8 and 12 steps of blades. From the Results and plot table it is concluded that Backward blade has reduction in deformation, Stress and Strain when compared with other types of blades by increases in blade numbers. Thus by results we are reducing the time for various prototypes, and reducing the financial investments for each trials.

Percentage of reduction of stress comparing Backward blade with Forward & Radial is varies from 6 to 14 % for 4no. blade, 8 to 32 % for 8 no. blade,31 to 69 % for 12 no. blade. By results we come to conclusion by increasing number of blades in backward flow gives the best design for high head and low stresses and Concluded with best results.

Future scope:

- This study can also be done with other design parameters of pump for achieving the better performance.
- Can also be analysed with the CFD, MAT LAB etc.
- Can also be analysed by changing the material suitable for the impeller defects like cavitation,etc
- Can also be done on different types of centrifugal pump like mixed flow and axial flow .
- Vibrational analysis can be done for the same impeller specifications.
- By changing the curved shape of blade into trapezoidal shape, the performance can be analysed.

9 REFERENCES

1) S.Chakraborty and K.M.Pandey, Numerical Studies on Effects of Blade Number Variations on Performance of Centrifugal Pumps at 4000 RPM, IACSIT International Journal of Engineering and Technology, Vol.3, No.4, August 2011.

2) Haridass Ramasamy, Prabhu Prakash, CFD Approach in the Design of Radial Flow Centrifugal Pump Impeller, International Journal of Scientific Engineering and Applied Science (IJSEAS) - Volume-1, Issue-5, August 2015

3) Sambhrant Srivastava, Apurba Kumar Roy and Kaushik Kumar, Design analysis of Mixed Flow Pump Impeller Blades Using ANSYS and Prediction of its Parameters using Artificial Neural Network, 12th global congress on manufacturing and management, gcmm 2014

4) Sambhrant Srivastava, Apurba Kumar Roy and Kaushik Kumar, Design of a mixed flow pump impeller blade and its validation using stress analysis, 3rd International Conference on Materials Processing and Characterization (ICMPC 2014).

5) Val S. Lobanoff and Robert R. Ross, Centrifugal Pumps, Design & Application, Second Edition: Woburn Ma, USA, Gulf Publishing Company, 1992.

6) Rotardynamic Pumps: Centrifugal And Axial, K.M Srinivasan, First Edition, New Delhi, India, New Age International (P) Ltd., Publishers, 2008.

7) R. Badie and J.B. Jonker, Finite Element Calculations and Experimental Verification of the Unsteady Potential Flow In A Centrifugal Volute Pump, International Journal for Numerical Methods in Fluids, Vol. 19, 1994, 1083-1102.

8) Pham Ngoc Son, Jaewon Kim And E. Y. Ahn, Effects Of Bell Mouth Geometries On The Flow Rate Of Centrifugal Blowers, Journal Of Mechanical Science And Technology, Vol. 9, 2011, 2267~2276.

9) R. Spence and J. Amaral-Teixeira, a CFD Parametric Study of Geometrical Variations on the Pressure Pulsations And Performance Characteristics of a Centrifugal Pump, Elsevier, Computers & Fluids, Vol. 38, 2009, 1243–1257.

10) L.E Reece, Some Fundamental Aspects of Centrifugal Pump Design in 11th Australian Fluid Mechanics Conference, 1992.