Experimental study of pumps in a pipe bench

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Abstract. This paper presents an experimental study of radial flow propeller pumps in a pipe bench. For the development of the research, flow and pressure sensors are used in order to determine the fluctuations and the characteristics dynamics fluid of the pump. A control system was used using a Solid-State Relay to vary the speed of the pump and a virtual platform coupled to a data acquisition system to characterize the network. The characteristic curve of the propeller pump was obtained with a value of $R^2=0.97$, in addition the characteristic curves of the hydraulic network for turbulent flow are calculated with the Reynolds number between 13821 and 81521. Finally, the volumetric losses are calculated in the pipe, which equals 10% for a flow of 10 l/min and as the flow increases up to 6 times the value decreases to 2%.

1. Introduction

The transport of liquid volumes to distant areas and continuously is organized in hydraulic networks whose applications extend to manufacturing processes, agriculture, food industry, public services among others.

The pump is one of the main elements in a hydraulic installation has the function of circulating water from the generator used in the hydraulic network. For this, the pump supplies a flow of water whose pressure is sufficient to overcome the resistances along the distribution circuit. "Pumps are machines designed to move incompressible fluids" [1].

There are two fundamental groups of pumps, called positive displacement and centrifugal effect. The pumps of positive displacement are used to pump small flow to a great height, their operation is based on extracting a defined volume independently of the revolutions of the engine, but of way practically independent of the pressure.

The centrifugal effect pumps have main function is to transform in pressure the energy that comes through the shaft that produces the rotation of the impeller. Centrifugal pumps are classified according to the flow direction in radial flow, axial flow and radial-axial flow [2].

Radial flow pumps are used for high loads and small flow rates. The radial flow is developed mainly due to the centripetal force. The axial flow pumps are used for high flow and low-pressure applications, the liquid enters and exits axially through the impellers.

In this experimental research, a radial flow centrifugal pump coupled to a data acquisition system is used to obtain the characteristic curves of both the pump and the piping system with this is designed the hydraulic networks.
This document is organized as follows: in section 2 it presents the characteristic curves of the system; section 3 presents the experimental configuration used for the characterization of centrifugal pumps in hydraulic networks; section 4 shows the results; and section 5 the conclusion is presented.

2. Pump characteristic curves
The operation of a hydraulic network design is characterized by curves that describe its behavior during its operation. These curves are called characteristic curves; these curves are plotted according to the flow, pressure and efficiency.

2.1. Characteristic curve of pump operation
The characteristic curve of a pump shows the relationship between the discharge flow and the energy that the pump adds to the fluid or dynamic height. As expected, the higher the flow rate of the pump, the lower the energy consumption.

The pump performance curve depends engine speed and rotor diameter, in Figure 1 a running curve of a centrifugal pump is shown. The total height delivered by the pump decreases as the flow increases.

\[ \frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} + h_A = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g} \]  

(1)

2.2. Pump performance curve
The pump performance determines the relation between the shaft power and hydraulic power. Since the power of the shaft is also available in graphs of open access, then, in addition, it allows calculating the performance. However, there is no simple analytical model for shaft power. Therefore, the adjustment of the power curve of the axis is done using a low-order polynomial adjustment locally weighted [4].

Figure 2 shows the efficiency curve of a centrifugal pump. The value of the efficiency is zero when the flow is zero as the flow increases the efficiency increases to a maximum value, called the maximum performance point. When it reaches the point of maximum performance, when the flow increases, the efficiency decreases. Equation (2) shows the pump performance.

\[ P_e = \frac{p_h}{\eta} \]  

(2)

2.3. Pumping system characteristic curve
A pumping system curve shows the required pumping height as a function of the flow rate at a constant speed of rotation. The pumping height required by the system is equal to the elevation of the pump that must provide the fluid plus the total loss of load throughout the system (see Figure 3). It consists of
varying the flow that circulates through the same system, restricting the percentage of the valve opening in the discharge line.

The second method uses to obtain the curve of the system, it consists in varying the revolutions of the engine. This method requires an operating point known to a speed of rotation.

![Figure 3. Characteristic curve of the pumping system [4].](image)

In the operating range of the pump, it presents operating efficiencies higher than 60%; otherwise, it is convenient to modify the diameters of the pipes or change the pump. The characteristic curve of the system varies with the change of diameter of the impulsion or suction pipe, increasing or decreasing the energy losses.

### 3. Materials and methods

The radial pump has 5 phases that include the assembly of the hydraulic system, electronic, data acquisition and control.

#### 3.1. Hydraulic system

The test bench has a water circulation line, two propeller pumps, two water tanks, two pressure sensors, two flow sensors, a data acquisition system, and a control system using solid state relay (see Figure 4).

![Figure 4. Experimental diagram of the test bench.](image)

#### 3.2. Pressure sensor

The pressure sensors MPX10DP is a non-compensated silicon pressure sensor with double port for environmental control systems and level indicators. The pressure sensor provides a very precise linear voltage output, directly proportional to the applied pressure. This standard uncompensated sensor allows manufacturers to design and add their own external temperature compensation and signal conditioning networks. Table 1 lists the main instruments used in the test bench.

![Figure 5. Virtual Instrument. [5](image)
Table 1. Main instruments used in the experiment.

| Instrument          | Type                  | Parameters                | Measuring range          |
|---------------------|-----------------------|----------------------------|--------------------------|
| Pressure gauge      | MPX10DP               | Pressure at the entrance and exit | 0kPa~10kPa               |
| Flow meter          | YF – S201             | Flow at the entrance and exit | 1 – 30 l/min             |
| Data acquisition card | Arduino card one     | Data acquisition system   | N/A                      |
| Pump                | Radial flow centrifugal pump | Pumping system          | Power: 32 W             |
| Solid state relay   | ASH-C 25VA            | Crop the waveform         | Voltage: 120 v          |

3.3. Flow sensors
This type of sensors the vanes are perpendicular to the flow are not parallel as in the turbine sensors, due to the solid design of the rotor, which does not include a ball bearing, this sensor is very tolerant to particles in the flow line and does not require filters. Because the blades must have a transverse contact with the flow, the rotor insertion depth and proper flow profile are fundamental for the precise performance of the flow meter [6].

3.4. Data acquisition system
An Arduino ONE card takes data acquisition, the pressure and flow sensors reference MPX10DP and YF-S201 are connected to it. The response speed of the Arduino card is in the order of 112 μs, which is satisfactory for the speed of change of the flow. A graphical interface Processing allows to collect the data in a table in Excel in order to perform the respective analysis.

3.5. Control system
A solid state relay (SSR) varies the flow and pressure level during the test. This process has a period of approximately 40 minutes. A virtual instrument developed in Labview controls the system, this obtains the data from the sensors to characterize the pump (see Figure 5) [7,8].

4. Results
Analysis of the hydraulic network: the test has a difference between the flow at the outlet of the propeller pump located at point 1 of Figure 4 and point 2 at the end of the pipe.

Therefore, in Figure 6 presents the percentage of volumetric losses along the pipeline. In spite of not having a good fit with an $R^2=0.1597$ for an adjustment of a 4th degree polynomial: A decrease in the percentage of losses is found from 10% to 2.5%, when the flow increased from 10 l/min to 62 l/min.

![Figure 6. Percentage of volumetric losses.](image)

The Fourier series are used for the purpose of finding the amplitude and frequency of oscillation, in the case that the flow rate of the pump is periodic. A $R^2=0.77$ was obtained from the periodicity analysis (see Equation (3) and Figure 7). The frequency is equal to 0.02452.
The propeller pump was characterized taking it to the steady state and at the end of the pipeline where the volumetric losses were negligible, in Figure 8 the pump adjustment graph is presented with $R^2 = 0.9791$ [9-11]. It is located below of level water to avoid the cavitation [12,13]. In the same that way ramp pump cycles are repeated periodically [14].

\[
Q(t) = 8.23 + 0.1514 \cos(0.02452t) + 0.04469 \sin(0.02452t)
\]  \quad (3)

Reynolds numbers has values oscillate between 10000 and 80000. The losses in the pipe depends of them and Darcy’s Law (see Figure 9 and Figure 10) [15].

\[
h_L = 5 \times 10^{-7}Q^2 + 5 \times 10^{-6}Q - 2 \times 10^{-5}
\]

\[
R^2 = 1
\]

Table 2 shows the calculation of minor losses for the accessories.

| Entry            | Losses       | K   | K total |
|------------------|--------------|-----|---------|
| 3 Elbows 90°     | 0.81         |     | 2.43    |
| Expansion        |              | 0.36|         |
| Contraction      | ASH-C 25VA   | 0.32|         |

The expression allows calculating the friction factor for turbulent flow [16] in Equation (4).

\[
f = \frac{0.25}{\log \left( \frac{1}{3.72 \cdot \frac{5.74}{Re^{0.8}}} \right)}
\]  \quad (4)
5. Conclusion
The difference in flow between the inlet and outlet determines the volumetric losses for a propeller pump. The losses are equivalent to 10% of the total flow, they decrease to 2% as the flow increases. The flow is turbulent with a Reynolds number between 13821 and 8152 and the losses in the pipeline amount to 0.0232 m. The characteristic curve of the pump is determined without losses in the pipeline and accessories. This methodology is used because it is not possible to stabilize the flow values at the outlet of the pump. This is because the flow is periodic with a frequency of 0.02011 rad/s with an R2 of 70%. The characteristic curve adjusted with $R^2=97.91\%$, so it is possible to calculate its operating point to design hydraulic networks.

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