LABORATORY SETUP FOR MEASUREMENTS BASIC PUMP SYSTEM CHARACTERISTICS

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Abstract

This paper presents the laboratory pump system realized at the Faculty of Technical Sciences, Cacak. The aim of the realized pump system is to use it primarily for educational and scientific purposes. It is designed as an open system in which water is taken and returned from a 400 liters capacity tank. 4 kW centrifugal pump with 3-phase induction motor was used. For pressure (p) and water flow (Q) control through motor-pump system the commercial frequency converter was used. The operating pressure of the pump system is going up to 6 bar with a maximum flow rate of 5 l / s. The system contains pressure valves and bypass control. With the available pressure sensors, flow meters and acquisition equipment, the characteristic quantities of pump system are measured. LabVIEW software was used for process and graphical visualization of measured flow and pressure rates. Pressure and flow rates, as well as the diagrams of measured functions p=f (Q) and η=f (Q) are shown as the experimental results at the end.

Keywords: pump system, water flow measurement, pressure measurement, data acquisition, LabVIEW.

INTRODUCTION

Setup for education about the principles of hydraulic and pumping systems operation can easily be realized in laboratory conditions. One such system can be made with components such as water tank, pump with motor and system with pipes and valves. For mechanical parameters measurement, in order to determine the characteristics of the pump system, it is necessary to measuring the pressure and the flow of water. This can be done with analogue barometers and flowmeters or using acquisition equipment, pressure and flowmeter sensors. Example of determining the pipe system and centrifugal pumps performance is given in [1].

Pump system can be used to determinate the characteristics of hydraulic components such as turbines, (pump as turbine), valves, etc. Measured characteristics and characteristics of pump given by the manufacturer can be compared with this laboratory setup. For determination of the hydraulic power (or power losses) of hydraulic component it is necessary to measuring the inlet and outlet pressure and flow, what this laboratory pump system makes possible.

The used equipment and results of pressure and flow measurement are presented in this paper. The *p-Q* (pressure-flow) and *P-Q* (power-flow) characteristics describing the system and the centrifugal pump at different speeds are graphically presented. These characteristics define maximum hydraulic power in the system. One of the additional goals of the realized laboratory system is to provide better understanding of the pump system principles to the students and provide a platform for further testing and research.

PRESSURE, FLOW AND POWER IN THE PUMP SYSTEM

To determine the operating point, it is necessary to define the curve of the pressure-flow dependence of the pump and the hydraulic pipe system. Measured values of pressure and flow can be used to define following hydraulic characteristic: pump speed (n) vs pump flow rate (Q), pressure (p) vs outlet pump power (P). Mathematically relations describing the pump speed impact on the system flow rate, pressure and power are given by (1) [2, 3].

$$Q = Q_n \left(n / n_n \right)$$
$$p = p_n \left(n / n_n \right)^2 \qquad (1)$$
$$P = P_n \left(n / n_n \right)^3$$

In the previous equation nominal values are indexed with n. Hydraulic power of the centrifugal pump can be determinate using measured values of the system's pressure and flow by following equation:

$$P = 100 Q \cdot p \qquad (2)$$

where: Q –water flow in l/s, p –pressure in bar.

EXPERIMENTAL SETUP

At the Laboratory for Process Engineering at Faculty of Technical Sciences Cacak, pump system was implemented for the teaching and scientific research purposes. Figure 1 shows the pump system, while Figure 2 shows the diagram of its hydraulic part. The maximum system pressure that can be make is 6 bar, with a maximum flow rate of 5 l/s.

The system consists of a 400 liters capacity circulation tank (1) from which the system is supplied with water. The pipe system is made with 6/4" PVC pipes, which are connected by compatible couplings and valves. The pump unit (3) consists of a centrifugal pump ran by induction motor. Pump is located below the water level in the tank. For water movement makes six section centrifugal pump *Grundfoss* type CM10-6 A-R-I-E-AQQE F-A-A-N was used [4]. The pump nameplate data are following: flow rate Q = 10 m^3/h (2.78 l/s), head H = 78.3 m (pressure ≈7.7 bar), speed of rotation n = 2900 min^{-1} and MEI ≥ 0.52. The pump is run by a three-phase 4 kW induction motor, with power factor of 0.87-0.84, and efficiency of 85.5% (IE2 class).

In order to obtain different system flow and pressure (i.e. pump speed of rotation) Danfoss VLT Aqua Drive FC 202 frequency converter [5] was used. This frequency converter was designed for operation in pumping systems for water supply. Speed reference was realized by a potentiometer placed on the door of electrical cabinet (9). The frequency converter with other electrical control equipment is located in the cabinet (9).

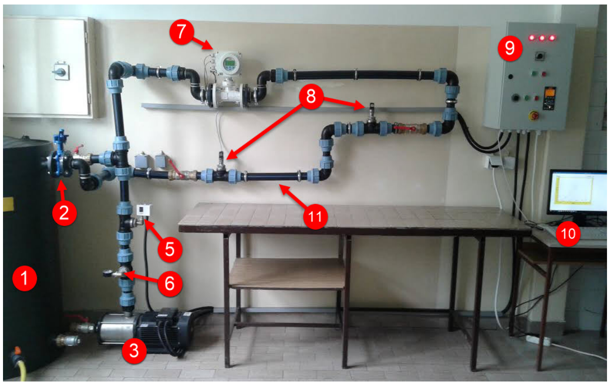

Fig. 1. *Components of the pump system*

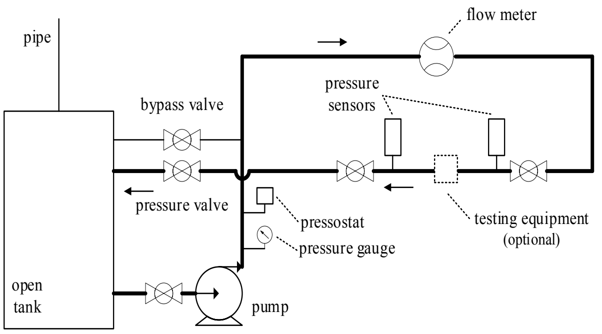

Fig. 2. *Hydraulic diagram of the pump system*

For measurement of water flow in the pipes the electromagnetic flow meter (7) was used. This flow meter can measure the flow rate in the range of 0 – 60 m^3/h (16.6 l/s). Flowmeter provides a 4 – 20 mA current signal at its output. In addition, the flow meter has an LCD display on which the current values of flow can be read.

For pressure measurement, *Danfoss* two sensors (8) was used. Measuring range of this type of sensor is 0 – 10 bar with current output signal in the range of 4 – 20 mA. Between these two pressure sensors (11) equipment for testing can be installed (turbine - PAT system, valve, etc.). In this paper testing of hydraulic components was not considered. Therefore, between two pressure sensors only a pipe was installed and sensors provides identical value of the pressure. In that sense measurement of one pressure value is used for determination of the system and pump characteristics.

Current signals from the flowmeter and pressure sensors are measured by using NI

6009 acquisition card and its analog inputs. All current signals from sensors are converted into a voltage signals. The acquisition card is galvanically isolated from the computer. The measured signals are processed in LabVIEW software. In this way measured signals are numerically and graphically presented. Functions $p=f(Q)$ and $P=f(Q)$ are graphically presented using this software.

Pressure valve (2) is used for changing the position of the working point of system. In this way the characteristics of pump and pipe system was measured. The pressure valve has a handle with marked positions.

From the safety reasons pressure switch (5) was used. Pressure limit is necessary to avoid pipe damage or damage of any other element in the system. If the pressure exceeds permitted value, pressure switch will react and turn off the induction motor. Beside pressure sensor, analog barometer (6) was used for visual monitoring of pressure value.

EXAMPLES OF MEASUREMENT RESULTS

One of the base characteristics of pump system is pressure (or head) depends on the flow. Each pump system has an operating point, which can be determined as the cross section of the two characteristics: *p-Q* characteristic of hydraulic system and *p-Q* characteristic of pump.

Figure 3 shows the pressure values depending on the water flow in the system. In this way, the characteristics of the centrifugal pump at different speeds of rotation (motor frequency) are obtained. The measuring of these characteristics was carried out by gradually closing the pressure valve for each frequency. In this way, the pressure in the system was increase, with decrease of flow. For example, at a frequency of 50 Hz, with the gradual closing of the pressure valve, the flow rate decreased from 4.4 to 3.2 l/s with the pressure increase from 0.7 to 6.2 bar.

Figure 4 show the results of measurement for *p-Q* characteristic of hydraulic system. These characteristics are obtained for set precept of closing (position) of the pressure valve, with the gradual change in the pump speed (i.e., the motor frequency change). As expected, the minimum pressure (0.5 bar) and the maximum flow rate (4.4 l/s) was realize with the fully open of valve. If the valve gradually closes, the pressure increases in the pipe. Thus, at a 90% valve closed, water flow was reduced to 0.6 l/s, and pressure was increased to 6.3 bar.

The operating point of the hydraulic system is obtained by cross-section of two characteristics from Figures 3 and 4. In fact, the operating point will determine the pump speed (frequency) and the pressure valve close position.

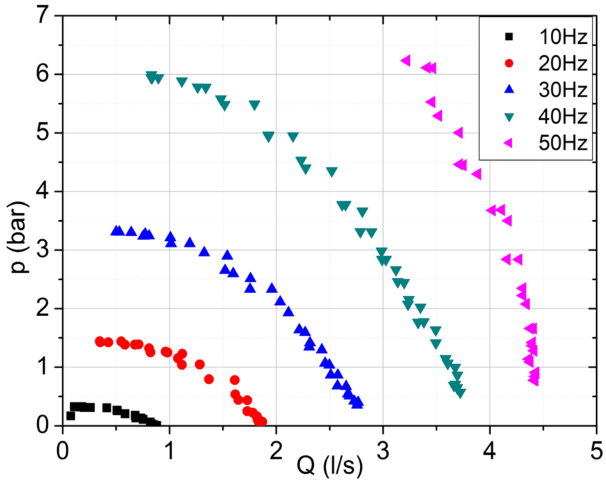

***Fig. 3.** Pressure-flow characteristic of centrifugal pump for different speeds of rotation (motor frequency)*

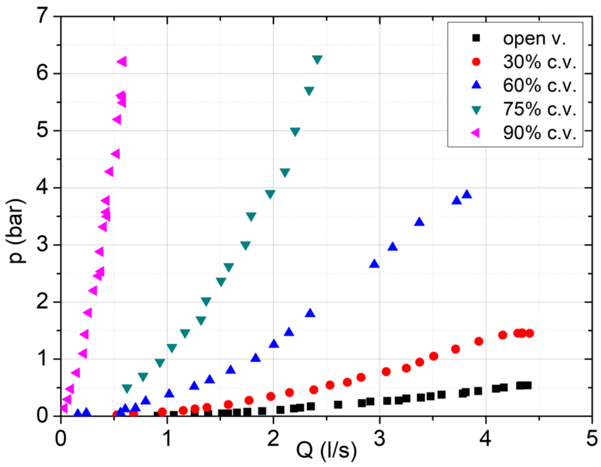

***Fig. 4.** Pressure-flow characteristics of hydraulic part of the system for different openness of valve*

Values of hydraulic power of the centrifugal pump for different speeds of the pump rotation (motor frequency) are shown on figure 5. Thus, the *P-Q* characteristics for the used pump are obtained. Values of power are calculate using equitation (2), pressure and flow values are given in Figure 3. It is noticed that the pump power is greater at higher speeds. Also, the measuring show that the maximum power is realized for the singular value of flow. The maximum hydraulic powers for specific frequencies are: 13.6 W (0.51 l/s) at 10 Hz; 137.5 W (1.1 l/s) at 20 Hz; 456.4 W (1.95 l/s) at 30 Hz; 1097.3 W (2.52 l/s) at 40 Hz; 2115.8 W (3.46 l/s) at 50 Hz. Measuring the maximum power at 50 Hz was not possible due to limited value of pressure in the pipe system.

Figure 6 shows the power of the hydraulic system for different pressure valve close position. Values of power are calculate using equitation (2) and values of the pressure and flow given in Figure 4. Power of the hydraulic system exponential rise with flow. Maximum power (1500 W) was achieved at 75% of pressure valve close position and flow rate of 2.4 l/s. A significantly higher power can be achieved with a 90% closed pressure valve, but the limitation of pressure does not allow the power more than 365 W.

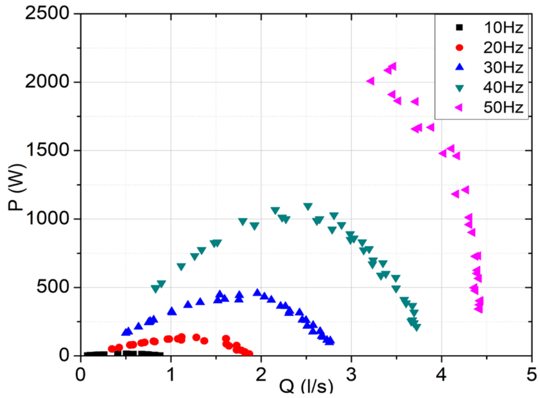

Fig. 5. *Power-flow characteristic of centrifugal pump for different speeds of rotation (motor frequency)*

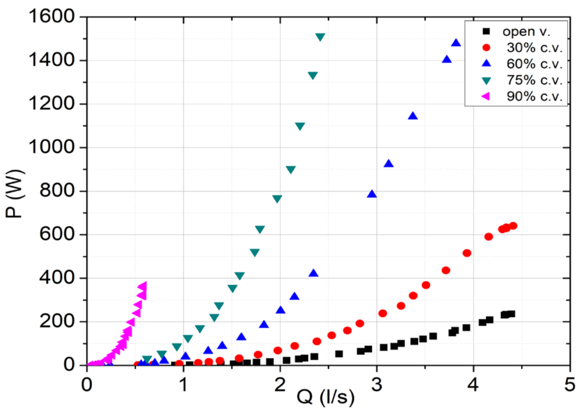

Fig. 6. *Power-flow characteristics of hydraulic part of the system for different pressure valve close positions*

CONCLUSION

The paper presents the realized educational setup for measuring the characteristics of the pump system. The used equipment and the results of measured pressure and water flow in the system are described. Working on this system allows:

- determination the characteristics of a centrifugal pump and the pipe system,
- measurement of flow and pressure using the sensors,
- determination of the operating point of the pump system,
- relation between pump rotation speed and pump efficiency or hydraulic power,
- use the frequency converter for optimal operation of the pump system by adjusting the operating point, etc.

In further work the pump system can be used for the input (electrical) power measurement, with purpose to determine the efficiency of motor-pump system. Also, measurements of *p-Q* characteristics of individual valves or turbine can be performed.

ACKNOWLEDGEMENTS

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