IJESRT: 8(9), September, 2019 ISSN: 2277-9655

International Journal of Engineering Sciences & Research Technology

(A Peer Reviewed Online Journal)

Impact Factor: 5.164

IJESRT

IJESRT
INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

NUMERICAL SIMULATION AND OPTIMIZATION OF CAVITATING AND NON CAVITATING FLUID FLOW IN CENTRIFUGAL PUMP

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DOI: 10.5281/zenodo.3467835

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 (Blade). 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.

ISSN: 2277-9655
Impact Factor: 5.164
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2. LITERATURE REVIEW

2.1 V. Muralidharan, V. Sugumaran et.al studied about rough set based rule learning and fuzzy classification of wavelet features for fault diagnosis of monoblockcentrifugal pump. In this studyas a classification problem the fault diagnosis problem is conceived. The signals used in this are vibration signals through this using wavelet analysis, fault diagnosis of centrifugal pump can be used. From the vibrations signals, to generate rules, rough set theory is applied. Faults are identified on the basis of strength of the rules. For the study of different faults that are considered are: -

Cavitation, pump with faulty bearing, pump at good condition, pump with faulty impeller, and pump with both faulty bearing as well as impeller. Based on the number of rules, and strength that are generated from rough set theory, the classification accuracy is based. By using (DWT) i.e. discrete wavelet transform from the vibration signals wavelet featured are compared. And through rough sets rules are generated and finally through fuzzy logic these are classified. In a confusion matrix form the results are presented. This helps in finding out that weather monoblock centrifugal pump is in good condition or bad condition. The monoblock centrifugal pump focuses on use of rough set theory. Fitted to drive the pump, the motor has 2hp capacity. To adjust the inlet valve and outlet valve, a valve control system is provided. To drop the pressure between an eye of an impeller and suction head, we need to adjust the inlet valve. In inlet pump, acrylic pipe is fitted.

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 characteristics for variable speed drive system. In the power plant applications, commercial and industrial applications centrifugal pumps are widely used. By constant speed drive system, most of these pumps 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 variable speed drive system, the pump performance characteristics of multistage centrifugal pump are investigated. To achieve the centrifugal pump performance an experimental set up of system was constructed.

This curve and operating points included: -
H-Q, ŋ- 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

ISSN: 2277-9655
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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.

4. MATERIALS AND METHODS

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 5..Experiment for input parameters.

	Outlet pressure	Viscocity	Density	Normal speed	**Absolute pressure (Blade)**
1. 1	450000	0.03	1300	8.5	307788
2.	450000	0.03	1100	8.5	453195
3.	450000	0.03	1100	8.5	453195
4.	750000	0.03	1100	8.5	750298
5.	600000	0.05	1000	10.0	616158
6.	450000	0.01	1100	8.5	453155
7.	150000	0.03	1100	8.5	258790
8.	450000	0.03	1100	11.5	569534
9.	450000	0.07	1100	8.5	452944
10.	450000	0.03	1100	8.5	452992
11.	300000	0.05	1000	7.0	302768
12.	450000	0.03	1100	8.5	453195
13.	300000	0.05	1200	10.0	417500

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14.	300000	0.01	1000	7.0	307347
15.	450000	0.03	1100	8.5	258809
16.	600000	0.05	1200	7.0	605290
17.	600000	0.05	1200	10.0	618972
18.	450000	0.03	900	8.5	452918
19.	450000	0.03	1100	8.5	453195
20.	600000	0.01	1200	10.0	618088
21.	300000	0.05	1000	10.0	333041
22.	450000	0.03	1100	8.5	453195
23.	600000	0.01	1000	10.0	616640
24.	600000	0.01	1200	7.0	603801
25.	300000	0.01	1200	10.0	394386
26.	300000	0.01	1200	7.0	333841
27.	300000	0.05	1200	7.0	327550
28.	450000	0.03	1100	5.5	451122
29.	300000	0.01	1000	10.0	333041
30.	600000	0.01	1000	7.0	601924
31.	600000	0.05	1000	7.0	601134

6. RESULT AND DISCUSSION

In the table shown above all the 31 experiment were run in the ansys software and value for the Absolute pressure (Blade) is calculated for the all the experiment. All the cases were analyzed by the Ansys Fluid flow (CFX) and the correspondence value for the Absolute pressure (Blade) is calculated for that. The aim behind using the ansys software is to minimize the cost or predicting the man, machine, money and the labor cost, hence it is not possible to run all the experiment at real life environment, because in most of the cases Blade is deviated or, Blade got crack that why by using the virtual environment all the 31 cases were successfully conducted and predicting the value for the Absolute pressure (Blade). From the given table, the maximum value of Absolute pressure (Blade) is in the case 4 and the case 7 is the having the minimum Absolute pressure (Blade)

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

Source	**DF**	**Contribution**	**F value**	**P Value**
Model	14	90.24	10.62	0.000
Linear	4	82.76	34.07	0.000
Outlet pressure	1	80.61	132.77	0.000
Viscosity	1	0.00	0.00	0.962
Density	1	0.06	0.09	0.763
Normal speed	1	2.08	3.43	0.082
Square	4	6.69	2.75	0.065
Outlet pressure*Outlet pressure	1	2.38	4.66	0.046
Viscosity * Viscosity	1	0.37	0.83	0.376
Density*Density	1	0.74	0.72	0.408
Normal speed * Normal speed	1	3.21	5.28	0.035
2-Way Interaction	6	0.84	0.23	0.960
Outlet pressure*Viscosity	1	0.00	0.00	0.960
Outlet	1	0.43	0.72	0.410

ISSN: 2277-9655
Impact Factor: 5.164
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pressure*Density				
Outlet pressure*normal speed	1	0.28	0.45	0.510
Viscosity*Density	1	0.01	0.01	0.911
Viscosity* normal speed	1	0.01	0.02	0.881
Density 8 Normal speed	1	0.11	0.18	0.680
Error	16	9.71		
Lack-of-Fit	10	3.26	0.30	0.953
Pure Error	6	6.45		
Total	30	100		

6.1 Result from Model Summary: Model summary is the final conclusion for the data analysis and for our results as there are three term R –sq, R-sq (Adj) , and the R-sq(pred) gives the final shape to the analysis.

6.2 R-sq : According to the research methodology the value for the R-sq is must be above 40% for predicting the good agreement between the input and the output values. From the table below the value for the R-sq is 90.29% which reflects the good agreement between the input and the output variables. Hence there is strong relationship between the input and the output variables.

6.3 R-sq(Adj) : In the corresponding to the value of the r-sq the value of R-sq (adj) must also be above the 40% for predicting the well relationship between the input and the output variables. Hence in the table below the value for the R-sq(Adj) is 81.78% hence the value shows the indication of strongest relationship between trhe input and the output variable in correspondence to the value of the R-sq.

6.4 R- sq (prediction): the value for the R-sq prediction is considered for the new set of experiment by using the same output or the similar results were used for prediction the new sets of data's, hence in the table given below the value for the R-sq prediction is the 72.43% hence it validate that the model is equation is also well fitted for the new sets of the experiment.

Table : model summary

S	R-sq	R-sq(adj)	R-sq(pred)
55192	90.29%	81.78 %	72.43%

6.5 Residual Plot for Absolute pressure (Blade)

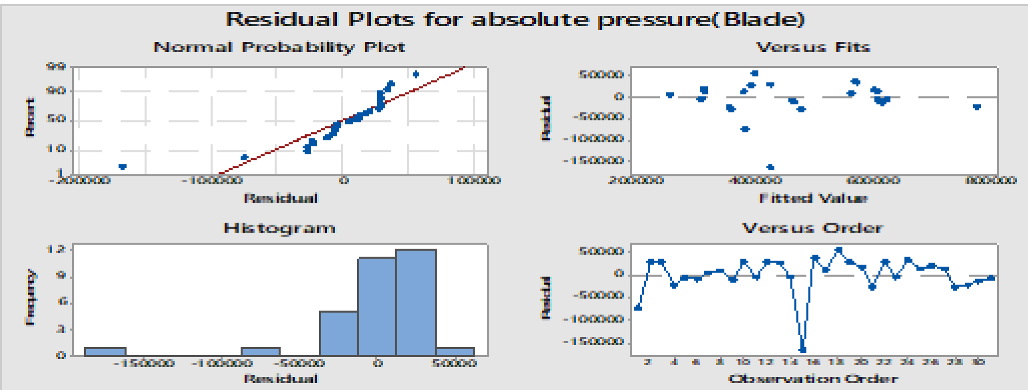

Fig 6.5: Residual plot for Absolute pressure (Blade)

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Above the residual plot for the Absolute pressure (Blade) is shown , in this graph first graph is of the normal probability graph in which all the point are along with the normal probability line, which means the data are well fitted for the observation and there must be a strong relationship between the input and he output variables. Second graph is of the histogram plot in which the plot showing the maximum value at 0, which mean the most of the data were falls on the zero or the distance between the residual and the normal probability graph is zero. The final graph is shown deflection of the residual as the number of the observation performed.

6.6 Main effect plot for Absolute pressure (Blade)

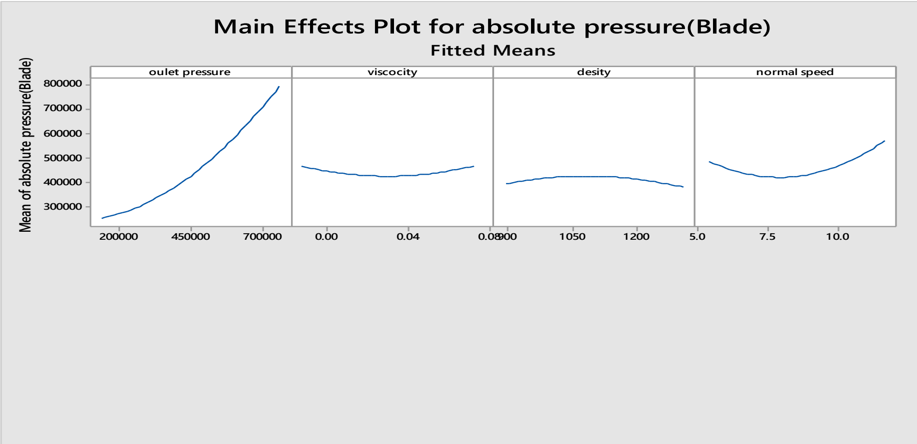

Fig 6.6 :fitted mean plot for Absolute pressure (Blade)

In above graph the main effect plot is shown for the Absolute pressure (Blade), in the first part it can be seen that by increasing the value of the Outlet pressure the value for the Absolute pressure (Blade) are also increases, the second graph of the Viscosity is the reciprocal of the Absolute pressure (Blade) as the value of the Viscosity increases the value for the Absolute pressure (Blade)es are decreases. Finally last one is for the Density first the as the value of the Density is increases than the value of the Absolute pressure (Blade)es are also increases and then after some time the as the higher Density the value of the Absolute pressure (Blade) are decrease.

6.7 Interaction plot for Absolute pressure (Blade)

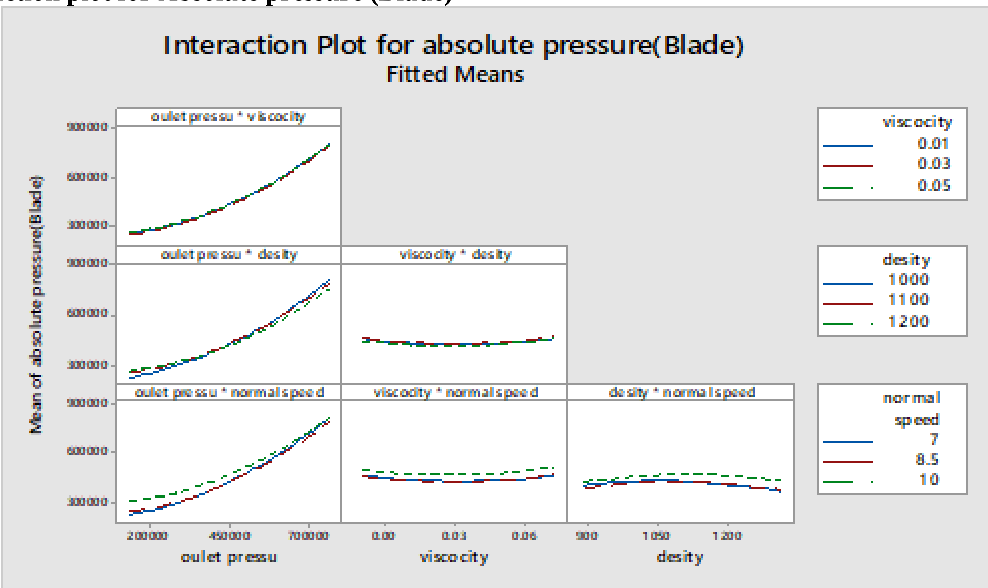

Fig 6.7 Interaction plot for Absolute pressure (Blade)

Above is the interaction plot for the Absolute pressure (Blade) are shown, the interaction plot reflects the effect of the two combined variables on the output , in the first graph the effect of the Outlet pressure * Viscosity into Absolute pressure (Blade) is shown , in the second one the effect of the Outlet pressure *Density on the Absolute pressure (Blade) are shown and in the final graph the effect of the Viscosity *Density on the Absolute pressure (Blade) are shown.

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

Table : Model equation for Absolute pressure (Blade)

Absolute pressure	-265479 + 1.19 oulet pressure - 2735601 viscocity + 1895 desity - 191296 normal speed + 0.000001 oulet pressure*oulet pressure + 23490971 viscocity*viscocity- 0.88 desity*desity + 10540 normal speed*normal speed - 0.23 oulet pressure*viscocity - 0.000778 oulet pressure*desity- 0.0413 oulet pressure*normal speed + 783 viscocity*desity+ 70181 viscocity*normal speed+ 38.6 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 side of the blade and 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 (Blade), 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 (Blade).
- In the linear model for the Absolute pressure (Blade), 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 (Blade) are getting effected or by changing the value of the Outlet pressure the Absolute pressure (Blade) 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 0.410 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(Blade) were get deflected. Or quality of the product in two way interaction can be change by changing the value of Outlet pressure * Density.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

- The value for the R-sq is 90.92% 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.
- Mathematical modeling of Pump working under different operating condition may be carried out.

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