Centrifugal Pump Impeller Design by Model to Proto Method and Its Performance Verification by Simulation and Experimental Method

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Abstract -

The use of centrifugal pumps has increased because of their capability of handling a variety of liquid applications. It converts rotational kinetic energy to the hydrodynamic energy of the fluid flow. The source for the generation of rotational kinetic energy is the driver (an electric motor). Today, due to the vast change in industrial scenarios, more and more complicated requirements are arriving at pump manufacturers. Drinking water is the basic need to live for every human being on earth. In India, rivers are the main source of water supply. The subject customer's specified duty parameters requirement calls for a pump that should be suitable for liquid water application, have inadequate suction/inlet conditions at the site due to variation in sump water levels, and also be installed in the limited space available at the site.

To achieve customer-specified duty parameter requirements at specified speeds, Net Positive Suction Head Requirements (NPSHr) and to suit available site conditions This paper revolves around the hydraulic design of a centrifugal pump impeller by the model-to-protocol method. After that, performance verification is done by simulation methods like computational fluid dynamics (CFD) analysis and also by physical testing of prototypes in the test lab.

Key Words*: *Centrifugal pumps, CFD analysis, specified speeds, NPSHr

1. INTRODUCTION:

The centrifugal pump is the most widely used type of pump in a variety of liquid applications. In this paper, the type of pumping liquid considered for experimentation is water. There is a city water supply scheme, and the river is the main source of water for the city. Two major water treatment plants are there for water treatment. The objective is to maintain a steady supply of raw water to the water treatment plant and an uninterrupted supply of treated drinking water to the city. The main obstacles on site are

- There is frequent variation in river water levels.
- Inadequate suction/inlet conditions at the site are due to variations in sump water levels.
- Space limitation

Customer specified duty parameters requirements

- Flow (Q) : 7945 m^3/hr (34980.77 USGPM)
- Head (H) : 36.6 mtr (120.08 ft.)
- Speed (N) : 595 rpm.
- Efficiency : 87%
- NPSHr : Less than 6 meter

To achieve customer-specified duty parameters at specified speeds, it is proposed to carry out the design of a new hydraulic impeller. The subject impeller is to be assembled in Horizontal Split case Type centrifugal pump with a bottom suction configuration. The main objectives of this research work are

- Impeller hydraulic design based on specific speed and model to proto phenomenon
- Lower Net Positive Suction Head Requirement (NPSHr) of pump to operate satisfactorily at site for varied water levels in sump
- Verification and validation of the actual design in comparison to analytical and Computational Fluid Dynamics (CFD) prediction.

- To compare predicted results with actual results

For the successful performance of the pump, hydraulic components play an important role. It gives the best performance by ratio of outflow to inflow of any pump. The impeller is the most important rotating part of a pump; it imparts energy to the fluid. The type of impeller design is based on the specific speed of the pump. Refer to Figure 1.1

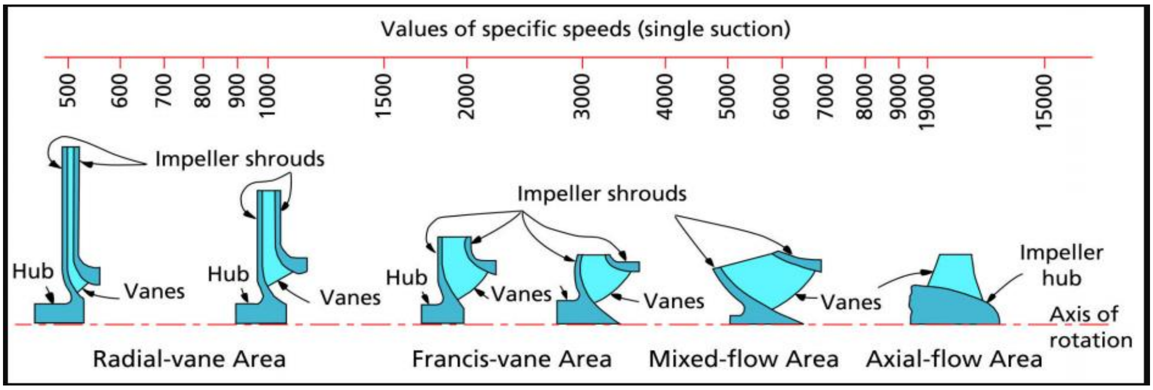

Figure 1.1-Specific speed and Shape of impeller.

There are a variety of design procedures and methods of calculation. The methods that we have used for the design of the proto-pump impeller are.

A] As per the guidelines given in the JIS B 8327-2002 standard: Model to Proto scale ratio

B] As per the guidelines given in the Val S Lobanoff pump book

2 Impeller Design As Per- JIS B 8327-2002 standard guidelines:

This standard specifies the method of predicting the performance of a proto pump based on the performance of a model pump having approximately the same specific speed. This method is followed when proven hydraulics are available in a model pump. We have a standard performance curve for the model pump at the required duty parameters, and based on the same and using the model to proto performance prediction formulas given in the standard **JIS-B-8327-2002, we** can predict the performance of the proto pump.

- Flow/Discharge Of proto pump : $Qp=[Dp/Dm]^3 \times [Np/Nm] \times Qm$
- Head Of Proto pump : $Hp=[Dp/Dm]^2 \times [Np/Nm]^2 \times Hm$
- Power Of Proto pump : $Pp = Pm \times [Np/Nm]^3 \times [Dp/Dm]5$
- NPSHr of Proto pump : $NPSHp = [Dp/Dm]^2 \times [Np/Nm]^2 \times NPSHm$

Where,

H = Total head of pump in meter

Q = Discharge/Flow of pump in m^3/s

P = Shaft power of pump in kW

N = Rotational speed in rpm

D = representative dimension of impeller dia. [mm]

m : model pump , p : proto pump

Table 1.1 - Proto pump and Model pump duty parameters-

Description	Proto Pump Duty Parameters	Model Pump Duty Parameters
Flow/Discharge Q,m^3/hr	7945	650
Total Head H, meter	36.6	23.3
NPSHr, meter	5.5	3.46
Speed N,rpm	595	1480
Pump efficiency η,%	87%	88%
Liquid specific gravity	1.0	1.0
Power P,kW	910.23	46.67
Specific Speed,Ns (metric)	153.31	153.05
Specific Speed,Ns (US units)	2169.98	2166.27

Table.1.2-Model to Proto scale ratio.

PREDICTION OF PROTO PUMP PERFORMANCE FROM MODEL PUMP PARAMETERS (JIS-B-8327-							
MODEL PUMP	Q	325	m^3/hr	Q	3973	m^3/hr	PROTO PUMP
		0.09028	m^3/s		1.1035	m^3/s	
	H	23.3	meter	H	36.6	meter	
	N	1480	rpm	N	595	rpm	
	P	47.41	kW	P	895.87	kW	
	η	87	%	η	88.34	%	
	g	1.0		g	1.0		
	Ns	153.05	metric	Ns	153.31	metric	
	Ns	2166.23	US Units	Ns	2169.98	US	
	NPSHr	3.460	meter	NPSHr	5.44	meter	
	Nss	9055.55	US Units	Nss	9063	US	
	Dp/Dm ratio from discharge				3.121		
	Dp/Dm ratio from head				3.118		
	Mean model to proto ratio				3.119		

Q = Flow/Discharge in m^3/s (For single suction)

H = Total head (per stage) in meter

N = Speed in rpm
η = Efficiency,%
g=Specific gravity
Ns = Pump Specific speed
Nss= Pump suction specific speed

Based on the model-to-proto scale ratio of 3.119, we are now able to predict the tentative dimensions of the proto pump impeller by multiplying the model pump impeller hydraulic dimensions by arrived scale ratio. Refer to figures 1.2 and table 1.3

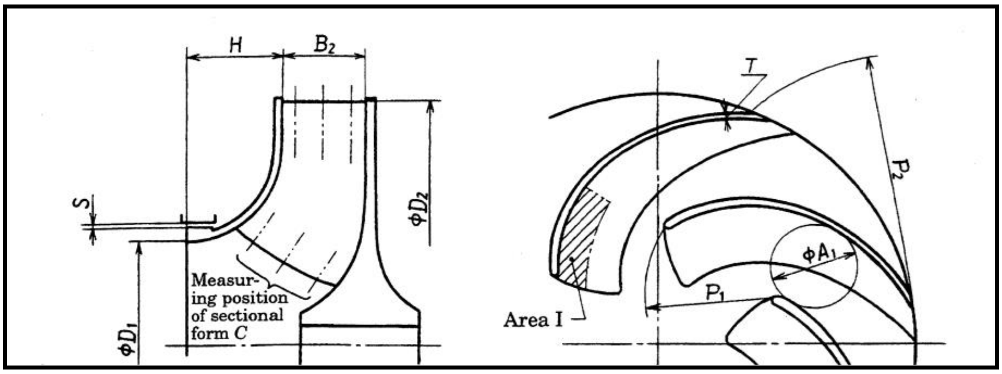

Figure1.2-Impeller Design Parameters

3. Impeller Design - as per pump book Labnoff guidelines

As per the guidelines from the Pump Book by Labnoff, we have carried out the impeller design and compared the design parameters with the results of the impeller design done as per the guidelines from the **JIS B 8327-2002 standard (**refer figure 1.2 and table 1.3

Table.1.3: Comparison of Design parameters

Parameters	Model Pump Parameters	Proto Pump Parameters JIS-B-8327-2002	Proto Pump Parameters Labnoff Pump Book Theory
Pump Specific speed (Ns),US units	153.05	153.31	153.31
NPSHr, mtr	3.46	5.5	7.3
Pump Suc. Sp. Speed (Nss), US units	2166	2169	7270
No of Vanes	5	5	5
Vane Discharge Angle in degree	23	23	23
Impeller Full Diameter (D2), mm	310	967	Not required
Impeller Rated Diameter (Dr), mm	300	936	955
Impeller Eye Diameter (D1) ,mm	189.2	590	495
Impeller Shroud Opening (B2), mm	75	234	200

Project order requirement is NPSHr of the pump to be below 5.5 meter. However, Impeller design calculations by Labnoff Pump Book theory shows NPSHr as 7.3 meter, so to reduce the pump NPSHr. We tried following means as per guidelines given in pump handbook.

a) Increase the impeller eye diameter.
b) Increase the impeller outlet width B2.

After so many iterations, we have arrived at the following conclusions

After increasing the impeller eye diameter to Ø590mm (23.22 inch) and impeller outlet width to 117mm (4.6 inch) (for double suction impeller 234mm (9.21 inch)) NPSHr arrived is 5.3m. Which is well-being acceptable limit.

Hence, we proceeded with following design parameters as final for impeller design

Table.1.4: Proto pump final design parameters

Parameters	Values
NPSHr, mtr	5.3
No of Vanes	5
Vane Discharge Angle in degree	23
Impeller Full Diameter (D2), mm	967
Impeller Rated Diameter (Dr), mm	936
Impeller Eye Diameter (De) ,mm	590
Impeller Shroud Opening (b2), mm	234 ouble suction)

4. Computational Fluid Dynamics (CFD) Analysis :

After finalization of impeller design parameters, hydraulic performance verification is determined by computational fluid dynamics (CFD) analysis before actual manufacturing of the impeller. After manufacturing, experimental performance testing of the pump is carried out to validate the physical performance with respect to design parameters. Based on the above-mentioned scale ratio and study, we have prepared a 3D model of the hydraulics of the proto impeller. And carried out the CFD analysis. The results obtained from CFD analysis are as follows (refer to figure 1.3 and 1.4)

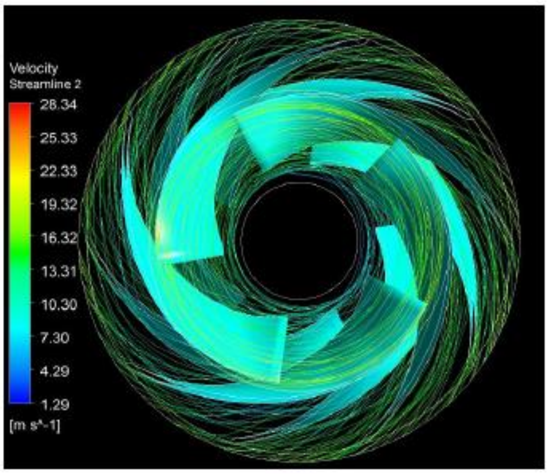

Fig: 1.3 Streamline plot-Impeller Geometry

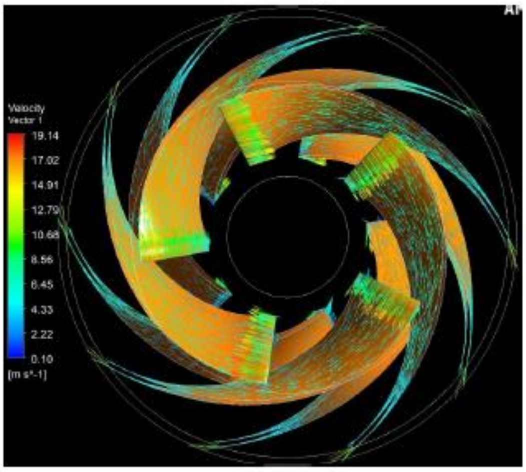

Fig: 1.4 Vector plot - Impeller Geometry

5. Experimental testing :

Verification and validation of hydraulic and mechanical performance of pumps in terms of head, discharge, efficiency, power absorbed, and NPSHR with respect to designed parameters is carried out at the pump testing department. The liquid used in testing will be water at ambient temperature.

5.1 Test Results Comparison:

The comparison between the CFD analysis and experimental results for the hydraulic performance of the pump is as shown in Fig 1.5,1.6 and 1.7

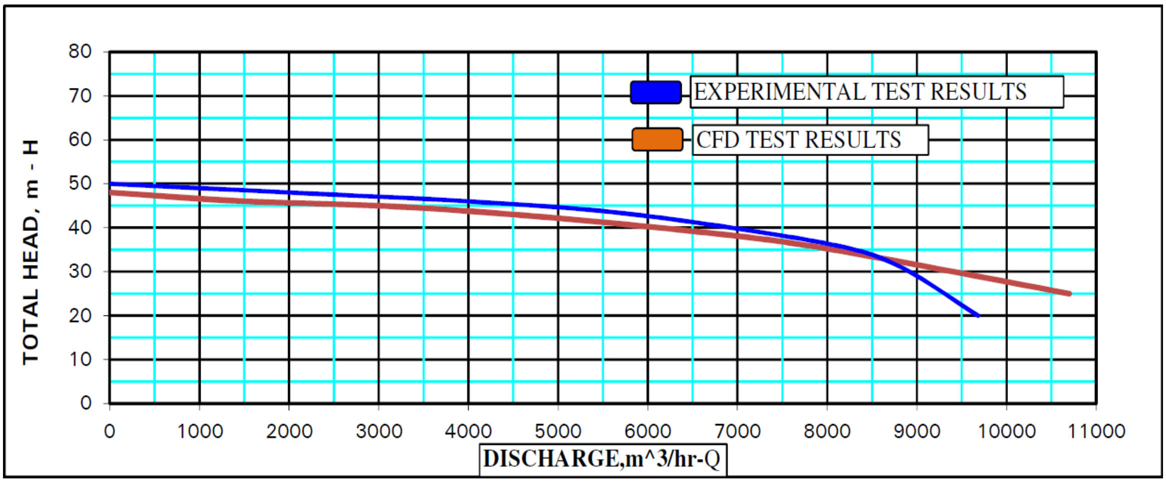

Fig.1.5: Discharge vs. Head Comparison

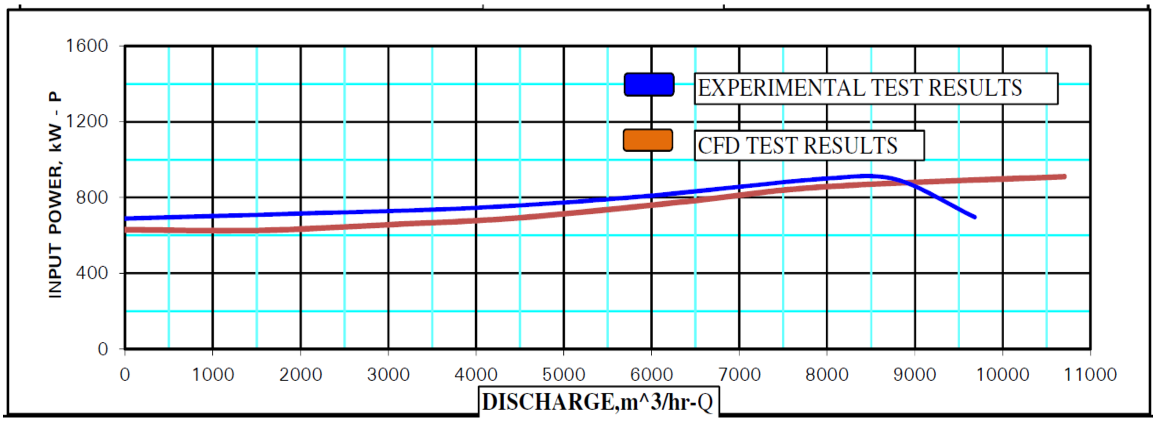

Fig.1.6: Discharge vs. Input Power Comparison

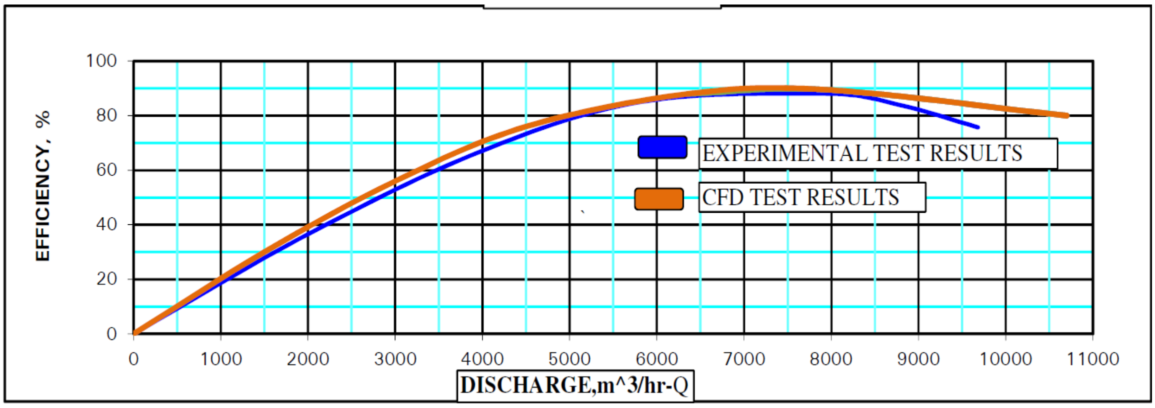

Fig.1.7: Discharge vs. Efficiency Comparison:

Small variations in the experimental results Head, input power, and efficiency are found to vary because of manufacturing variation during the casting and machining stages, and factors like surface finish along the hydraulic passage inside the casing and impeller vary as compared to the assumed surface finish in CFD analysis. The head at the full discharge side is of a drooping nature, and the full open discharge is slightly low because of the NPSH available constraint at the test lab. Overall performance is satisfactory and well within acceptable limits of the Gr 2B tolerances mentioned in ISO 9906-2012 Rot Dynamic Pumps-Hydraulic Performance Acceptance Tests International Standard.

The vibrations are slightly higher because of the temporary foundation and clamping arrangements at the test lab.

Table 1.5 - Comparison for specified and actual test results :

Sr.	Parameter	Specified	Observed	Remarks
01	Total Head (m)	36.60	36.96	Satisfactory
02	Flow/Discharge (m^3/hr)	7945	7953.5	Satisfactory
03	Pump Efficiency (%)	87%	88.09%	Satisfactory
04	Noise	87 dBA	82 dBA	Acceptable
05	NPSHr, (m)	5.5	5.3	
06	Power,P,kW	910.23	908.78	
07	Vibrations at Duty RMS mm/s ----------------------------- Direction X /Y/Z	As per ISO10816 Cat-II Zone B 6.1	4.7 /2.9 / 7.2	Acceptable

Overall performance is satisfactory and well within acceptable limits of the Gr 2B tolerances mentioned in ISO 9906-2012 Rot Dynamic Pumps-Hydraulic Performance Acceptance Tests International Standard.

6. CONCLUSIONS :

- The method of 'Model to Proto Ratio' is accurate and the best-suited method for the design of pump hydraulic components when proven hydraulic at the same specific speed is available.
- Due to the design of the double suction impeller, the pump requires a low NPSHr as compared to to pump with a single suction impeller having the same capacity.
- The computational fluid dynamics (CFD) analysis technology used is a very useful tool. not only to know the flow pattern in hydraulic passages but also to predict the hydraulic performance well before building the actual proto.
- In comparison to CFD results, a small variation is observed in the experimental results. It is because of manufacturing variations during the casting and machining stages.
- To be cost-competitive, the subject impeller is cast using the sand casting method. Further Improvement in performance will be achieved if we go for 3D printing casting.

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