Modeling and Prototyping of a Centrifugal Pump Impeller For Better Efficiency

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ABSTRACT

Because of the expanding engineering needs, transient performance of fluid equipment during transient operating periods, such as startup and stopping, has received increased attention recently. The transient behavior of a prototype centrifugal pump with an open impeller is investigated experimentally in this research during a quick startup period. Experiments at various discharge valve openings are used to record fluctuations in rotational speed, flow rate, head, and shaft power during the rapid startup period. The non-dimensional flow rate and head are also utilized to investigate transitory behavior. The findings reveal that the rising characteristic of rotational speed is mostly influenced by the startup characteristics of the driving motor, rather than working points. In comparison to the quick increase in rotating speed, the flow rate increases slowly at first. Furthermore, the flow rate lags behind the rotating speed in reaching a final stable value, and the lag becomes more pronounced as the discharge valve opening is increased. The shaft power impact phenomena is common during the startup process. The non-dimensional study reveals that the non-dimensional head is very high at the start of starting, quickly drops to the minimum, and then gradually rises to the final stable value, but the non-dimensional flow rate always exhibits a rise trend throughout the startup time. In conclusion, the quasi-steady analysis is unable to appropriately estimate the transient flow during the startup period, as evidenced by the non-dimensional results.

Keywords:- Centrifugal pump, experimental study open impeller, transient behavior, startup periods.

1. ITRODUCTION

Centrifugal pump usually operates at stable starter in which the rotational speed or working point is invariable or varies slowly. However, some transient process such as startup and stopping are also transient and inevitable. In this kind of process performance parameters such as flow rate and head will be subjected to significant change in a very shot time with the growing increase of engineering needs. It is necessary to deeply investigate the transient performance so as to effectively utilize these processes and avoid them. For example- for abrupt startup of the special mixed flow pump is used to generate the instantaneous pressure to launch under water. On the other hand, the abrupt startup of the large scales pumping station may cause the strong impact on local power grid. In the past 30 years, some attentions have been paid to the transient performance of the pumps during transient operating periods.

2.LITERATURE SURVEY:

Tsukamoto et al. [1] studied the transient behavior of a volute type centrifugal pump during rapid startup period using experimental test and theoretical analysis.

The result shows that the impulsive pressure and lag in circulation formation around the impeller varies play predominant role in the difference between dynamics and quasi-study characteristics.

Lefebure et al. [2**]** studied the hydrodynamics performance of a mixed flow pump during acceleration and deacceleration period by means of experimental study. The result manifest the quasi steady assumption is not valid for predicting the transient performance.

Thanapandi et al. [3] investigate the dynamic behavior of volute type pump with different valve opening during normal startup and stopping through experimental test. It is found that the normal transient process can meet the quasi steady assumptions at the same time also originally adopted the methods of characteristics to study the transient characteristics of pump.

Dozi et al. [4] proposed a model based on the angular momentum and energy equation to predict the internal torque, power and impeller head of turbomachinery during transient operations. The result shows that the transient behavior not only depends on the acceleration rate and flow rate but also on velocity profile and their revolution during transient period. In recent year with the rapid development of computational fluid dynamics (CFD), Numerical simulation has been widely used to predict transient performance of pumps during transient operating periods (5-7).

Hossein Yousefi et al. [5] Given the ubiquitous use of centrifugal pumps for handling viscous fluids in numerous industries, both academic researchers and businesses have been interested in increasing the performance of these oil pumps. Using a numerical simulation model of a three-dimensional flow of water and oil, we demonstrated a significant decline in the performance of centrifugal pumps for handling viscous oil in this study**.**

Jianjun Feng et al. [6] The transient process induced by a centrifugal pump's power loss is simulated in this paper using ANSYS CFX, along with a user-defined function built to solve the angular momentum equation repeatedly for computing pump rotational speed. External characteristic curves and pump runaway parameters are obtained by experiments. The results reveal that the pump's characteristic curves and runaway parameters predicted by numerical simulations match those measured experimentally. Following a power outage, the transient process goes through four basic modes: pump mode, brake mode, turbine mode, and runaway mode.

Hamidreza Bozorgasareh et al. [7] Experimental and numerical methodologies are used to investigate the impact of a new impeller configuration with innovatively built shrouds on the pressure head and efficiency of a semi-open centrifugal pump. The proposed concept involves attaching blade inlets to a semi-open impeller to reduce secondary flows across the blades, resulting in increased pump head and efficiency. Experimentally, the hydraulic performance of a centrifugal pump with three distinct blade inlets at angles of 30^0, 6^0, and 90^0 degrees is studied, and the results are compared to semi-open and closed impellers.

Rajiv Tiwari et al. [8] The primary goal of this research is to develop a method for detecting the presence and severity of blockages and cavitation in centrifugal pumps using fluid pressure, which is critical for fluid-related defects. The flow area of the suction pipe is restricted by dividing it into six equal periods (i.e., 0 percent, 16.7%, 33.3 percent, 50 percent, 66.6 percent, and 83.33 percent) using a mechanical modulating valve to simulate the blockage in the pump. The major characteristic that is directly influenced by obstruction and cavitation is the fluid dynamic pressure. As a result, pressure signatures were obtained in the current investigation using a pressure transducer installed on the circle of the centrifugal pump casing at various blockage levels and running speeds. The data from the pressure transducer is classified using a binary data classification algorithm based on deep learning.

Zhenguo Ge et al. [9] The revolving stall inside the impeller is the main focus of research, with the vaned diffuser receiving less attention. The cross-power spectrum approach is used to discover low-frequency pressure signals in this study, which investigates rotating stall behaviour in a vaned diffuser centrifugal pump. Experimental results, including flow structures provided by PIV measurements, have confirmed the numerical method used. Between 0.25Qd and 0.5Qd conditions, a hump in the head curve is noticed for the vaned diffuser pump. Revolving stall occurs in the vaned diffuser of the pump under 0.41Qd conditions, with three stall cells rotating in the opposite direction of impeller rotation.

Chunlei Shao et al. [10] One of the most significant parts of a centrifugal pump is the suction chamber. The hydraulic efficiency of the impeller is greatly influenced by the flow in the suction chamber. Two cameras were used to photograph the flow patterns in the suction chamber in order to examine the law of gas–liquid two-phase flow. Under various working situations, the pump's exterior characteristics were measured. FLUET was used to numerically simulate the gas–liquid two-phase flow in the centrifugal pump at the same time. The simulated results matched the experimental results very well.

The above mentioned study mainly aim at non cavitations state transient behavior the non-dimensional flow rate and head are alone used to describe the transient flow of pump during startup periods.

3.EXPERIMENTAL FACILITY AND PUMP MODELS:

The test rig and the centrifugal pump unit are shown in figure. The test rig consists of water tank pump unit pipeline and test system. The driving motor of the studied pump is the three phases alternator re current a synchronous motor its rated output power is greater than 50 Watt. The JCO type talk speed sensor installing between pump model and motor is used to test the instantaneous model rotational speed and torque.

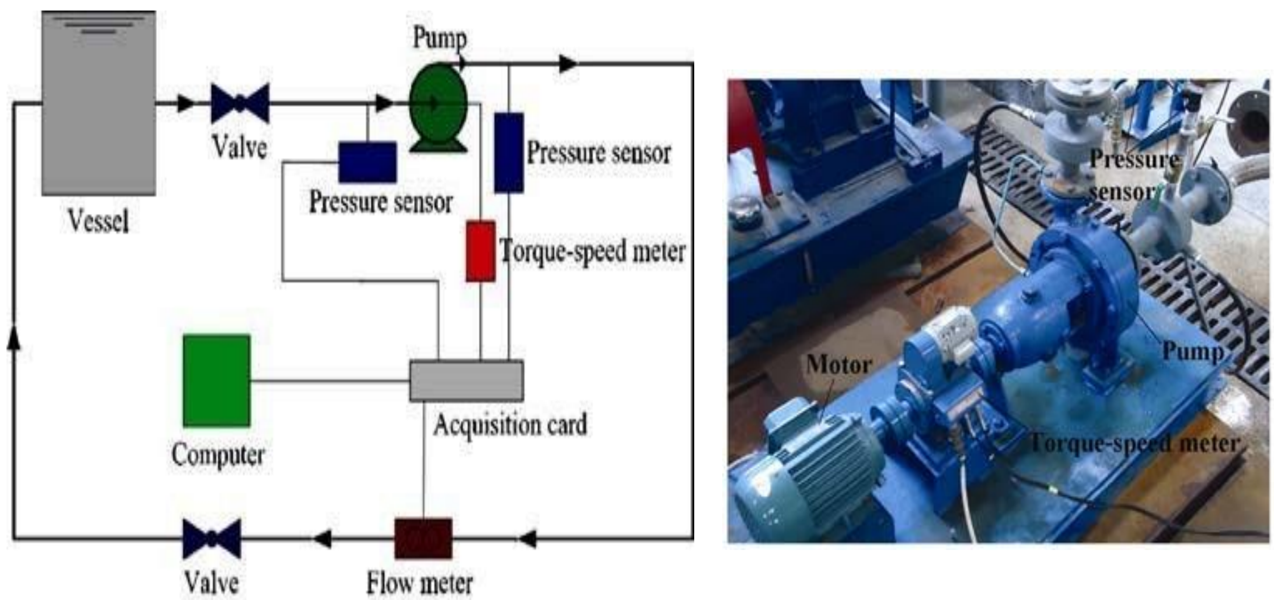


Fig. 1. Test rig and centrifugal pump unit:

The OPTIFLUX 2100 C types electromagnetic flow meter is used to measure the instantaneous volume flow rate. The WIKA-S-10 type pressure sensor is used to obtain the instantaneous pressure at the inlet and outlet of the pump. All output signals from sensor are current signals of 4 to 20 mA, and are input to PCI 8361 BN type A/D acquisition card and on converted to digital signal. The transport medium is pure water at common condition.

3.1 Components of centrifugal pump

Pressure sensor, Motor, Pump, Torque, speed meter, torque of speed meter and casing.

Pressure sensor:- A pressure sensor is an instrument that measures the pressure of gases or liquids. Pressure is the force required to prevent a fluid from expanding, and it is commonly expressed in force per unit area. A pressure sensor is typically used as a transducer, producing a signal as a function of the applied pressure. Such a signal is electrical for the purposes of this article.

Motor:- An electric motor is a machine that turns electricity into mechanical energy. The interaction between the motor's magnetic field and electric current in a wire winding generates force in the form of torque imparted to the motor's shaft in most electric motors. Direct current (DC) sources, such as batteries or rectifiers, or alternating current (AC) sources, such as a power grid, inverters, or electrical generators, can power electric motors. An electric generator is physically equivalent to an electric motor, but it converts mechanical energy into electrical energy using a reversed flow of power.

Pump:- A pump is a device that moves fluids (liquids or gases), or sometimes slurries, by mechanical action, typically converted from electrical energy into hydraulic energy. Pumps can be classified into three major groups according to the method they use to move the fluid: direct lift, displacement, and gravity pumps.

Fig. 2. Components of Centrifugal Pump

3.2 Pump model:-

The tested model is a low specific speed centrifugal pump with an open impeller. The open impeller is shown in figure. The original design parameter are; flow rate, Qd 6 m^3/s. Head: $(H_d) =$ 8m. Rotational Speed= nd=1450 RPM.

Blades are off 2 D cylindrical profile and volute is spiral. The tip clearance between casing and blade is 1.2 mm the other main geometric dimensions are shown in table 1.

3.3 Result and discussion:

As it is well known adjusting the discharge bowling opening could obtain the cross ponding stable working point under certain rotational speed. Clearly the final stable flow rate will increase as the discharge valve opening increases.

In the case that discharge valve opening is invariable the corresponding floret head and shaft power are constant and unique before each experimental of startup the water in whole system including pump tank and pipeline is kept static and ensuring that the free surface of water in tank is always higher than that tested pump and pipeline.

3.4 Experimental study on a centrifugal pump with an open impeller during startup period:

a.) Real Model b.) Meridional view c.) Plane View

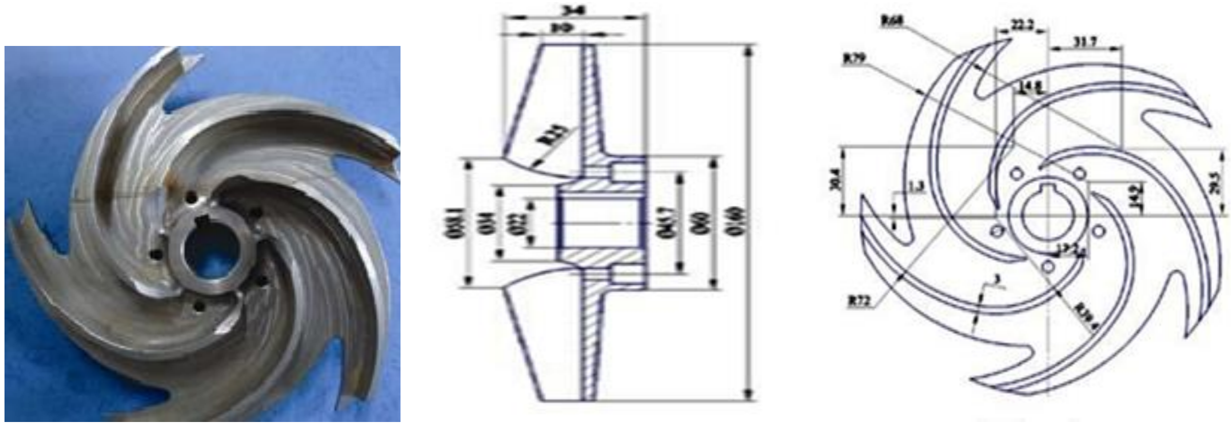


Fig 3. Open centrifugal pump

3.6 Main geometric parameter of centrifugal pump

Tested centrifugal pump

Suction diameter Di/mm	48
Discharge diameter Do/mm	38
Number of blades z	4.5
Blade angle at inlet Bi/C^{O}	23
Blade angle at outlet Bi/C^{o}	23
Impeller inlet diameter D1/mm	46
Impeller outlet diameter D2/mm	154
Blade inlet width b1/mm	18
Blade outlet wades b2/mm	9
Volute basic diameter D3/mm	158
Volute inlet width b3/mm	14
Volute throat diameter Dth/mm	14
Blade thickness d/mm	2.5

Figure 3 shows the experimental result of the rotational speed flow rate head and shaft power with the time during rapid startup read at different discharge valve opening for centrifugal pump, the soft power will increase with the increase of the discharge valve opening or flow rate, 10 the shaft torque of the driving motor also become larger.

In theory, it may affect the rise characteristic of the rotational speed of motor in the process of startup. However, the experimental result shows that for a startup cases the change of the rotational speed is very small all or basically unchanged during startup period.

eight startup case shows that the rotational speed rises to their final stable volume at about 0.2 second. That difference among eight cases is that the final rotational speed is different. When θ/θd is equal to 0.0 and 1.414,

The final rotational speed are about 1476 and 1460 RPM respectively and the variation between in them shows approximate linear characteristics. For the present pump unit, it is found that the rise characteristic of the rotational speed during startup period does not basically rely on the final stable working points while mainly depends on the startup characteristic of the driving motor.

It can be seen from figure 3 e that compared with the rapid rise of the rotational speed during startup period the rise of the flow rate is slow at the beginning and gradually accelerates and finally slow down till the final stable value. The reason for the slow rise in the flow rate at the beginning of startup can be attributed to the fact that the fluid is static before startup.

When the ratio of the flow rate (θ/θd) are respectively 0.206, 0.408, 0.615, 0.805, 1.02, 1.209, 1.414, the time spent on the flow rate rise from 0 to their stable value is about 0.6, 1.0, 1.4, 1.5, 1.6, 1.7, 1.8 respectively.

Clearly, the rise history of the flow rate severally lags behind that of the rotational speed (at about 0.2 s) , and the required time of the flow rate rise shows that the increase tendency with the increase of the discharge value opening. For θ/θd, less than 0.615, the magnitude of the rise of the required time is very obvious for θ/θd greater than 0.615.

The magnitude is relatively smaller. In conclusion, the rise delay in the flow rate becomes more severe with the increase of the discharge value opening during startup period. For eight startup cases, the final stable heads are 9.32, 9.27, 9.01, 8.54, 7.80, 6.98, and 5.87 respectively. based on the similarity theory of pumps, the above head can be converted into the corresponding value in

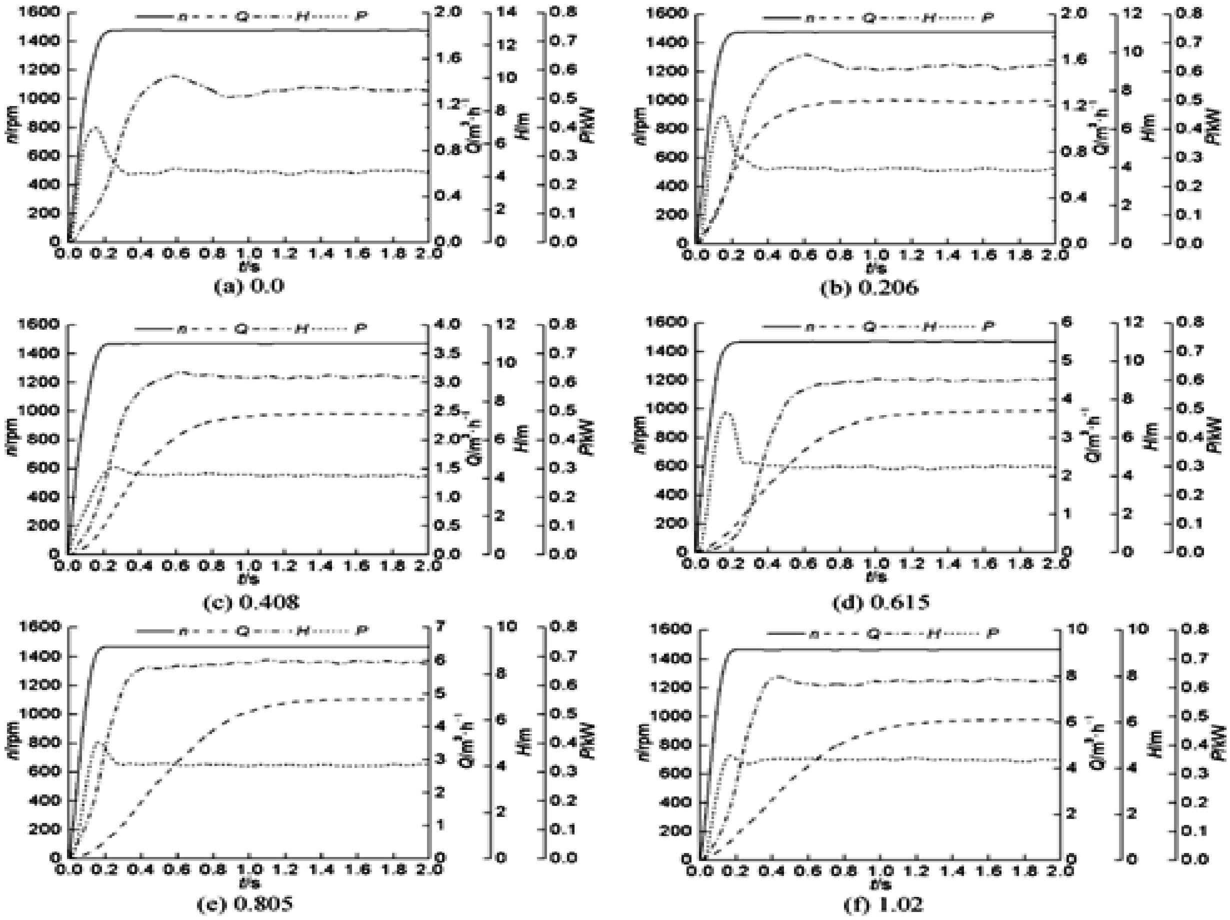


Fig. 4 Experimental results of external performance during startup periods (Q/Q_d)

the case of design rotational speed, namely 8.98, 8.96, 8.99, 8.77, 8.34, 7.64, 7.86 and 5.79m respectively. Clearly, there is a very slight hump phenomenon in the range of smaller flow rate. Therefore, the pump models may be regarded that it is of the reliable operation stability as whole from fig 3. It is seen except for two cases θ/θd =0.615 and 0.805 other than six cases show that there exists the head impact phenomenon more or less before reaching the final stable values. For θ/θd = 0.0, 0.206 and 0.408 the highest heads are 10.16 mm, 9.89 mm and 9.55 mm respectively. The impact heads that is defined as the difference of the highest head and the final stable head, are respectively 084m, 063/2m and 0.28m. and the required time reaching the highest heads is about 0.6s. Clearly for θ/θd less than 0.615, The head (Pressure) impact shows that the decrease tendency with the increase of the discharge value opening.

For θ/θ_d =1.02, 1.209 and 1.414 the Highest heads are 8.0, 7.82 m and 7.76 m respectively. Thus, the impact heads are 0.21, 0.84 and 1.89 m respectively.

Meanwhile the required time reaching the highest head is about 0.4 second clearly for θ/θ_d greater than 0.805 the head impact shows the increase tendency with the increase of the discharge value opening.

It is also seen that absolute value of the stable head is smaller in the case of large flow rate show the pump vibration caused by the pressure impact may not be very severe during startup period. It is well known that the best efficiency point (BEP) of pump should be in agreement with design point theory. Actually, the BEP of the concerned pump model deviates from the design point and is located in the range of smaller flow rate. This is also so why the obvious pressure impact does not occurs in the case that theta by theta d is equal to 0.615 and point 0.805.

It is seen from the experiment result that the final shaft powers are respectively about 0.245, 0.259, 0.277 0.299, 0.323, 0.349, 0.371 and 0.395 kilowatt under at startup condition.

Obviously, the variation tendency is basically linear. In addition, it is also seen from figure 3 that there generally e limits the shaft power impact phenomenon during startup period.

for those centrifugal pumps with the large shaft power that shaft power impact may cause the current impact on local Power grid so as to destroy the locality equipment. For $\theta/\theta d$ =0.0, 0.206, 0.408, 0.615, 0.805 and 1.02 the shaft power impact phenomenon is very remarkable. The corresponding height highest soft power are respectively 0.408, 0.457,0.307, 0.501, 0.415 and 0.373 kW and are in the time range of 0.15- 0.25 s. The impacts of power that is defined as the difference of highest power shaft power that and final stable shaft power are 0.457, 0.307,0.501, 0.425 and 0.373 kW. Shaft power are 0.163 0.198 0.03 0.202 0.090 and 0.024 KW respectively. For $\theta/\theta d$ = 1.209 and 1.414 the shaft power impact phenomenon is not very remarkable.

In addition, it is also seen from figure f and g and h that there exists local minimum of the shaft power before reaching the final stable values. The minimum values are respectively e 0.335 kilowatt 0.3 40 KW and 0.33 6kw and the corresponding rising time is about 0.25 s.

3.7 Non dimensional analysis: -

in the process of start-up rapid rising of the rotational speed causes each parameter such as flow rate and pressure to vary greatly. In order to better analyze the transient behavior of the centrifugal pump during startup period the effect of the variable rotational speed should be eliminated. As such the non-dimensional volume flow rate and head are employed to describe and analyze the transient flow.

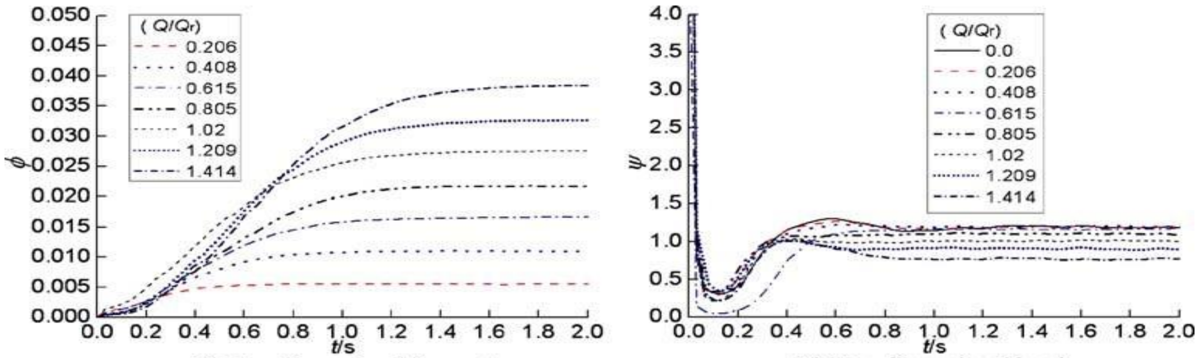
The definition are below:-

$\Phi(t) = \theta(t)/ \pi D_2 b_2 U_2 (t)$ (i)

$U(t) = 2gH (t)/U_2^2 (t)$

Where u t is the circumferential velocity at the impeller outlet YouTube p is equal to 2 into by 60.therefore, the non-dimensional flow rate and head should be independent of the rotational speed as in figure 4 shows the result of non-dimensional flow rate and head due during startup period.

Non dimensional flow rate:-



(a) Non-dimensional flow rate (b) Non-dimensional head

Fig.5 Non-dimensional flow rate and head during startup period (Q/Q_d)

It is clearly seen from figure 4A that the non-dimensional instantaneous flow rate shows the continuous rise trend during startup period.in addition figure for a also shows that the final stable non dimensional flow rates vary by the law of approximate linear relation among different working points. This manifest that variation of the flow rate meets the similarity theory of the firm under stable working condition in spite of some slight fluctuations.

From figure 4b it is seen that the variation of the non-dimensional head is more complex than that of the non-dimensional flow rate at the very beginning of a startup the non-dimensional instantaneous head is very high and quickly falls to the minimum value at with the time then gradually rises to the final stable value the reason for very high and quickly non-dimensional head can be attributed to the fact that the sudden rotation of the centrifugal impeller generates a pressure impact on the static fluids. meanwhile it is also found that the variation of the head also meet the similarity theory of firm under stable working condition but the variation during startup periods are far from the similarity theory of the pump. If the startup process meets the quasi steady assumptions namely meeting the similarity theory of pump if the startup process meets the quasi steady assumptions namely meeting the simulated theory of pump the non-dimensional volume flow rate and head should be constant during startup periods.

However, this present results clearly shows that both of them greatly derived from the result based on the Quasi steady characteristics. Therefore, the simulated theory of firm all the case study analysis cannot be used to accurately described or analyze the transient flow during startup periods.

4.Conclusion:-

in this paper the transient behavior of prototype centrifugal pump with open impeller during startup process is studied experimentally and analyzed using non-dimensional parameters. the research result shows that the rise characteristic of the rotational speed is not basically changed by working points which mainly depends on the startup characteristics of the driving motor compared with the rapid rise in the rotational speed flow rate rise slowly in the initial stage of a startup and greater lags behind the rotational speed to reach the final stable values. moreover the delay becomes more severe with the increase of the discharge value opening in the range of a smaller discharge value opening pressure impact shows the degrees tendency with the increase of the discharge valve opening.

While in the range of higher discharge valve opening. it is also seen that the shaft power impact phenomenon generally, exist in the process of startup. The non-dimensional head is very high at very beginning of start-up then quickly fast to the minimum. Finally, gradually rise to the final stable values that the non-dimensional flow rate always shows the rise tendency during startup periods. In conclusion the Quasi steady assumptions is not used to accurately e access the transient flow during startup period. Transient performance of fluid machinery during transient operating periods such as startup and stop ine has been drawn more attention recently due to growing engineering needs in this paper the transient behavior of prototype centrifugal with an open impeller during rapid startup period is studied experimentally.

The variation of rotational speed flow rate head and staff power during rapid start a period is studied experimentally. The variation of rotational speed flow rate head and staff for rapid startup period are recorded in the experiment at different discharge valve opening. In addition, the non-dimensional flow rate and head are also used to analyze transient behavior.

the research result shows that the rise characteristic of rotational speed is not basically changed by working points while many depends on startup characteristic of driving motor compared with the rapid rise of the rotational Speed the flow rate rises slowly in the initial stage at startup. more over the flow rate lacks behind the rotational speed to rise the final stable value and the delay becomes more severe with the increase of the discharge valve opening.

the shaft power impact phenomenon generally, exist in the process of startup. the non-dimensional analysis shows that the non-dimensional head is very high in the beginning of a startup and quickly fast to minimum then gradually rises to final stable value while the non-dimensional flow rate always shows the rise tendency during hole starter period.

In conclusion it is found from the non-dimensional flow rate always shows the rise tendency during hole start up period in conclusion it is from the non-dimensional result that the Quasi study analyses is unable to accurately accept the transient flow during start-up period.

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