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Study the Effect of Blade Wrap Angle on Performance of Centrifugal Pump by FEM Analysis

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Abstract- *Main focus in Centrifugal pumps is an impeller, rotating one which rotates with motor speed and informs centrifugal forces to the creation fluid and the second one is diffuser the static which is the fixed part guiding the flow to the ejection. Shape of the impeller is the most impacting 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 several technical applications. Regarding their aerodynamic performance, they are well optimized now a days, this work was therefore concerned with analysing the flow structures inside the casing of the centrifugal pump. Numerical and optimization techniques were going to apply in order to study the effect of varying wrap angle, inlet angle and outlet angle. Here we have taken readings of 5 different impellers of same capacity centrifugal pumps in order to calculate the wrap angle. Considering the distribution of static pressure is the most uniform and relative velocity sudden changes do not exist. Distribution of turbulent kinetic energy is the smallest. Based on performance experiment delivery head and efficiency of centrifugal pump of best impeller will get increased. Centrifugal pump with the best impeller has better hydraulic performance than the regular centrifugal pump. The preferred prime one centrifugal impeller can be obtained with given design parameters by using this method. Also remaining another 5 impellers using the same parameters were also designed following to the previous one.*

Key words- Centrifugal pump, impeller, blade wrap angle.

I. INTRODUCTION

The centrifugal pump is of wide-ranging application in industrialized and agricultural fabrications, such as irrigation and water supply, consuming a huge amount of electric power with great probable in energy saving. The centrifugal pump is far the commonest type of dynamic pump also called as velocity pump. They have good discharge capacity. They can used for high viscous fluids such as oils, muddy and sewage water, paper pulpless. They are having comparatively very less maintenance cost. For the same discharge, centrifugal pumps are compact, smaller in size and have low weight. They are highly efficient pump due to all these characteristics. The centrifugal pump design optimization through objectives to increase head and efficiency is influenced by numerous design constraints such as the number of the blades, inlet and exit blade angles, wrap angles, blade profile curves.

It typically contains four different parts: Suction pipe (Suction Manifold), Impeller, Volute, and Exit pipe (Discharge Manifold). Suction pipe also contains strainer and foot valve. Centrifugal pump works on the principal that when a certain mass of liquid is made to rotate along the impeller from the central axis of rotation, it impresses a centrifugal head. It causes the water to move radially outwards at higher velocity and causes the water to rise to a higher level. The motion of water is restricted by casing of pump, it results into pressure build up. In addition, the change in angular momentum of liquid during its flow results into increase in pressure head.

The centrifugal pump design optimization through objectives to increase head and efficiency is influenced by numerous design constraints such as the number of the blades, inlet and exit blade angles, wrap angles, blade profile curves. The impeller is the core part and it converts the mechanical energy into pressure energy, which directly determines the transport capacity and the hydraulic performances of centrifugal pump. The impeller adds kinetic energy to pumping fluid and the volute casing converts kinetic energy into pressure energy. The blade wrap angle is well-defined as the angle between the tangent lines at leading and trailing edges of the blade. A rise in blade wrap angle would lead to a longer flow passage between the blades and hence a considerable rise in friction loss. On other hand, a small blade angle will generate a short flow passage but result in a poor control on the flow in impeller arousing separation loss probably. Therefore, the blade wrap angle is a key parameter for blade shape, flow pattern in impeller and performance of pump. The pump head and efficiency are also influenced by the blade wrap angle. The highest head and efficiency are also observed for the largest angle.

Blade exit angle and blade wrap angle are two important parameters in the impeller improved design process. The presentation of a centrifugal pump is generally determined by these parameters. Some researchers calculated the effects of blade exit angle and blade wrap angle on the hydraulic performances of the centrifugal pump. The selection of blade wrap angle and blade exit angle mostly depend on the specific speed of the centrifugal pump and the actual optimized design practice. If the blade wrap angle is too large, the friction area of impeller becomes large, which affect badly on the improvement of efficiency. If the blade wrap angle is too small, the impeller is not able to control the flow of water efficiently and the impeller operation is not stable. For the blade exit angle, a sensible value might effectively improve the performances of the centrifugal pump.

II. LITERATURE REVIEW

Amitkumar Bhimrao Salunkhe, Ranjit Ganaptrao Todkar, Kedar Madanrao Relekar [1] 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.

Ahmed Ramadhan Al-Obaidi [2] had done this work, to detecting and diagnosing the cavitation phenomenon within centrifugal pumps using vibration technique was investigated. The results obtained for vibration signal in both time and frequency domains were analyzed in order to gain a better understanding about the detection of cavitation in the pumps in question. They studied the effect of different operating conditions including various flow rates and pump rotational speeds related to the cavitation were measured. The detection of cavitation experimentally has been achieved by using vibration through the use of accelerometer as well as pressure using two pressure transducers at suction and discharge of the pump under the different range of operation conditions. After their experimental results, they predicts several flowing conclusions regarding the effect of different flow rates and pump rotational speeds on the vibration signal and performance of the centrifugal pump. Their results shows that when the pump works under unstable flow rate, it leads to change in the dynamic characteristics within a centrifugal pump.

Ming Liu, Lei Tan *, Yun Xu, Shuliang Cao [3] 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.

Rui Yu, Jinxiang Liu [4] had analyzed the looseness failure between impeller and shaft. He studied to determine the cause of the failure, the torque produced by external loads was calculated theoretically. He also work for the torque capacity of interference connection was analyzed using finite element method (FEM). He used the basic mechanical properties of different impeller were tested and applied to the FEM model to find out the influence of mechanical properties on interference connection between impeller and shaft. The results he got were indicating that interference connection condition is greatly affected by mechanical properties. In their study, they studied failure analysis of interference connection looseness of impeller and shaft using theoretical analysis method and finite element method. Elastic modulus, hardness and microstructure of impeller material are tested. The influence of material properties and external load on interference connection are discussed. Based on those results, the reason of impeller looseness failure is determined. They are also essential parameters affecting the use of impellers. In the following section, the microstructure, hardness and elastic modulus of failure pump's impellers were tested. They obtained the conclusions as, they analyzed the impeller looseness failure occurring in the pump rated working condition. It is clear that the degradation of the microstructure of failure impeller material will result in the decrease of mechanical properties. The failure impeller material has lower elastic modulus and hardness, which directly lead to the reduction of torque capacity of interference connection.

Mane Pranav Rajanand [5] 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.

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.

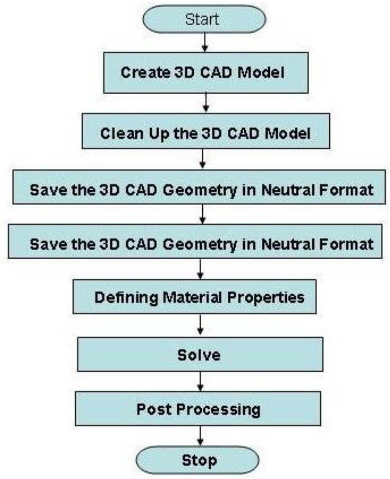


Fig.1: Typical flow chart of FEM analysis

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:

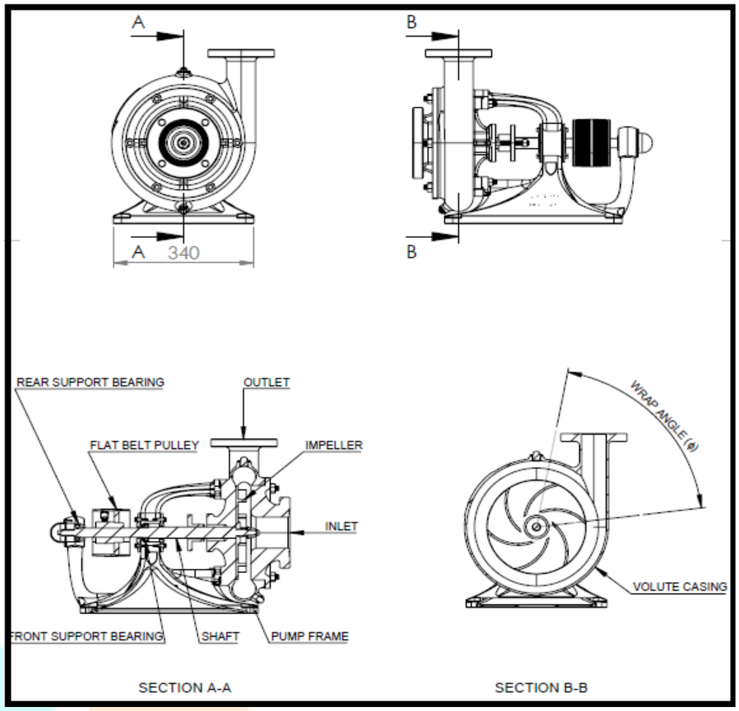


Fig.2: Parts of Centrifugal Pump

- 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

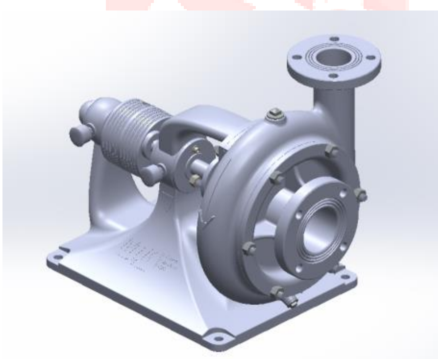


Fig.3: Isometric View of Centrifugal pump

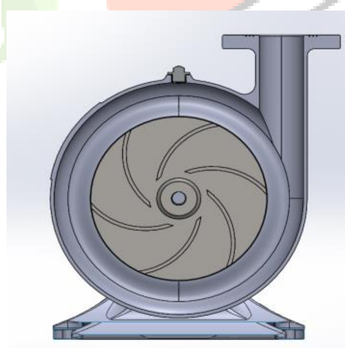


Fig.4: Cross Section of Centrifugal Pump at Impeller

1. 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

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

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

C. *ANALYTICAL CALCULATIONS:*

Reference Data for Calculations:

$\beta_1=22^0$ and $\beta_2=26^0$

D_o=238 mm

D_i=112 mm

D_{shaft}= 18 mm

N= 2880 RPM

No of Blades: 6 nos

For mass calculation of single blade we have considered it as straight blade likewise in DRW,

To find location of combined CG,

$\bar{y}= (V_1y_1+V_2y_2+V_3y_3) / (V_1+V_2+V_3) = 35.76$ mm

And location of CG is from axis,

35.76+56.32=92.08 mm

$F_C = mr\omega^2$ (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

$\omega = 2\pi N/ 60 = 301.6$ rad/sec

$F_C= (0.1) X (92.08/1000) X (301.6)^2 =837.58$ N

$\sigma_{Total}= \sigma_{direct\ tensile} + \sigma_{bending\ due\ to\ eccentricity\ of\ blade}$

$\sigma_{direct}= F_C/Area= 837.58/(163.2/(1000)^2) = 5.132x10^6\ N/mm^2$

where area= (19.2X4)+(21.6X4)= 163.2 mm^2

Now, $\sigma_{bending}= M.y / I$

$I_{XX} =8.148x\ 10^{-9}\ m^4$

y is the distance of extreme fiber from neutral axis,

for this we need centroid of c/s

$\bar{x}$=6.65 mm

$\bar{y}$=5.57 mm

y=21.6-6.65=14.95 mm (Maximum)

y=19.2-5.57=13.63 mm

$\sigma_{bending} = M.y/I= 39.24x10^6\ N/m^2$

$\sigma = 39.24x10^6+5.132x10^6 =44.38$ Pa

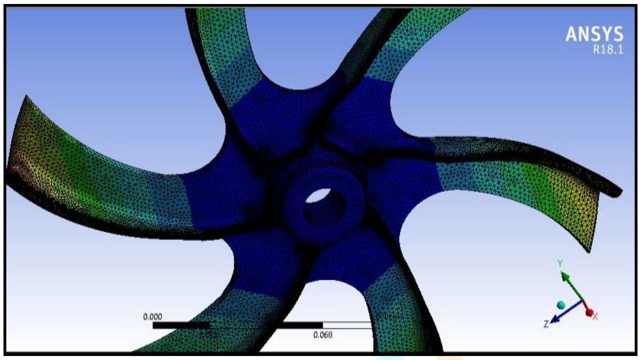
As per Ansys (simulation) analysis result for model 2 (SS) are $\sigma=41.98x10^6$ Pa

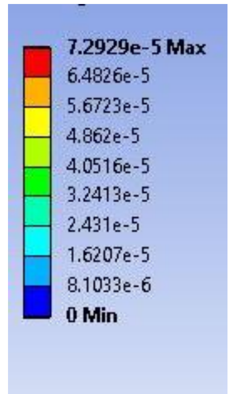
Due to some assumptions, there is error in between Software and Analytical calculations:

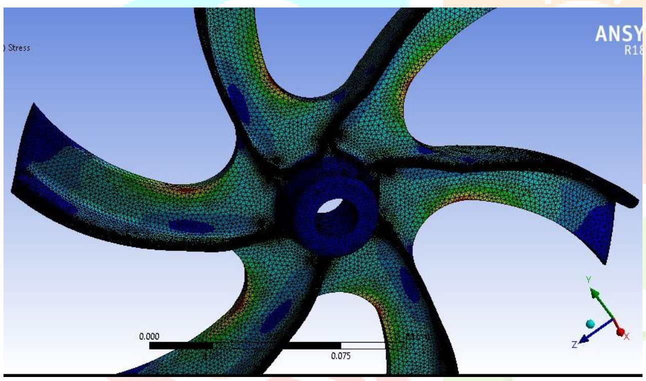
%error= 5.71%

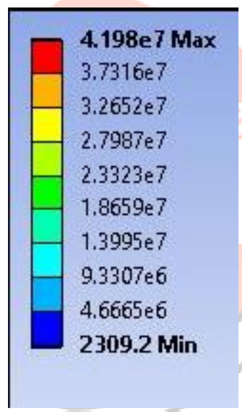
IV. RESULT

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 face. And obtained results are shown below with reference to model no 2.









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

IV. 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.

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