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NUMERICAL SIMULATION AND OPTIMIZATION OF CAVITATING AND NON CAVITATING FLUID FLOW (ABSOLUTE PRESSURE HUB) IN CENTRIFUGAL PUMP

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ABSTRACT

The phenomenon of cavitation is an unsteady flow, which is nearly inevitable in pump. It would degrade the pump performance, produce vibration and noise and even damage the pump. Hence, to improve accuracy of the numerical prediction of the pump cavitation performance is much desirable. In the present work, a cavitation model and the non-cavitation model, is considered to investigate the influence of the empirical coefficients on predicting the pump cavitation performance, concerning a centrifugal pump. One coefficients is analyzed, namely the Absolute pressure (Hub). Also, the experiments are carried out to validate the numerical simulations also investigate the process parameters which would deteriorate the pump performance and cause damage to the pump.

KEYWORDS: Cavitation, Non-Cavitation,DOE, ANOVA, Orthogonal array.

1. INTRODUCTION

The occurrence of unsteady cavitation in pump is nearly inevitable, where the local pressure drops below the saturated vapor pressure, especially for those applied on vessels and offshore platforms, since the particles contained in seawater can increase the probability of cavitation generation. Cavitation may cause various problems, like vibration, noise and material erosion, which would deteriorate the pump performance and cause damage to the pump. In the recent years, owing to the continuous improvement of Computational Fluid Dynamics (CFD) technologies and computational capabilities, the prediction of pump cavitation performance based on CFD method has been beneficial for preliminary pump design. Thus, it makes the cavitation model play a significant role in numerical simulation progress. During the last decades, great efforts have been made in the development of cavitation models. These models can be put into two categories, namely interface tracking methods and homogeneous equilibrium flow models. The former assumes that the cavity region has a constant pressure equal to the vapor pressure of the corresponding liquid and the computations are calculated only for the liquid phase. However, these methods are limited to 2-D planar or axisymmetric flows because of the difficulties dealing with complicated 3-D models. In the second category, the homogeneous equilibrium flow models assume the flow to be homogenous and isothermal, applying either a barotropic equation of state or a transport equation for both phases. The barotropic equation links the density to the local static pressure. A recent experimental study implied that the vorticity production is an important aspect of cavitating flows, especially in the cavity closure region. But in the barotropic law, the gradients of density and pressure are always parallel, which leads to zero baroclinic torque. Therefore, the barotropic cavitation models cannot capture the dynamics of cavitating flows, particularly for cases with unsteady cavitation flows. Furthermore, this method is prone to instability because of high pressure-density dependence, which makes it difficult to reach the convergence levels of non-cavitating flow simulations. Conversely, these limitations can be avoided by applying the transport equation models (TEM). In this approach, volume or mass fraction of the two phases are solved by an additional transport equation with different source terms. Besides, there is another apparent advantage of this method, which could predict the impact of inertial forces on cavities like elongation, detachment and drift of bubbles. In the past years, a great number of transport equation models are proposed. These models apply different condensation and evaporation empirical coefficients to regulate the mass and momentum exchange. However, most of these empirical coefficients are calibrated on simple hydraulic machinery, such as hydrofoil or blunt body.

2. LITERATURE REVIEW

2.1 Xiaoruicheng, Rennian li et.al studied about parameter equation study for screw centrifugal pump. According to this study opening flow passage and spiral radial impeller is present in the screw centrifugal pump and this makes it different from other general centrifugal pump.
Spiral blade is the impeller inlet whereas, mixing flow pump blade is the blade in the outer inlet.This structure of centrifugal pump has spiral propelling effects as well as centrifugal effects that make this structure more special. Therefore, merits of both screw pump and centrifugal pump are present in it.

2.2 Hon-lin LIU, Dong-xi LIU, Yong WANG, Xian-fang WU, Jian WANG et.al studied about application of modified k-ῳ model to predicting cavitating flow in centrifugal pump. In this study, cavitating flow's compressibility of the cavity has been considered. For predicting the cavitating flow in centrifugal pump, the k-ῳ model is presented. In this schnerr-sauer cavitation model and k-ῳ model were combined with CFX ANSYS. These two models were performed with numerical simulations to evaluate k-ῳ model and also modify it. And then finally experimental data were compared to the calculation results. With the 3 different values of the flow coefficient, numerical simulations were executed. And the showed agreement with most of experimental data is showed by the k-ῳ model.
A modified k-ῳ model is presented in this paper. A cavitation model frequency in centrifugal pump that is used in propellers and hydrofoils to model cavitating flow is introduced here. Due to the development of cavitation, breakdown of pump performance is the main and this is demonstrated by numerical investigation. The impeller passage is filled by vapor filled cavities that are attached on blades. This results in separation of flow and blades.

2.3 Rakibuzzaman, Sang-Ho Suh, Kim Kyung-Wuk, Hyung-Ho Kim, Min Tae Cho, In Sik Yoon et.al studied about the study on multistage centrifugal pump performance characteristicsfor variable speed drive system. In the power plant applications, commercial and industrialapplications centrifugal pumps are widely used. By constant speed drive system, most of thesepumps are operated. Total energy of each nation, huge energy is consumed by pump.Energy saving would be provided to operate variable speed drive system. With this variablespeed drive system, the pump performance characteristics of multistage centrifugal pump areinvestigated. To achieve the centrifugal pump performance an experimental set up of system wasconstructed. This curve and operating points included: -
H-Q, ῃ- Q, P-Q.

This interaction is between system curves and performances. In the experimental system of the variable drive system, a vector controlled inverter driving was installed. For reliability of the pump design development and to get the pump performance for validation a numerical investigation was applied and also analyzed velocity effects and pressure in internal flows. By the finite volume method in the numerical analysis, navier-stokes equation were discretized. A comparison of experimental and computed data is carried out for validating a numerical approach. Efficiency, power and pump head is shown at different flow rates and with rotational speed. So that average deviation of the head value remains 5.4% this is the reason agreement between experiment data and numerical data is done.

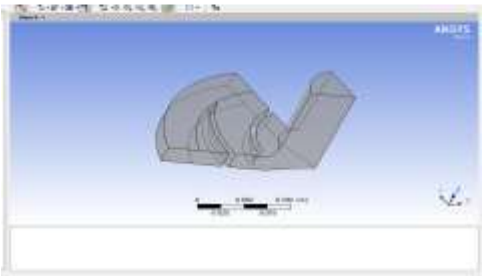
Inverter controlled variable speed drive multistage centrifugal pump is the topic on which the study is based. This study is done in pressure system and a closed loop variable flow system. In the designed layout, a model pump was installed so that constant speed drive conditions and variable speed drive conditions can be achieved. At the same speed ratio when the similar types of would be running then energy savings is obtained. The condition where pump and system flow rates are said to be equal and the pump and the system head are also found equal simultaneously is the condition of the point of interaction of operating point. For the model pump curve validation three pump systems curves are considered. And because of the low pressure, there would be improved performance and life cycle of the pump.

3. PROBLEM DESCRIPTION

The main aim of the study is to model cavitation in a centrifugal pump, which involves the use of a rotation domain and the cavitation model and also identify effect of the cavitation and non-cavitation by using different process parameters in the centrifugal pump. In this study different process parameters like outlet pressure, velocity, density and viscosity were deal as input parameters.

MATERIALS AND METHODS

4. DESIGN OF PROBLEM



5. DESIGN OF EXPERIMENT AND RESEARCH METHODOLOGY

The effects of process parameters were studied by various researchers from last decades. It is very difficult to design, experiments for any type of research and here a scientific approach is helpful for researchers which is known as "DESIGN OF EXPERIMENT". This technique is adopted by researcher for this study. By use of D.O.E. techniques any researcher can determine important factors which are responsible for output result variation of experiments. DOE can found optimum solution for particular experiments. In this study Response Surface methodology is used for ANOVA analysis, after selection of factors and levels for current study it is important to select accurate orthogonal array and for this task MINITAB software is used for making of orthogonal array of factors.

Table .Experiment for input parameters.

s.no	Outlet pressure	Viscocity	Density	Normal speed	Absolute pressure (Hub)
1. 1	450000	0.03	1300	8.5	300701
2.	450000	0.03	1100	8.5	444704
3.	450000	0.03	1100	8.5	444704
4.	750000	0.03	1100	8.5	749446
5.	600000	0.05	1000	10.0	609356
6.	450000	0.01	1100	8.5	445479
7.	150000	0.03	1100	8.5	237551
8.	450000	0.03	1100	11.5	522175
9.	450000	0.07	1100	8.5	443971
10.	450000	0.03	1100	8.5	444220
11.	300000	0.05	1000	7.0	296043
12.	450000	0.03	1100	8.5	444704
13.	300000	0.05	1200	10.0	377367
14.	300000	0.01	1000	7.0	298171
15.	450000	0.03	1100	8.5	196640
16.	600000	0.05	1200	7.0	581028
17.	600000	0.05	1200	10.0	610731
18.	450000	0.03	900	8.5	445780
19.	450000	0.03	1100	8.5	444704
20.	600000	0.01	1200	10.0	604917
21.	300000	0.05	1000	10.0	314072
22.	450000	0.03	1100	8.5	444704

23.	600000	0.01	1000	10.0	606703
24.	600000	0.01	1200	7.0	583713
25.	300000	0.01	1200	10.0	374530
26.	300000	0.01	1200	7.0	327578
27.	300000	0.05	1200	7.0	326136
28.	450000	0.03	1100	5.5	419451
29.	300000	0.01	1000	10.0	314072
30.	600000	0.01	1000	7.0	583329
31.	600000	0.05	1000	7.0	582244

6. RESULT AND DISCUSSION

In the table below shown the anova analysis is performed for the Absolute pressure (HUB) v/s Outlet pressure , Viscosity and the Density. In the very first column the sources are given which include the types of anova analysis, which are linear square and the 2 way interaction also the variables. In the second column the value for the degree of freedom is shown. at the top sum of the degree of freedom for all of the variable and below the degree of freedom is shown for the individual variable. In the third column the seq. ss are shown and the next to it contribution percentage of the all variable are shown. Then in the next column the value for the adj SS are given which indicate the relationship of the input and the output variable with correspondence to the value of R-sq. Now from the table below it can easily predicted that the contribution of the linear model is maximum among all the three model the contribution of the linear model is 81.19%, and in the linear model the contribution of the Outlet pressure is maximum 79.56% among all the three parameters, hence Outlet pressure is the parameters having maximum response on the output or Outlet pressure is most responsible parameter for producing the output. Now in the square model Outlet pressure * Outlet pressure is the parameter responsible for producing response, the value of the Absolute pressure (HUB) is get deflected by the changing the value of the of the Outlet pressure *Outlet pressure, finally in the last model of the anova analysis which is 2 way interaction Outlet pressure *Density having maximum contribution among all the parameters which is 0.41 hence it is the only factor responsible in the case of 2 way interaction.

Table 6.For Analysis of Variance for Absolute Pressure (Hub)

Source	**DF**	**Contribution in %**	**F value**	**P Value**
Model	14	87.11	7.72	0.000
Linear	4	81.19	25.20	0.000
Outlet pressure	1	79.56	98.77	0.000
Viscosity	1	0.00	0.00	0.998
Density	1	0.09	0.12	0.798
Normal speed	1	1.54	1.91	0.186
Square	4	5.44	1.69	0.202
Outlet pressure*Outlet pressure	1	2.66	3.85	0.067
Viscosity * Viscosity	1	0.61	0.91	0.353
Density*Density	1	0.37	0.27	0.612
Normal speed * Normal speed	1	1.80	2.23	0.155
2-Way Interaction	6	0.47	0.10	0.996
Outlet pressure*Viscosity	1	0.00	0.00	0.984
Outlet pressure*Density	1	0.41	0.51	0.487
Outlet	1	0.01	0.01	0.907

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pressure*normal speed				
Viscosity*Density	1	0.00	0.00	0.985
Viscosity* normal speed	1	0.00	0.01	0.944
Density 8 Normal speed	1	0.05	0.06	0.806
Error	16	12.89		
Lack-of-Fit	10	2.80	0.17	0.993
Pure Error	6	10.09		
Total	30	100		

6.1 Result from Model Summary:

Finally the regression equation is shown give the exact model equation or it will show the relationship between the input and the output variables. The value for the R –sq is 87.11% which is good agreement between the input and the output relationship. It shows that there is strong relationship between the input and the output variables. Now the value of the R-sq prediction is 70.16% hence the data are well fitted for the new sets of the variables.

Table: model summary for Absolute pressure (HUB)

S	R-sq	R-sq(adj)	R-sq(pred)
64860	87.11 %	75.83%	70.16%

6.2Residual Plot for Absolute pressure (Hub)

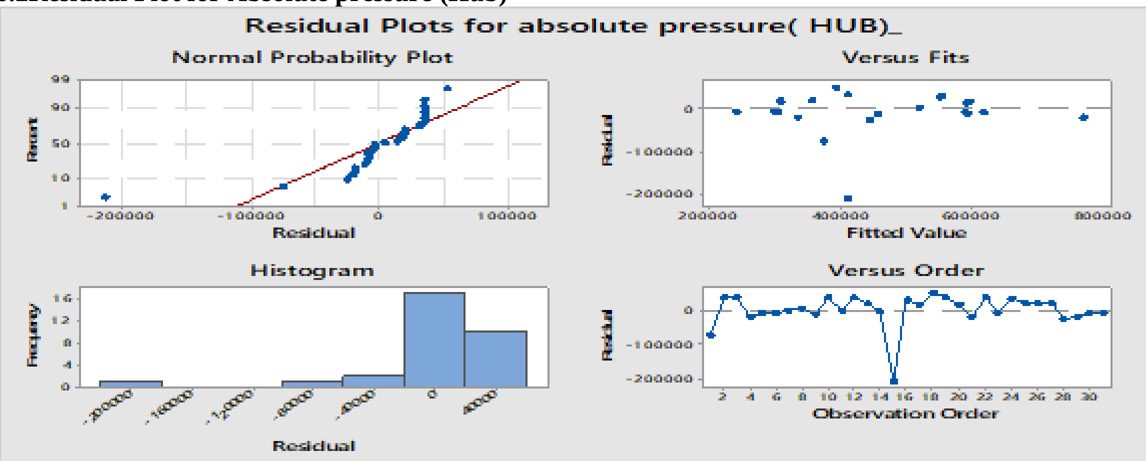

Fig6.5: Residual plot for Absolute pressure (Hub)

Above is the residual plot for the Absolute pressure (HUB) is shown, in the normal probability graph all the data are normally distributed to the normal probability line, hence the data are well fitted for the observation and the deflected from the normal probability line are the data which are not having the effect on the response. In the histogram plot maximum data are on the 0 and -0.05 which also mean there is no too much distance betwqeen the data and the normal probability line, final graph shows the deflection in the residual with respect to the number of the observation

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6.3 Main effect plot for Absolute pressure (Blade)

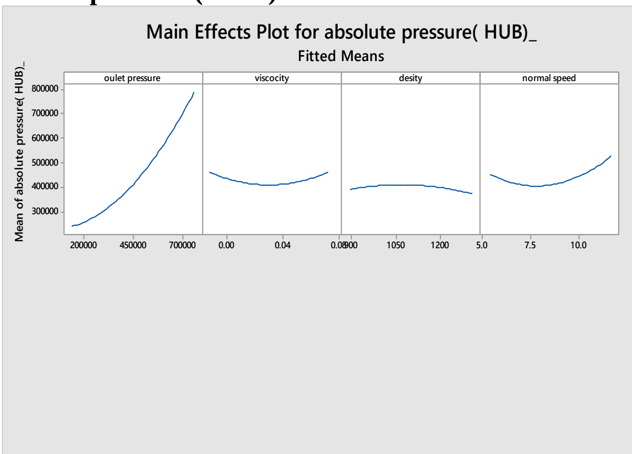

Fig6.3: fitted mean plot for Absolute pressure (Hub)

The above plot shows the man effect plot for the Absolute pressure (HUB), in the first graph the graph shows the relation between the Absolute pressure (HUB) and the Outlet pressure , now in this graph as the value of the Outlet pressure is increases the value of the Absolute pressure (HUB) is also increase, in the second graph is for the Viscosity , hence there is not too much effect of the Viscosity on the Absolute pressure (HUB) , as the value of Viscosity is increases the value is constant for Absolute pressure (HUB). And finally in the last graph is for the Density the value of Absolute pressure (HUB) is increases up to some level.

6.4 Interaction plot for Absolute pressure (Hub)

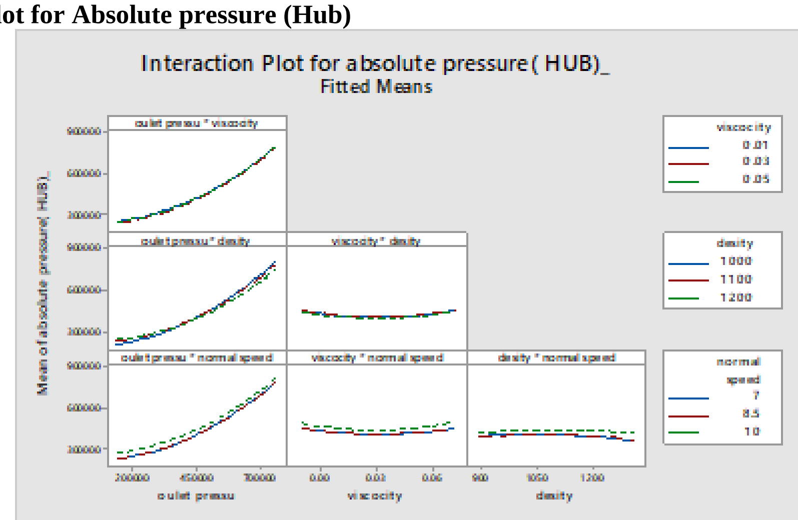

Fig 6.4 Interaction plot for Absolute pressure (Hub)

In the above graph the interaction plot for the Absolute pressure (HUB) is shown , which is showing the combined effect of the two variables on the output , first is for Outlet pressure * Viscosity second graph is for the Outlet pressure * Density showing their effect on the Absolute pressure (Hub) and finally the contribution of the Viscosity* Density showing their effect on the Absolute pressure (Hub).

6.5 Resultant Model equation for the Absolute pressure (Hub) : Finally the regression equation is shown give the exact model equation or it will show the relationship between the input and the output variables.

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Table: model equation for the Absolute pressure (HUB)

Absolute pressure (HUB)	-120928 + 0.84 oulet pressure - 2293771 viscocity + 1447 desity - 151692 normal speed + 0.000001 oulet pressure*oulet pressur + 28998713 viscocity*viscocity - 0.63 desity*desity + 8054 normal speed*normal speed + 0.11 oulet pressure*viscocity - 0.00077 oulet pressure*desity- 0.0085 oulet pressure*normal speed + 159 viscocity*desity+ 38842 viscocity*normal speed + 27 desity*normal speed

7. CONCLUSION AND FUTURE SCOPE

The major limitations of the mini/micro hydropower schemes are the higher cost of small capacity hydro turbines. Also it is very cumbersome, time consuming and expensive to developed the site specific turbines corresponding to local site condition in micro/mini hydro range. In such plant small centrifugal pump can be used in turbine mode by running in the reverse direction. The efficiency of PAT is usually lower than convention hydro turbines however, it offers various advantages like lower initial cost and easy availability in wider range of head and flow rates. In this research finite element simulation and the optimization of the cutting process parameter had done using different cutting tool material. All 31 experiment design and analyzes into the response surface method and all this experiment were project into the simulation environment using ansys 19.1, a the process parameter outlet pressure , Viscosity, Density and normal Speed are taken into the consideration as a input parameters. Following are the conclusion made from this research are given below

- From the Graph of Ansys it is clear that the main area of the cavitation exists between the suction sides of the Hub in many cases. A secondary area of cavitation is just behind the leading edge of the blade on the pressure side.
- From analysis it is clear that for occurrence of cavitation, the minimum absolute pressure is equal to Saturation pressure.
- There were many significant spikes in residual of all 31 experiments in CFX, due to the outlet pressure difference and also by Normal speed and absolute pressure hence these entire factor are low enough to induce cavitation.
- In the first case the or anova analysis performed for the Absolute pressure (Hub), the value for the linear model is 0.000, which less 0.05 or minimum as compared to both other models, so that linear model play major roles in deflecting Absolute pressure (Hub).
- In the linear model for the Absolute pressure (Hub), the P value of the Outlet pressure is 0.000, which is less than 0.05 or into the confidence interval, it means the Outlet Pressure in the linear model is the parameter by virtue of which the value of Absolute Pressure (Hub) are getting effected or by changing the value of the Outlet pressure the Absolute pressure (Hub) will get deflected or the quality of the product can be changed by changing the value of outlet pressure in the linear model.
- In the two way interaction model Outlet pressure * Density is parameter having the P value 0.478 which nearly to the 0.05, it means in the two way interaction model this is only parameter, by changing the value of which, Absolute Pressure(Hub) were get deflected. Or quality of the product in two way interaction can be change by changing the value of Outlet pressure * Density.
- The value for the R-sq is 87.11% which show that there is strong relationship between the input and the output variables.

8. FUTURE SCOPE

- The Analysis correlation developed in the present study is applicable in the specific range of the diameter and the rotational speed. More detailed investigation may be carried out to apply the correlation in the wider range.
- Many of cavitation research focus on the water as working fluid but one can also found application for energy recovery in petroleum industries gas scrubbing, sewage treatment plant etc.
- More detailed cavitation and vibration analysis may be carried out.

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- Mathematical modeling of Pump working under different operating condition may be carried out.

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