Design and Manufacture of a Water Pump to Study the Effect of Impeller Blades Number on the Pump Performance

A. S. A. Elmaryami1*, Abdulla Souss2, Magdi E. M. El-Garoshi3, Abdelkareem Aljair1, Ahmed Almasry1, Farag Mahjob1 & Hana Othman1

1Department of Mechanical Engineering, Bright Star University, El-Brega - Libya
2The High Institute of Technical Sciences [HITS], Al-Guba, Libya.
3The High Institute of Technical Sciences [HITS], Tobruk, Libya.

*Corresponding author: damar604@yahoo.com

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Research Article

Abstract

In this study, the flow rate, velocity, head, and power in a designed and manufactured centrifugal water pump were studied and determined experimentally. The effect of the impeller with different blades on the centrifugal pump performance has been investigated. Three different impellers with 4, 5, and 6 blades are tested to determine the number of the optimum blades. The experimental results showed that the flow rate, velocity, heat, and power are higher for the case of the impeller with 6 blades than that for the two cases of 4 and 5 blades. The losses decrease by increasing the number of the blades due to the reduction of the secondary flow for a certain limit. The experimental results showed better centrifugal water pump performance when an impeller with 6 blades is used.

Keywords: Blade number, Impeller losses, pump performance, Design a pump, Flow rate, Velocity, Head, Power.

1. Introduction

Centrifugal pumps have been used in industrial and domestic applications, such as steam power plants, water supply plants, sewage, drainage or irrigation, oil refineries, hydraulic power services and ships. Due to the rotation of the impeller, the fluid is drawn at the inlet to the pump, continuous lifting of fluid takes place from source to the pump while passing through the impeller the fluid takes the energy from vanes in form of kinetic energy and pressure.

Centrifugal pumps are the most common type of kinetic pump and are used most often in applications with moderate-to-high flow and low head. A lot of research has been carried out to make it more efficient. Over the last decades, many researchers have investigated the centrifugal pump performance either experimentally or theoretically. Among these researches, the performance of the centrifugal pump has been studied by changing the impeller configurations; its blade shape, blade angles, adding splitters. In addition, the performance has been investigated for different operating conditions with these configurations change.
2. Literature Review and Its Outcomes
The impeller is the most important part in a centrifugal pump since it is the place where the mechanical energy is converted into hydraulic energy. Hence the parameters related to the impeller are directly affecting the performance of the pump [1].
Centrifugal pumps are probably among the most often used machinery in industrial facilities as well as in common practice. After being invented, they passed long evolutionary way until they became accessible for various applications. A few centuries ago, Euler described their physical principle through a well known equation named after him “Euler’s equation for turbo machinery”.
Since then, many studies have been conducted to improve the centrifugal pump performance. These studies used a lot of methods and ideas seeking a better centrifugal pump performance through attempts to increase the pump total efficiency and slip factor.

One of these methods that took a lot of interest was to improve the pump performance by impeller trimming. These studies found that as the diameter is reduced, the head and power curves decrease continuously. The efficiency, however, will increase at first and then drop for a certain value of diameter. The main reason for this might be attributed to the growth of the gap between the impeller and stator as the impeller diameter is reduced [2-4].

Improvement performance of centrifugal pumps is critical to reduce the consumption of electrical energy. One to improve the performance is to break down the circulation near the impeller exit. This can be achieved through the use of shorted blades. Effect of different sizes of shorted blade on pump performance is studied theoretically in this research which, test rig for testing centrifugal pump with standard impeller is constructed. Three impeller configurations with different size shorted blade are installed. The head, flow rate and shaft power are measured at 1500 rotational speed for the standard pump only. Also computational model using “Fluent” under ANSYS is constructed to predict the performance parameters of centrifugal pumps and to analyze the flow field in the impellers’ passages. Standard impeller (A) and three impellers configuration with different shorted blade length of 0.25 (configuration B), 0.2 (configuration C), and 0.15 (configuration D) of the full blade length are analyzed [5].
The pump design is facilitated by the development of computational fluid dynamics and the complex internal flows in water pump impellers can be well predicted. Various parameters affect the pump performance and energy consumption. The impeller outlet diameter, the blade angle and the blade number are the most critical. The present paper describes the simulation of the flow into the impeller of a laboratory pump in a parametric manner. In this study, the performance of impellers with the same outlet diameter having different outlet blade angles is thoroughly evaluated. The one-dimensional approach along with empirical equations is adopted for the design of each impeller. The predicted performance curves result through the calculation of the internal flow field and a successful correlation of local and global parameters [6].
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finite-volume code. For each impeller, the flow pattern and the pressure distribution in the blade passages are calculated and finally the head-capacity curves are compared and discussed [7].

Centrifugal pumps are the largest used hydraulic machine. However, the performance of centrifugal pump is generally not very good. Making them more efficient is a major challenge. The performance of the centrifugal pump greatly depends on its geometrical parameters and the vane profile. Computation fluid dynamics (CFD) has been found to be a very good tool for numerical analysis of flow through complex system including centrifugal pumps. The present study deals with the performance analysis of a mixed flow type centrifugal pump designed centrifugal pump to deliver 0.25 m³/s water at a head of 20 m running at 1450 rpm using ANSYS CFX 14.0 software. Modeling of the pump unit has been done using PTC Cre-o 2.0 software. The performance of the pump was first determined using the initially obtained vane angles. The inlet vane angle and outlet vane angle are then varied to analyses the improvement in pump performance. The results shows that for an initial inlet angle 20.08° and outlet angle 16.28°, the efficiency of the pump is 83 %; however, for an optimized angles at inlet and outlet as 20.16° and 16.62° respectively, the efficiency of pump raised to 88 % thus showing an improvement in the performance of mixed flow pump [8].

The effect of impeller backward blades with slot on the centrifugal pump performance has been investigated numerically. Impeller blades have been modified with different geometrical parameters of slot such as: slot radial position (Rs), slot height (hs) and slot inclination angle (θs). 3-D numerical simulation has been carried out using commercial software, ANSYS® CFX, to study the effect on the pump performance at different flow rates. The numerical simulation has been compared with previously published experimental results to verify the numerical solution. In addition, the results have been compared with the impeller without slots for the same operating conditions. It has been shown that the slot parameters have a significant effect on the centrifugal impeller performance [9].

3. The designed and manufactured pump and its equipment
Most of the industrial processes include the conduction of fluids or energy transfer. This is possible thanks to the centrifugal pumps which are the most popular turbo machinery. The growth and improvement of the industrial processes have been always linked to the improvements in the pumping equipment. Centrifugal pumps constitute more than 85% of the world production of pumps, due to their capacity to handle high flows.

Fig. 1. The designed and manufactured pump
### 3.1 The impeller Blade

Impeller design is the most significant factor for determining performance of a centrifugal pump. A properly designed impeller optimizes flow while minimizing turbulence and maximizing efficiency. In general, centrifugal pumps can be classified based on the manner in which fluid flows through the pump. It is not classification based on the impeller alone, but it is based on the design of pump casing and the impeller.

The impeller of a centrifugal pump can be of three basic types as shown in Fig. 2.

- **Open impeller.** Open impellers have the vanes free on both sides. Open impellers are structurally weak. They are typically used in small-diameter, inexpensive pumps and pumps handling suspended solids.

- **Semi-open impeller.** The vanes are free on one side and enclosed on the other. The shroud adds mechanical strength. They also offer higher efficiencies than open impellers. They can be used in medium-diameter pumps and with liquids containing small amounts of suspended solids. Because of minimization of recirculation and other losses, it is very important that a small clearance exists between the impeller vanes and the casing.

- **Closed impeller.** The vanes are located between the two discs, all in a single casting. They are used in large pumps with high efficiencies [10].

In this work three different semi-open impellers with 4, 5, and 6 blades designed and manufactured as the following:

- **Fig. 3.** Impeller with 4 blades
- **Fig. 4.** Impeller with 5 blades
- **Fig. 5.** Semi-open impellers with 3, 4 and 5 blades
4. Pump's main results investigation

4.1 Volume Flow Rate (Q) Calculation

4.1.1. Impeller with 4 blades
The volume flow rate (Q) of three different impellers with 4, 5, and 6 blades can be calculated after computing the volume and time, the final results shown in Fig. 6.

Where: \( Q_4 \) of the impeller with 4 blades \( Q_4 = \frac{V}{t} = \frac{0.006}{46.16} = 1.299 \times 10^{-4} \frac{m^3}{sec} \)

4.1.2. Impeller with 6 blades
\( Q_5 \) of the impeller with 4 blades \( Q_5 = \frac{V}{t} = \frac{0.006}{40.6} = 1.478 \times 10^{-4} \frac{m^3}{sec} \)

4.1.3. Impeller with 8 blades
\( Q_6 \) of the impeller with 4 blades \( Q_6 = \frac{V}{t} = \frac{0.006}{36.3} = 1.652 \times 10^{-4} \frac{m^3}{sec} \)

![Effect of impeller blade numbers on (Q)](image)

**Fig. 6. Effect of Impeller Blade Number on (Q)**

4.2 Discharge Velocity (V) Calculation
The velocity of three different impellers with 4, 5, and 6 blades can be calculated by Continuity Equations, the final results shown in Fig. 7.

4.2.1. Impeller with 4 blades
\( V_4 \) of the impeller with 4 blades \( V_4 = \frac{Q_4}{A} = \frac{1.299 \times 10^{-4}}{0.000113} = 1.15 \frac{m}{sec} \)

4.2.2. Impeller with 5 blades
\( V_5 \) of the impeller with 5 blades \( V_5 = \frac{Q_5}{A} = \frac{1.478 \times 10^{-4}}{0.000113} = 1.31 \frac{m}{sec} \)

4.2.3. Impeller with 6 blades
\( V_6 \) of the impeller with blades \( V_6 = \frac{Q_6}{A} = \frac{1.652 \times 10^{-4}}{0.000113} = 1.452 \frac{m}{sec} \)
4.3 Head of the Pump (Hp) Calculation

Hp of three different impellers with 4, 5, and 6 blades can be calculated from the Energy Equation, the final results shown in Fig. 8.

4.3.1. Impeller with 4 blades

\[
\frac{P_1}{y} + \frac{V_1^2}{2g} + Z_1 = \frac{P_4}{y} + \frac{V_4^2}{2g} + Z_4 - H_{p4}
\]

\[
\alpha = \frac{V_4^2}{2g} + Z_4 - H_{p4}
\]

\[
H_{p4} = \frac{V_4^2}{2g} + Z_4 = \frac{1.15^2}{2g} + 0.5 = 0.5675 \text{ m}
\]

Where \( P_1 = P_4 = P_5 = 101325 \frac{N}{m^2} \) (\( P_o \)), \( V_4 \gg V_1 \), \( Z_1 = 0 \) and \( Z_4 = 0.5 \) (measured)

Then \( H_{p4} = 0.50101 \text{ m} \)

4.3.2. Impeller with 5 blades

\[
\frac{P_1}{y} + \frac{V_1^2}{2g} + Z_1 = \frac{P_5}{y} + \frac{V_5^2}{2g} + Z_5 + H_{p5}
\]

\[
0 = \frac{V_5^2}{2g} + Z_5 - H_{p5}
\]

\[
H_{p5} = \frac{V_5^2}{2g} + Z_5 = \frac{1.31^2}{2g} + 0.5 = 0.587 \text{ m}
\]

Where \( P_1 = P_5 = P_6 = 101325 \frac{N}{m^2} \) (\( P_o \)), \( V_5 \gg V_1 \), \( Z_1 = 0 \) and \( Z_5 = 0.5 \) m (measured)

Then \( H_{p5} = 0.587 \text{ m} \)
4.3.3. Impeller with 6 blades

\[ \frac{P_1}{V} + \frac{V^2}{2g} + Z_1 = \frac{P_6}{V} + \frac{V^2}{2g} + Z_6 + H_{P_6} \]
\[ \alpha = \frac{V^2}{2g} + Z_6 = 1.452^2 + 0.5 = 0.607 \text{ m} \]

Where \( P_1 = P_6 = P_0 = 101325 \frac{N}{m^2} (P_a) \), \( V_6 \gg V_1 \), \( Z_1 = 0 \) and \( Z_6 = 0.5 \text{ m} \) (measured)

Then \( H_{P_6} = 0.607 \text{ m} \)

4.4 Power of the Pump (\( \mathcal{P} \)) Calculation

Power of three different impellers with 4, 5, and 6 blades can be calculated from the following equation, the final results shown in Fig. 9.

\[ \mathcal{P} = \gamma \times Q \times H_p \]

4.3.1. Impeller with 4 blades

\[ \mathcal{P}_4 = \gamma \times Q_4 \times H_{P_4} = 1000 \times 9.81 \times 1.299 \times 10^{-4} \times 0.50101 = 0.64 \text{ W} \]

4.3.2. Impeller with 5 blades

\[ \mathcal{P}_5 = \gamma \times Q_5 \times H_{P_5} = 1000 \times 9.81 \times 1.478 \times 10^{-4} \times 0.587 = 0.85 \text{ W} \]

4.3.3. Impeller with 6 blades

\[ \mathcal{P}_6 = \gamma \times Q_6 \times H_{P_6} = 1000 \times 9.81 \times 1.652 \times 10^{-4} \times 0.607 = 1 \text{ W} \]

Fig. 8. Effect of Impeller Blade Number on (Hp)
Design and manufacture a model of centrifugal water pump can be used as visualization, to view the effect of the impeller blades number on the pump's performance, where a model of centrifugal water pump designed and manufactured to calculate the flow rate, velocity, head, and the power of the pump's model determined. Three different impellers with 4, 5, and 6 blades are tested to determine the optimum blades number. The experimental results showed that the flow rate, velocity, head, and the power are higher for the case of the impeller with 6 blades than that for the two cases of 4 and 5 blades. It was found that the optimum value of blades is 6 blades. The losses decrease by increasing the blades number due to the reduction of the secondary flow for a certain limit. The experimental results showed better centrifugal water pump performance when impeller with 6 blades is used. As a conclusion, the objectives of this research had been successfully achieved.

Finally the centrifugal pump is a simple but essential device as we have seen above. With the many varieties of the pumps that are available, proper design is the most important requirement for any facility. Generally, ensuring there is no cavitations and maintaining a continuous flow is enough. Only proper design using the steps listed here can guarantee that the pump suits the set conditions.

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