ISSN : 2455-9679
Impact Factor : 3.805

IJRTSM

INTERNATIONAL JOURNAL OF RECENT TECHNOLOGY SCIENCE & MANAGEMENT

"MATHEMATICAL AND CFD ANALYSIS OF CENTRIFUGAL PUMP IMPELLER FOR PERFORMANCE ENHANCEMENT IN CAVITATIONS"

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ABSTRACT

Cavitation is one of the most challenging fluid flow abnormalities leading to detrimental effects on both the centrifugal pump flow behaviors and physical characteristics. Centrifugal pumps' most low pressure zones are the first cavitation victims, where cavitation manifests itself in form of pitting on the pump internal solid walls, accompanied by noise and vibration, all leading to the pump hydraulic performance degradation.

Mathematical and computational fluid dynamics analysis has been performed for cavitation analysis on the impeller of centrifugal pump at different working pressure using CFX solver and proposed new design of impeller to reduce cavitation problem from the centrifugal pump. Different parameters like operating pressure, blade angles including inlet flow angle and trailing edge angle, NPSH have been used to find out the influence in the phenomenon of cavitation on impeller of a centrifugal pump.

Key Words: *Recirculation, Centrifugal pump, Cavitations, hydraulic machine, CFD Analysis*

I. INTRODUCTION

Cavitation is an abnormal condition that can lead to loss of production, material damage and, in the worst case, cavitation, which derives from the Latin word cavus, which means a hollow space or cavities. In the context of centrifugal pumps, the term cavitation involves a dynamic process of bubble formation in the liquid, its growth and subsequent subsidence when the liquid flows through the pump.

Type of Cavitations:
In the context of centrifugal pumps, the term cavitation involves a dynamic process of bubble formation in the liquid, its growth and subsequent subsidence when the liquid flows through the pump. In general, the bubbles that form in the liquid are of two types: vapour bubbles or gas bubbles.

Vapour bubbles are created by the evaporation of a pumped process fluid. The cavitation state induced by the formation and collapse of the vapour bubbles is commonly called Vaporous Cavitation.

Gas bubbles are formed due to the presence of gases dissolved in the liquid, which is usually the pumped air, but it can also be any gas in the system. The cavitation state induced by the formation and collapse of gas bubbles is commonly

ISSN : 2455-9679
Impact Factor : 3.805

called gas cavitation. Both types of bubbles are formed in a position in the pump in which the local static pressure is lower than the vapour pressure of the cavitation of liquid or vapour or the saturation pressure of the gas cavitation.

Cavitation Model: Cavitation is the process of the formation of vapour bubbles in low pressure regions within a flow.

II. CAVITATION PATTERNS

Traveling cavitation
In this type of cavitation, the micro bubbles otherwise called cavitation nuclei are curried along the flow field until they get to the flow's lower pressure zones, where they become macroscopic cavitation bubbles before collapsing at pressure recovery zones.

Attached cavitation Contrary to the above presented travelling cavitation, the attachedcavitation stays at the same location attached on a wall. This does not mean that the flow is steady. Actually, cavitation is almost always the source of unsteadiness which may be quite strong.

Vortex Cavitation
This type of cavitation is the mostly found in marine propellers. It is found at the vortex core generated by the secondary flow at the blade tip.

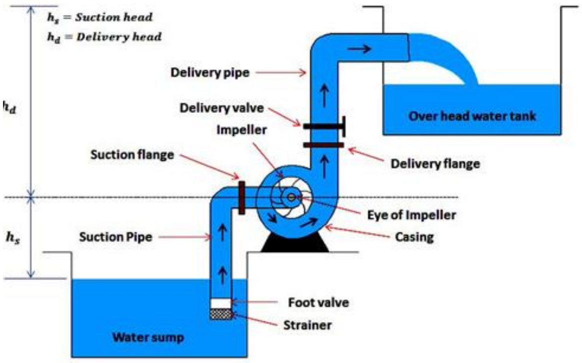

Figure 1: Centrifugal pumps

Losses in a Centrifugal Pump

- Loss of mechanical friction due to friction between fixed and rotating parts in bearings and glands.
- Loss of friction of the disc due to friction between the rotating surfaces of the impeller (or disk) and the fluid.
- Loss of losses and recirculation due to the loss of fluid from the pump and the return of fluid to the impeller. The pressure difference between the tip of the impeller and the eye can recirculation a small

Problems of centrifugal pumps

- Cavitation: the NPSH (Net positive suction head) of the system is too low for the selected pump
- Wear of the Impeller: can be deteriorate by suspended solids
- Overheating due to low flow
- Leakage along rotating shaft
- Lack of prime: centrifugal pumps

Cavitations Augmentation:-
The Centrifugal pump is used to transfer the fluid from one point to another in a system, by simply adding momentum. There is no rigorous procedure for designing a pump; Various manufacturers have developed their own approaches, involving thumb rules and proportions. The design is normally based upon desired head and capacity. Type of drive system may also be specified. To achieve better performance for a centrifugal pump, design parameters are

- Impeller Speed
- Pipe Connections and Velocities
- Impeller Inlet Dimensions

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- Impeller Outlet Dimensions
- Impeller Vane Shape
- Design of Volute

[1]The emergency relief needs associated with the flooding of the coal mine, a high capacity, high capacity and low flow submersible pump has been developed [2] Centrifugal pumps are widely used due to their suitability in almost all services for water supply systems. [3] The turbine for a centrifugal lixiviation pump to increase its performance and efficiency and take advantage of the design parameters .[4] It is very important that the centrifugal pump works effectively thanks to its great application. Pump performance is influenced by the speed triangle, depending on the input or output angle of the blade. [5] Centrifugal pumps are widely used in the oil and gas industry and pump performance decreases with higher viscosity and greater roughness of the pump wheel surface, and wheel design parameters have a significant impact on pump performance.[6] steam turbines, etc. Centrifugal pumps can be single or multi-stage. It depends on the number of wheels used in the pump.

III. MATHEMATICAL ANALYSIS

The Centrifugal pump is used to transfer the fluid from one point to another in a system, by simply adding momentum. There is no rigorous procedure for designing a pump, Various manufacturers have developed their own approaches, involving thumb rules and proportions. The design is normally based upon desired head and capacity. Type of drive system may also be specified. To achieve better performance for a centrifugal pump, design parameters are:

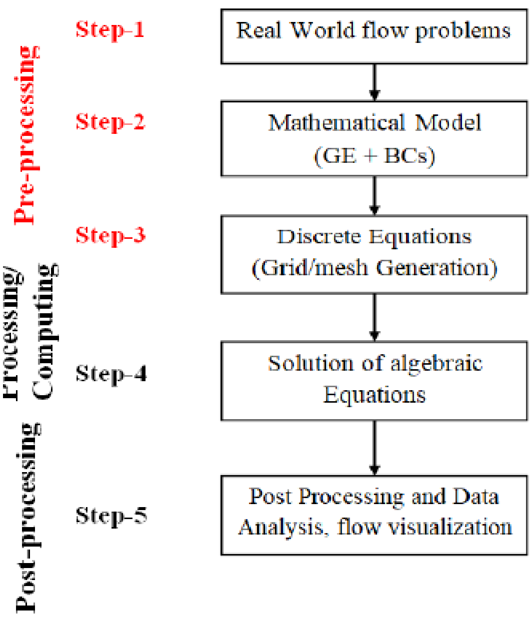

Figure 2: Steps in CFD Analysis

The cavitation in a pump can be noted by a sudden drop in efficiency and head, in order to determine whether cavitation will occur in any portion of the suction side of the pupm, the critical value of Thoma's cavitation factor is calculated.

$$\sigma = \frac{(H_b) - H_s - h_{Ls}}{H} = \frac{(H_{atm} - H_v) - H_s - h_{Ls}}{H}$$

The value of Thoma's cavitation factor σ for a pump may be calculated and compared with critical cavitation factor σc. If the value of σ is greater than σc the cavitation will not occur.

$$\sigma_c = 1.03 \times 10^{-3} N_s^{4/3}$$

Governing Equations:

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Conservation of mass or continuity equation:

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho\, \vec{v}) = S_m$$

Momentum Conservation Equations:

$$\frac{\partial}{\partial t}(\rho\vec{v}) + \nabla.(\rho\vec{v}\vec{v}) = -\nabla p + \nabla.(\bar{\bar{\tau}}) + \rho\vec{g} + \vec{F}$$

Energy Equation

$$\frac{\partial}{\partial t}\sum_{k=1}^{n}(\alpha_k \rho_k E_k) + \nabla.\sum_{k=1}^{n}(\alpha_k \vec{v}_k(\rho_k E_k + p)) = \nabla.(k_{eff}\nabla T) + S_E$$

k−∈ Model

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k v_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + G_k + G_b - \rho \in - Y_M + S_k$$

CAD modeling: After generating of two dimensional impeller blade profile by vista CPD Blade design module integrated with ANSYS workbench component system is transfer to create a three dimensional model of centrifugal pump impeller with the help of BaldeGen module integrated with ANSYS workbench

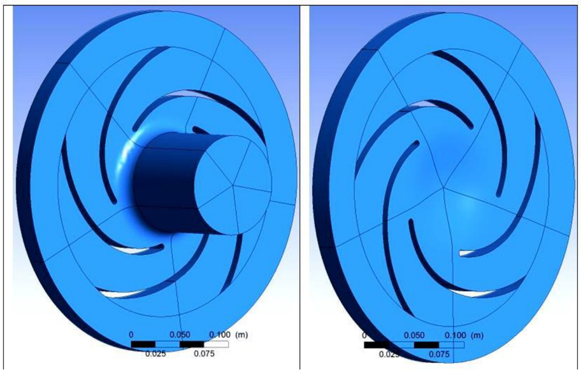

Figure 3 Three dimensional CAD model of centrifugal pump impeller

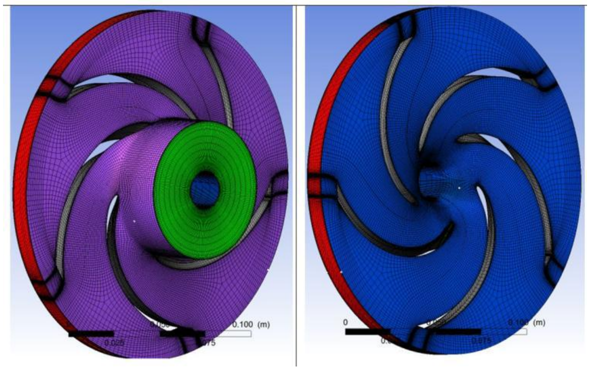

Figure 4 Meshing of centrifugal pump impeller Meshing

[07] After optimization, the velocity gradients on the suction surface are more uniform and the flow separations on the input portion of the blade are eliminated. [08] Phase change is carried out at constant temperature and the local fall pressure generated by the flow conditions. Turbomachines, like centrifugal pumps, suffer from loss of power. [09] Centrifugal pumps are widely used for their suitability for almost all irrigation services, water supply, steam plants, wastewater, oil refineries, chemical plants, hydropower plants, food processing plants and mines.[10] CFD approach was proposed to study the flow in the centrifugal pump impeller with Solid Workflow Simulation. [11] Vibration optimization of the centrifugal pump taking into account the fluid-structure interaction.[12] Water over a short to medium distance through the pipeline, where moderate height and discharge are required. To ensure optimal pump performance, the blades must be designed accordingly. [13] Performance of the deep well centrifugal pump with four different wheel output widths and studied numerical, theoretical and experimental methods. [14] Flow inside the centrifugal pump is very complex, mainly because of the structure of the 3D flow that includes turbulence,

To determine the cavitaion on the blade of centrifugal pump impeller turbulence.
1. Two different working fluids are taken for cavitation analysis, one is water liquid at 25oC and another fluid is water vapour at 25oC.
2. In the default domain set the Reference Pressure to zero Pa and Set angular velocity to 2900 RPM.
3. At the inlet of the of the pump the frame is kept stationary and option of mass and moment is set as normal speed which value set as 7.21259m/sec.
4. At the outlet of the of the pump the frame is kept stationary, flow regime option set as subsonic and mass & moment

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option set as static pressure with relative pressure of 100000 Pa, 80000 Pa, 60000 Pa, 40000 Pa, 30000 Pa and 20000 Pa Respectively.

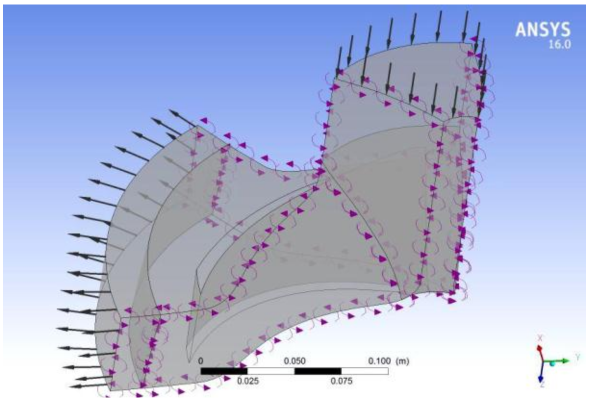

Figure no 5. Boundary conditions

[15] The different performance parameters of the centrifugal pump have been calculated, such as overall efficiency, cavitation, slip factor, losses, etc. [16] Wheel repair and voltage design are undertaken to improve the performance of the centrifugal pump. Design limitations related to the development of planetary aircraft options.
[17] Evaluated the performance of the wheels with the same outlet diameter with different numbers of blades for centrifugal pumps. [18] A high- speed impeller pump with a free wheel centrifugal wheel.

They found that the pump had a large high pressure exhaust head, because the blade angle at the wheel exit was important, the liquid coming out of the wheel had a high absolute speed and the dynamic distribution head of the wheel it was great. The kinetic energy of the liquid was converted into pressure in the volute and in the diffuser

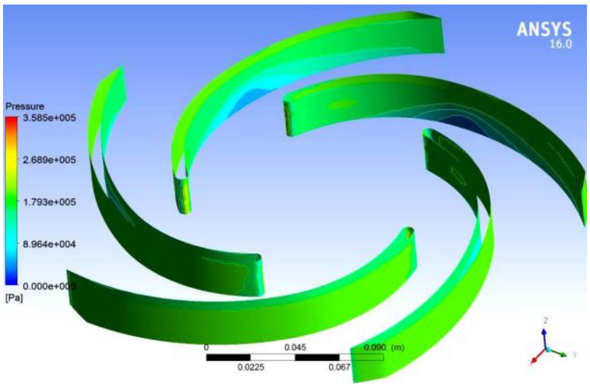

Figure no 6. Pressure distribution on the blade of impeller at 100000 Pa

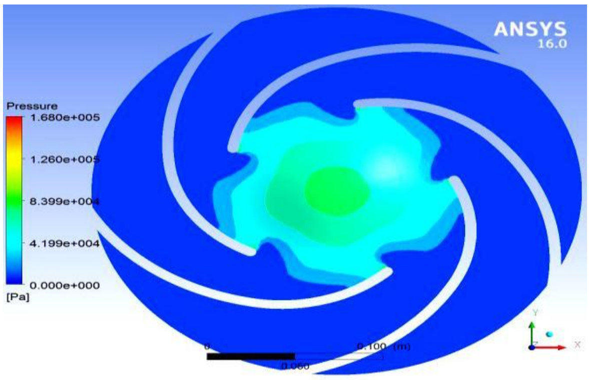

Figure no 7. Pressure distribution at the shroud of impeller at 80000 Pa

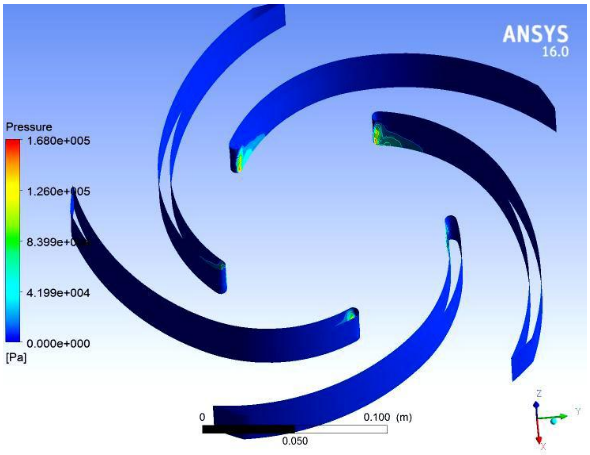

Figure no 8. Pressure distribution on the blade of impeller at 80000 Pa

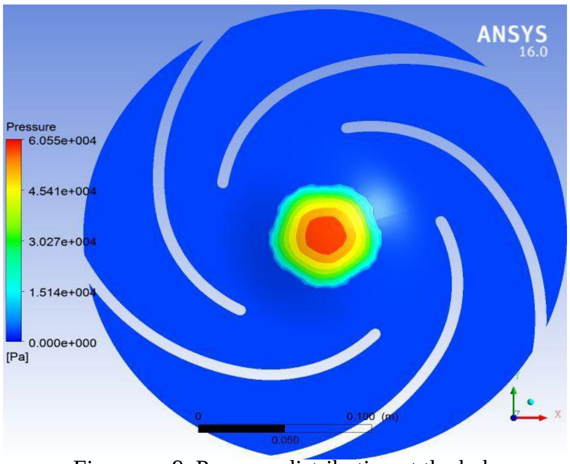

Figure no 9. Pressure distribution at the hub of impeller at 60000 Pa.

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[26] On the influence of the number of blades on the internal volume capacity and on the properties of the centrifugal pump. Numerical simulations and experimental [27] Performance and energy consumption, such as wheel outlet diameter, blade angle and blade number, and evaluated wheel performance with the same outlet diameter. [28] The simulation of three-dimensional turbulent flow in turbo-machinery is currently based on the resolution of Reynolds' average Navier-Stokes equations.

IV. Result Analysis

CFD analysis of pump impeller:

The blade lean graph is available. This graph shows a plot of the blade lean angle versus meridional coordinate (%M). The blade lean angle is essentially the angle between a constant-theta line and a straight line connecting the hub and shroud camber lines

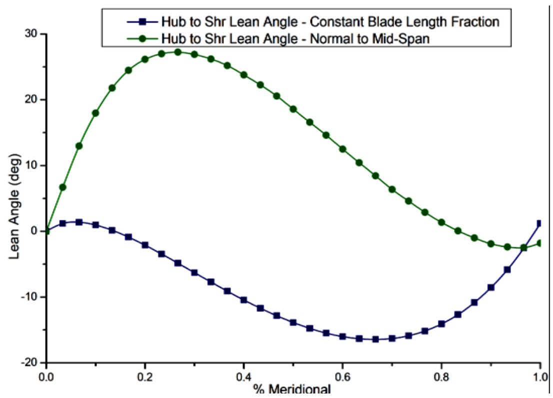

Figure no 10 Variation of blade lean angle hub versus maridional

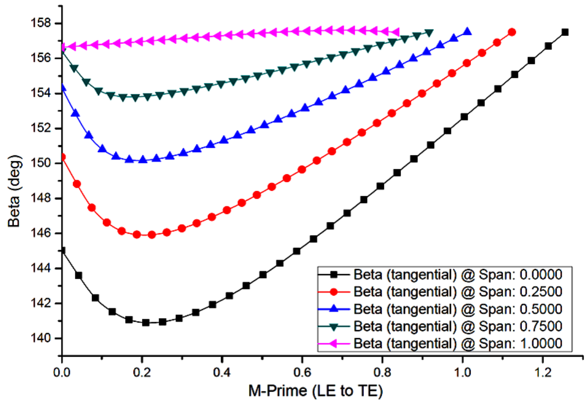

Figure no 11. Variation of beta angle to meridonial prime leading

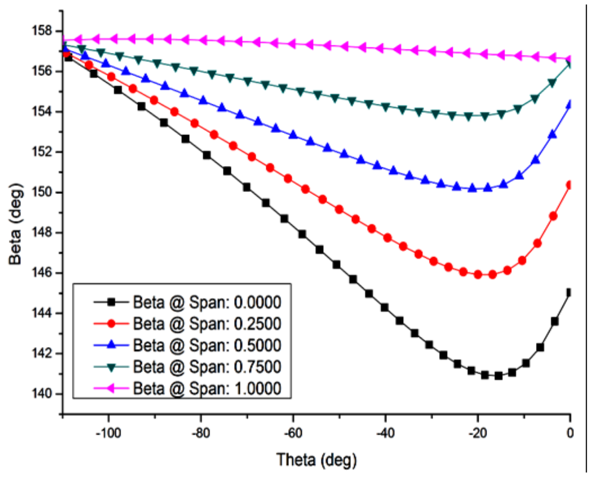

Figure no 12. Variation of beta versus theta

The main objective of present work to reduce the cavitational phenomena in the centrifugal pump.

V. Conclusion

In the present work Mathematical and computational fluid dynamics analysis have been performed for cavitation analysis on the impeller of centrifugal pump and proposed new design of impeller to reduce cavitation problem from the centrifugal pump. There are following conclusive points having been drawn from the above work.

computational fluid dynamics analysis on impeller of centrifugal pump at different operating pressure of 100000 Pa, 80000 Pa, 60000 Pa, 40000 Pa, 30000 Pa, and 20000 Pa Respectively.

1. It has been observed that the generated pressure on the leading edge of impeller, inlet of hub and shroud portion of

ISSN : 2455-9679
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the centrifugal pump. The values of maximum and minimum pressure are 4.73526e5 Pa and -5.63004e5 Pa at operating pressure 100000 Pa, 3.0745e6 Pa and -3.69823e5 Pa at operating pressure 80000 Pa, 9.04025e6 Pa and -0.719077e5
2. After performing computational fluid dynamics analysis on modified design of impeller of centrifugal pump at operating pressure of 40000 Pa. It has been observed that the generated pressure on the leading edge of impeller

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