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Parametric Study and Design Optimization of Centrifugal Pump Impeller

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Abstract

To improve the hydrodynamic performance of the centrifugal pump, in present work a DOE technique Taguchi L9 orthogonal array experiment was carried out to optimize the impeller design parameters. The Navier-Stokes equations for three-dimensional steady flow is solved by computational fluid dynamics (CFD) code. The experimental test result of the original pump was compared with the data predicted from the numerical simulation. The comparison shows the closeness of predicted values with the experimental values, leads to validation of the numerical model under the specific range of operating conditions. Four geometric parameters of impeller were chosen as the variable factors viz. Number of blade, Impeller blade outlet angle, Impeller blade Inlet angle and Impeller blade wrapping angle. According to L9 orthogonal array, nine impellers were modelled using CAD modelling software and CFD analysis is carried out using ANSYS CFX. The impellers were equipped with the same volute during all the simulations. The modelled impellers were simulated by the same numerical method, which has been validated. The best parametric combination for higher efficiency is analysed finally. Results show the improvement of 4.25% higher efficiency compared with the original pump. The geometry selected for this model may be the best one to get the maximum efficiency for such pumps.

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1 Introduction

The centrifugal pumps are widely used in industries and different sectors. The principal of centrifugal pump is based on centrifugal force, rotational kinetic energy of the impeller exerts centrifugal force to fluid, which causes fluid to go out of impeller with higher velocity, relative vacuum takes the fluid into the impeller as pump fluid has high velocity at outlet of impeller exit, which converted to pressure energy by using volute casing. Nevertheless, design and performance prediction of centrifugal pump is still a complicated task, mostly due to the large number of independent geometrical parameters involved. On the other hand predicting the performance of centrifugal pump by trial and error process by constructing and testing physical prototype requires significant cost and time, which reduces the profit margin of pump manufacturer. Because of this reason, CFD analysis is widely used in hydrodynamic performance prediction and design for different types of pump as discussed elsewhere [1]-[11]. Centrifugal pump is chosen for performance analysis in the current work is because of its wide application area as a mechanical rotodynamic machine in industries, domestic, irrigation, river water pumping system. To improve the performance and reduce the losses such as turbulence, shock, impeller friction and recirculation losses and power consumption so many researches are going in the field of centrifugal pump as discussed elsewhere [1]-[11].

2 Literature survey

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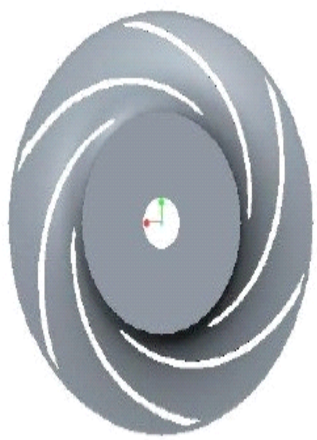
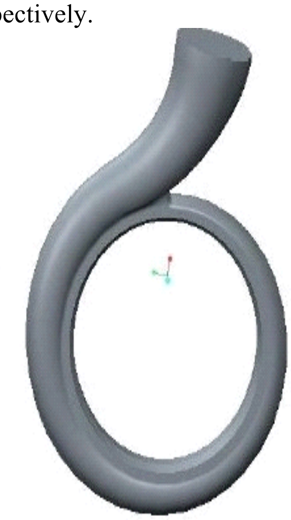
E.C.Bacharoudis et al [2] have investigated the effect of various geometrical parameters of centrifugal pump to improve the performance they found that performance curve becomes flatter and smoother for the entire range of the flow rates as outlet blade angle increases. A.Wilk [3] found that large delivery head can be obtained by high rotational speed L. Houlin et al [4] and S.Chakraborty et al [5][6] have studied effect of blade number on the performance of centrifugal pump and found that head and efficiency increases with increase in the blade number keeping casing and other geometric parameters constant. S. Weidong et al[7] have studied effect of impeller outlet width on performance of deep well centrifugal pump and found that outlet width is conducive to get a better performance. R R. Singh et al [8, 9] have introduced the application of Taguchi method for optimizing the design parameter of centrifugal blower. L. Zhou et al[10] have successfully applied orthogonal experiment technique to optimize the impeller design parameters. However, the focus in this study was to optimize the impeller inlet diameter and impeller outlet width. Mentzos et al [11] have tried to predict the flow pattern, pressure distribution and head capacity by using finite volume method. S.sheth et al [12, 18, 19] have applied orthogonal array optimization technique in steel ball manufacturing process. There are many CFD studies reported concerning the complicated flow in all type of centrifugal pump geometrical parameter are not satisfactory level [1]. In present work four primary geometrical parameters are taken for the analysis different level of parameter is being determined with help of literature survey and numerical analysis and using Taguchi orthogonal array optimization technique parameter combinations are generated and impellers being modelled with CAD modelling software and analysed by ANSYS-CFX14 CFD tool.

3 Geometry

Centrifugal pump model is designed using CAD modelling software. The shrouded impeller with six blades with constant width b=15mm, backward facing blades with inlet, outlet and wrapping angles $\beta 1=5°$, $\beta 2=20°$ and α =100° respectively have been modelled using CAD modelling software. Length of the blades changes with respect to wrapping angle. The diameter at the pressure side and suction (inlet) side are D2=165mm and D1=85mm respectively. Designed speed and flow rate of pump are N=2900RPM and Q=16m3/h respectively.





(a) (b)

Figure 1: (a) CAD model of centrifugal pump Impeller **Figure 2:** (b) CAD model of centrifugal pump casing

4. Numerical simulation method

All the calculations have been performed with ANSYS-CFX14.1 CFD software package that solves 3D Navier-stokes equations, including the centrifugal force in the impeller.

4.1 Governing Equations

3-D steady, conservative form of Navier-Stokes equations in two dimensional forms for incompressible flow of a constant viscosity fluid are as follow

$$\frac{\partial U}{\partial X} + \frac{\partial U}{\partial Y} = 0 \qquad (1)$$

X-momentum:

$$\frac{\partial (UU)}{\partial X} + \frac{\partial (VU)}{\partial Y} = -\frac{\partial Pn}{\partial X} + \frac{1}{\mathrm{Re}}\left(\frac{\partial^2 U}{\partial X^2} + \frac{\partial^2 U}{\partial Y^2}\right) \qquad (2)$$

Y-momentum:

$$\frac{\partial (UV)}{\partial X} + \frac{\partial (VV)}{\partial Y} = -\frac{\partial Pn}{\partial X} + \frac{1}{\mathrm{Re}}\left(\frac{\partial^2 V}{\partial X^2} + \frac{\partial^2 V}{\partial Y^2}\right) \qquad (3)$$

4.2 Computation Domain and Domain Discretization

The numerical simulation of centrifugal pump involves spatial discretization of flow domain. The computational domain consist of three sub-domains namely inlet, outlet and impeller. the impeller is in the rotating reference frame, inlet and outlet defined by fixed reference frame. fixed and rotating reference frames are related to each other through "frozen rotor" interface. The frozen rotor method employs a quasi-static algorithm, where the stator and rotor are modelled at a fixed (frozen) position relative to each other. The meshes of computational domain which consist of three sub-domains the impeller, inlet and outlet are generated separately fig.2 shows sketch of unstructured mesh model of pump.

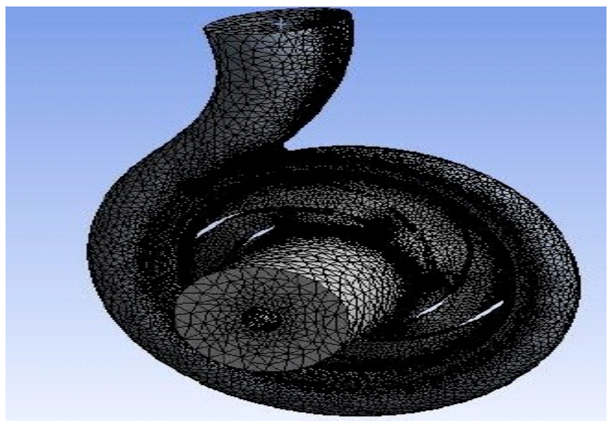


Figure 2: 3D unstructured mesh geometry of centrifugal pump

4.3 Boundary Conditions

For the centrifugal pump impeller closed type domain has considered as a rotating frame of reference with a rotational speed of 2900 rpm clockwise direction. The working fluid passes through the pump was water at 25°C. Casing was kept as stationary frame during analysis. The Non slip boundary conditions have been imposed over the impeller blades, hub and shroud. Different boundary conditions have been applied to the different domain at Inlet static pressure and outlet mass flow rate were given based on flow coefficients. Turbulence is simulated with the shear stress transport (SST) turbulence model. In the steady state, multi reference frame technique was applied for the simulation in which the impeller is situated in the rotating reference frame, the volute is in the fixed reference frame, and they are related to each other through the "frozen rotor."

The number of iterations adjusted to reduce the scaled residual below the value of 10^{-5}, which was a criterion of Convergence precision.

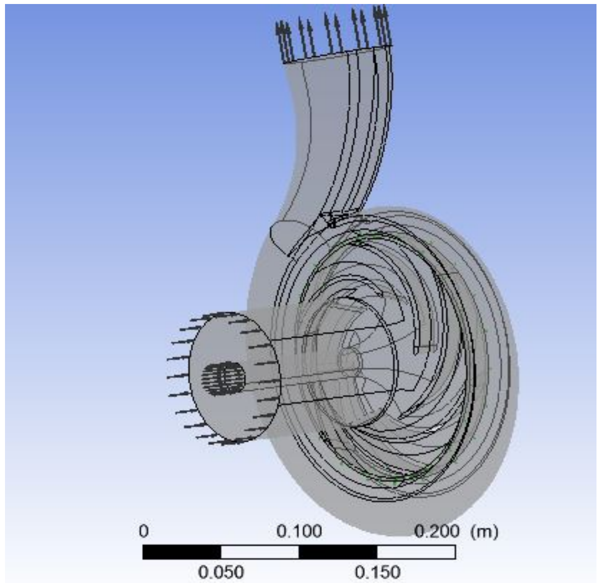


Figure 3: Applied boundary conditions on centrifugal pump model

4.4 Validation of Numerical Simulation Result

The experimentally observed data at designed speed and flow rate of the pump are mentioned in the table.1 below. The obtained simulation result of the centrifugal pump at its designed speed and flow rate was compared to validate the above study. The Efficiency of centrifugal pump was calculated using formula

$$\eta = \frac{waterpower(kw)}{shaftpower(kw)} \quad (4)$$

Mass flow rate	Head (CFD)	Head (EXP)	Efficiency (CFD)	Efficiency (EXP)
4.5 kg/s	29.85 m	30m	51.46%	52%

Table 1 Simulation and Experimental Result

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5. Design of Experiment Using Orthogonal Array

In this study, optimization of centrifugal pump impeller is carried out with an identical volute casing. Based on the impeller design literature, four critical geometrical parameters of centrifugal pump impeller were selected, namely (A) Number of blade Z, (B) Impeller blade outlet angle $\beta 2$, (C) Impeller blade Inlet angle $\beta 1$ and (D) Impeller blade wrapping angle α . Since the volute geometry remains unchanged, the impeller parameters should stay in a reasonable range to match the volute. Therefore, according to the characteristics of original pump three levels were chosen for each factor, as summarized in Table2. As long as the number of parameters and the number of levels are decided, the proper orthogonal table could be selected. The table has been created using Taguchi algorithm. In the present study, the L_9 orthogonal array tables has been used to arrange the experiments; four factors are evaluated each time and each factor takes three levels, and the detailed experimental programs are presented in Table 3.

Factor	Name Notation	A Z	B β_2 /0	C β_1 /0	D α /0
Levels	1	5	20	0	100
	2	6	25	5	110
	3	7	30	10	120

Table.2: Orthogonal experimental factors

Sr. No.	A	B	C	D
1	5	20	0	100
2	5	25	5	110
3	5	30	10	120
4	6	20	5	120
5	6	25	10	100
6	6	30	0	110
7	7	20	10	110
8	7	25	5	120
9	7	30	0	100

Table.3: Orthogonal experiment scheme

6. Result and discussion

6.1Orthogonal Experiment Results

According to Taghuchi L_9 array, nine impellers are designed and keeping same volute they are assembled. The assembled 9 pumps were simulated in the ANSYS-CFX keeping same computational methods of the original pump.Table.4 shows the predicted pump head and efficiency of the 9 pump models at the design flow rate.. These 9 test sets have tested all of the pair wise combinations of the independent variables. This demonstrates significant savings in testing effort over the all combinations approach. Variance analysis method (i.e., range analysis method) has been used to clarify the significance levels of different influencing factors most significant factors could be disclosed basing the result of range analysis. The average values of each level for each factor were named K_i as which is calculated as follows

$$K_i = \frac{1}{N_i}\sum_{j=1}^{N_i} y_{i,j} \qquad \text{.... (5)}$$

The variances between each factor were defined as k to analyze the difference between the maximal and minimal value of the three levels for each factor:

R = max $\left(K_1, K_2, \ldots K_i\right)$-min $\left(K_1, K_2, \ldots K_i\right)$ ..... (6)

Sr. No.	H /m	η /%
1	28.53	48.81
2	30.22	49.68
3	30.25	51.32
4	32.22	56.25
5	31.6	50.91
6	31.17	53.3
7	32.33	54.35
8	32.5	53.11
9	32.04	50.62

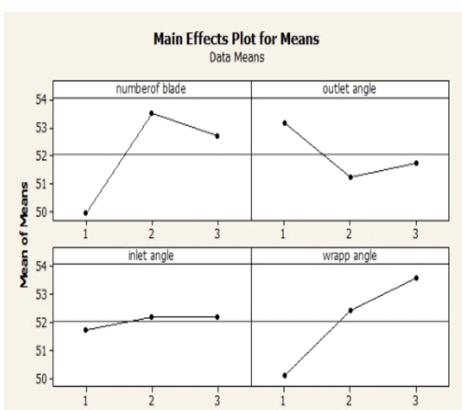
Table.4: Numerical simulation results of the 9 pump models under design point.

	A	B	C	D
K1	49.93	53.13	50.91	50.11
K2	53.49	51.24	53.01	52.44
K3	52.69	51.75	52.19	53.56
R	3.56	1.89	2.1	3.45

TABLE.5: Range analysis of pump efficiency

	A	B	C	D
K1	29.67	31.02	30.58	30.72
K2	31.66	31.44	31.65	31.24
K3	32.29	31.15	31.39	31.65
R	2.62	0.42	1.07	0.93

TABLE.6: Range analysis of pump head.



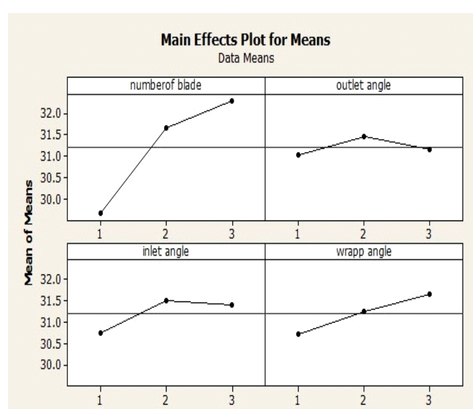


Figure.4: influence Level of each factor for pump efficiency. **Figure.5:** Influence Level of each factor for pump head

Table5. and from Fig4 shows the analysis results for pump efficiency, which shows the factor influences pump efficiency decreases in the order: A>D>C>B according to the k values. The number of blades of impeller was found to be the most critical parameter for efficiency. Accordingly, the best

parameter combination for optimized pump efficiency isA2, B2, C3and D3 namely z=6, β 2=200, β_1 =50 and $\alpha =$ 1200 .Table 6 and Fig.4 shows the range analysis of the head; the influence levels are indicated. According to the k values, factor influence rank is A>C>D>B>C for the head. The most critical parameter, which affects the pump head, is number of blades of impeller. The best parameters combination for higher head is A3, B2, C2 and D3 namely z=7, β_2=25°, β_1 =5°and $\alpha =$ 120°

7. Conclusion

In the present study, a centrifugal pump impeller optimized with the application of orthogonal experiment method. The result of efficiency of pump, which is obtained by analysis, is tabulated in Table 5. Four geometrical parameters were selected for geometrical design optimization of impeller. Analysis of results shows that number of blades and wrapping angle has the highest influence on the pump head and efficiency. For outlet angles from level one to level two, the efficiency of pump decreases whereas the head increases. From level two to three there is increase in efficiency and decrease in head. The inlet angle has insignificant effect on efficiency. For the optimal combination A2, B2, C3 and D3 namely Z=6, β_2=20°, β_1 =5° and $\alpha = 120°$ optimal designed pump gives highest efficiency of 56.25% compared to original pump having efficiency of 52%. Moreover, the analysis carried out here using Taguchi Orthogonal array for optimization shows significant reduction in time consumption to find optimum design.

8. References

[1] V.R. Singh, S.M.Sheth, M.J.Zinzuwadia "Parametric Study And Design Optimization Of Centrifugal Pump Impeller"-A review, IJERA ISSN :2248-9622,vol-4,pp45-49,2014.

[2] E.C. Bacharoudis, A.E. Filios, M.D. Mentzos and D.P. Margaris, "Parametric Study of a Centrifugal Pump Impeller by Varying the Outlet Blade Angle" The Open Mechanical Engineering Journal, 2, 75-83,2008

[3] A. Wilk "The Analysis Of A Hydraulic Efficiency Of An Open Impeller with Radial Blades Obtained In Laboratory Tests Of High Speed Impeller Pump" New Aspects Of Fluid Mechanics, Heat Transfer And Environment ISBN: 978-960-474-215-8 ,2010

[4] L. Houlin, W.Yong, Y. Shouqi, T.. Minggao, and W. Kai "Effects of Blade Number on Characteristics of Centrifugal Pumps" chinese journal of mechanical engineering vol. 23,2010

[5] 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, 2011

[6] K.M. Pandey, A.P. Singh, Sujoy Chakraborty "Numerical Studies On Effects Of BladeNumberVariations On Performance Of Centrifugal Pumps At 2500 Rpm" Journal of Environmental Research And Development Vol. 6 No. 3A, Jan-March 2012

[7] SHI Weidong, ZHOU Ling, LU Weigang, PEI Bing, and LANG Tao "Numerical Prediction and Performance Experiment in a Deepwell Centrifugal Pump with Different Impeller Outlet Width" Chinese Journal Of Mechanical Engineering vol. 26 *2013

[8] R.R. Singh & M.Nataraj, "Parametric Study And Optimization Of Centrifugal Pump Impeller By Varying The Design Parameter Using Computational Fluid Dynamics: Part-I" Journal Of Mechanical And Production Engineering (JMPE) Issn 2278-351,

[9] R.R.Singh & M.Nataraj, "Optimizing Impeller Geometry For Performance Enhancement Of A Centrifugal Blower Using The Taguchi Quality Concept" International Journal of Engineering Science and Technology (IJEST) ISSN : 0975-5462 Vol. 4 No.10 October 2012

[10] L. Zhou, W. Shi "Performance Optimization In A Centrifugal Pump Impeller By Orthogonal Experiment And Numerical Simulation" Hindawi Publishing corporation Advances in Mechanical Engineering Volume 2013.

[11] Mentzos M.,Filios A..Margarisp., papanikas D., "CFD prediction of flow through a centrifugal pump impeller,"Proceedings of international conf. Experiments/Process/simulation/Optimization.Anthes, pp. 1-8

[12] S. Sheth, P. Patel and P. Chauhan, "Effect of Various Parameters on Spread in Flashing Operation of Precision Steel Ball Manufacturing Process." Procedia Materials Science, 5, pp. 2224-2232, 2014.

[13] Dr.D.S.Kumar, Fluid mechanics and Fluid power Engineering. Press, year by.

[14] R.K.Rajput. Textbook of fluid mechanics and hydraulic machines Revised Edition, S.chand 2010
[15] Dr.R.K.Bansal A textbook of fluid mechanics and hydraulic machines, Revised 9th edition, laxmi publications,2010
[16] Grundfos Research And Technology Manual
[17] Douglas C. Montgomery, Design and Analysis of Experiments.7th Edition, John Wiley & Sons, 2009.
[18] S. Sheth, B. Modi, P. George & P. Patel, A Fuzzy Logic based Model to Predict MRR in Flashing Operation of Precision Steel Ball Manufacturing Process, Procedia Materials Science, 5, pp. 1837-1845, 2014.
[19] Patel, Pratik J., and Saurin Sheth. "Effect of various parameters on material removal rate in flashing operation of precision steel ball manufacturing process." In *1st International and 16th National Conference on Machines and Mechanisms (iNaCoMM2013)*, pp. 332-338. 2013.