EXPERIMENTAL DETERMINATION OF THE STEPPER MOTOR-CONTROLLED BUTTERFLY VALVE CHARACTERISTICS

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Abstract
This paper presents the procedure for experimental determination of the characteristics of a butterfly valve implemented in the pump system realized in the Process Engineering Laboratory at the Faculty of Technical Science in Cacak. The mechanical valve installed in the pump system has been upgraded by installing a stepper motor instead of a lever. LabVIEW software was used for stepper motor control and graphical visualization of the stepper motor position (valve angle) and pressure. Experimental results of pressure for different positions of the valve, as well as the diagram p=f(n) are shown. Using the obtained measured values of pressure and angle, approximation function of the upgraded butterfly valve was calculated.

Keywords: pump system, butterfly valve, LabVIEW, measurement.

INTRODUCTION

Laboratory setup for measuring the basic pump system characteristics, implemented at the Laboratory for Process Engineering at the Faculty of Technical Sciences in Cacak, was used to determine the characteristics of the butterfly valve. The pump system with its characteristics has been described in detail in [1].

The modification of the butterfly valve is presented in this paper. Acquisition application is described as well. Pressure-angle characteristics of the modified butterfly valve was measured and graphically presented. Using the obtained measured values of pressure and angle, approximation function of the butterfly valve was calculated.

Determination of the approximation function for the valve will be in use for further testing and research where the pressure in the pump system must be kept constant, or an exact pressure in the system must be obtained.

BUTTERFLY VALVE UPGRADE

In the pump system, described in [1], butterfly valve with a hand lever has been implemented. This valve is Danfoss type VFY-WH [2]. The valve nameplate pressure data is 16 bar at 20 °C. The butterfly valve has a hand lever with 90° rotation angle, cup of the lever has ten teeth with 10° module. That means that the valve can achieve ten positions, which is not precise enough for our system. This problem has been solved with valve modifications.

Cup of the lever and the lever have been replaced with a stepper motor, a shaft coupling, a motor holder and an inductive proximity limit switch sensor. Stepper motor (SM86HS45) [3] has 4.5 Nm torque, and 200 steps per rotation. Stepper motor torque was determined using torque wrench (3.5 Nm). Stepper motor is controlled by micro-stepping controller [4] which has 1/16 micro-stepping option. This controller increases number of steps per rotation from 200 to 3200 (resolution is 0.1125°).

This was a simple and cheap way to make the butterfly valve acceptable. The upgraded motor-controlled butterfly valve is shown on fig 1. Pulse and direction signals are connected to digital input/output of the NI 6001 acquisition card, as well as an inductive proximity limit switch sensor.

Modifications on the pump system hardware require changes in the LabView application. Changes in application are:

- digital output signals for pulse and direction control for stepper motor controller are defined,
- digital input for Home limit sensor has been added,
- pulse-direction control has been established,
- Home switch indication has been added,

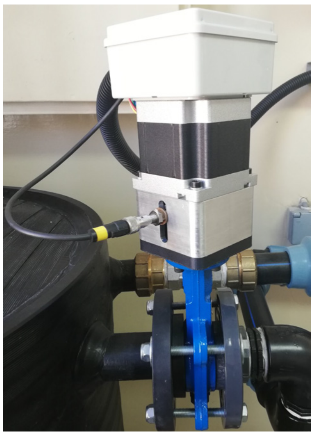

Fig. 1. *Upgraded butterfly valve*

EXPERIMETAL TESTING PROCEDURE

Before starting the experimental testing, the following procedure must be done. Close the valve to fully closed – Home switch indicator is on. Open valve step by step until the Home switch indicator turns off. When the Home switch indicator turns off the position of the valve is zero - 0°. Reset the number of steps to zero. Open the valve to fully open - 90° (800 steps must be sent to motor controller).

This procedure is important for the safe motor start and resetting past valve position. When the valve establishes the desired position, the pump motor can start.

Start the motor by adjusting the frequency on the inverter to 30 Hz. Close the valve on one side by 5 steps per cycle (0.56°) and record the value of pressure in the system. Open the valve 5 steps per cycle until fully open.

Repeat the last two steps for the maximum pressure in the system of 3 bar, 2 bar and 1 bar.

MEASURING RESULTS

Main mechanical butterfly valve characteristic is the possibility of closing of the valve in both directions fig 2. For safety reasons starting position of the butterfly valve is fully open, for in this position there is no pressure in the pump system. Fully open position of the valve is the neutral position (0). In relation to this position, the following manipulations were performed:

1. The valve was being closed in the right direction, until the pressure reached 3 bar (point 1, in Fig 3 black line);
2. When the pressure reached 3 bar, the direction was changed (left direction) and the valve was being opened until the valve reached the neutral position (0); Then the valve was being closed in the left direction until the pressure reached 3 bar (point 2, red line);
3. The valve moving direction was changed (from left to right) and the valve was being opened until the valve reached the neutral position, after which the valve was being closed until the valve reached the position where the pressure was 2 bar (point 3, blue line);
4. Neutral position of the valve has been established by changing the direction of rotation (point 0, cyan line);
5. Next step was to move the valve in the right direction until the pressure of 1 bar was established (point 4, yellow line);
6. Last step was to move the valve back to the neutral position (point 0, magenta line);

Fig. 2. *Both directions closing valve*

The measuring results are shown on the following figure.

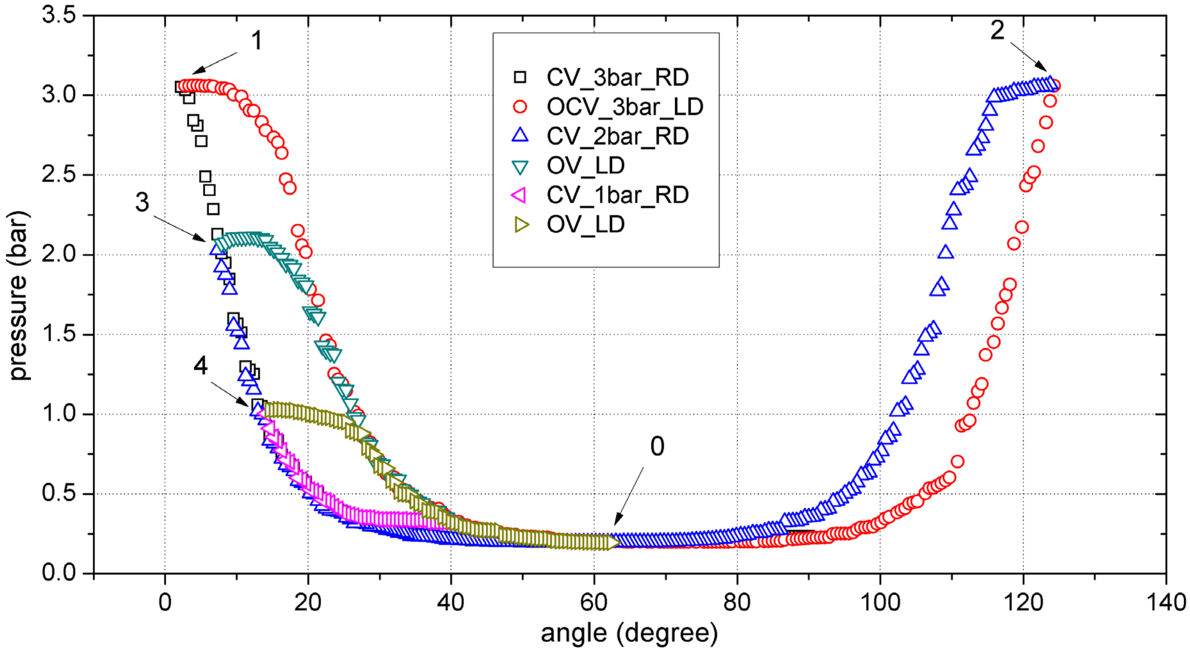

Fig. 3. *Measuring results*

Obtained figure shows:

– Butterfly valve characteristic is nor linear nor uniquely defined.
– Approximately 2/3 pressure change (ΔP=2 bar, from 0.5 bar do 2.5 bar) was achieved in 1/4 valve angle change ($\Delta\alpha$=15.5°, the maximum angle change from neutral position to totally closed valve in one direction is 62°; the reason why this angle is not 90° is mechanical limitation inside the valve - rubber O-ring around the blade of the valve).
– By changing the direction of rotation (opening or closing) the valve hysteresis occurs, but the curve remains unchanged, just translated (there is 11.7° idling).

These observations make this element difficult to use for continuous pressure control, which is one of the tasks of this research.

By analyzing the measured results, the following conclusions were made:

– Obtained results are repeatable during opening and closing of the valve (the curves match each other).
– If the curves obtained from closing the valve translate to the left by 11.7°, they will be the same as the curves obtained during opening of the valve.
– Using the measured point set, interpolation polynomial could be made.

The analytical form of this function is as follows:

$$\alpha = g(p) = \frac{\left(0.03186 \cdot p^2 - 2.204 \cdot p + 48.78\right)}{p + 9.577} \quad (1)$$

Measured results with calculated interpolation function are shown on the following figure.

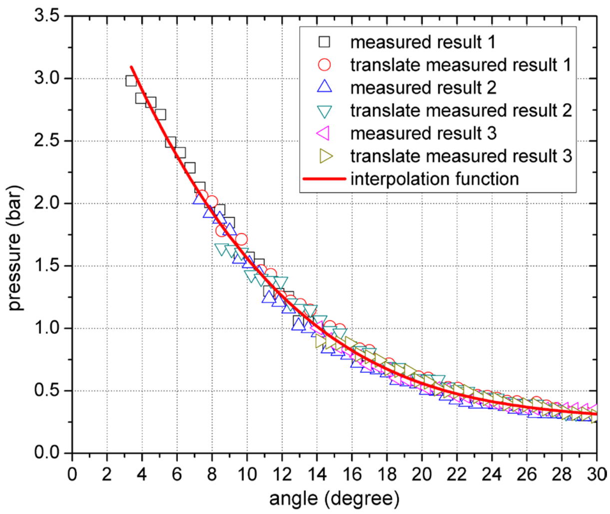

Fig. 4. *Measured results with calculated interpolation function*

However, the inverse interpolation function, which defines the angle α for the desired pressure in the system, provides information that is of more value than the previous function.

Measured values and the calculated inverse interpolation function (in the case of closing the valve) are shown on the next figure.

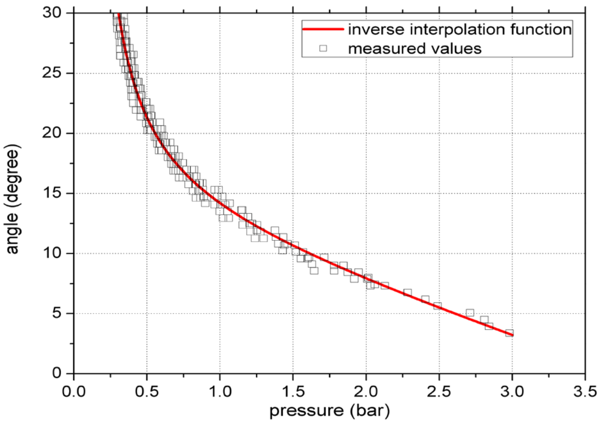

Fig. 5. *Measured results with calculated inverse interpolation function*

$$\alpha = f_1(p) = \frac{\left(-3.997 \cdot p^2 + 14.13 \cdot p + 3.027\right)}{p - 0.07346} \quad (2)$$

The function of opening of the valve (in range 0.5-2.5 bar) is defined by:

$$\alpha = f_2(p) = f_1(p) + 11.7 \quad (3)$$

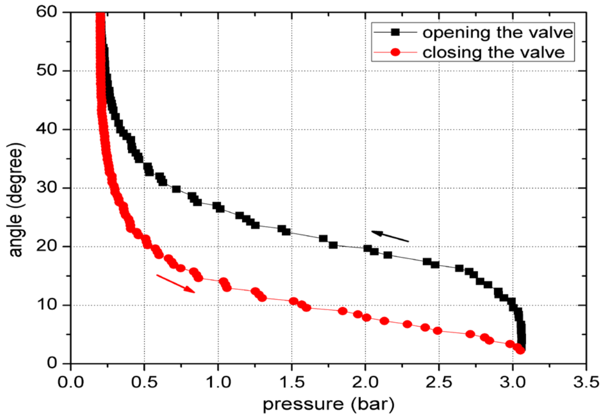

Fig. 6. *Function of the valve opening ang closing*

It is possible to calculate the needed step angle of the valve for the desired pressure using the described procedure. For this procedure it is necessary to know the exact position of the valve, current pressure in the system.

There are 4 distinct cases:

A. Closing the valve when the valve has previously been closed
B. Opening the valve when the valve has previously been opened
C. Closing the valve when the valve has previously been opened
D. Opening the valve when the valve has previously been closed.

Control algorithm has the following structure:

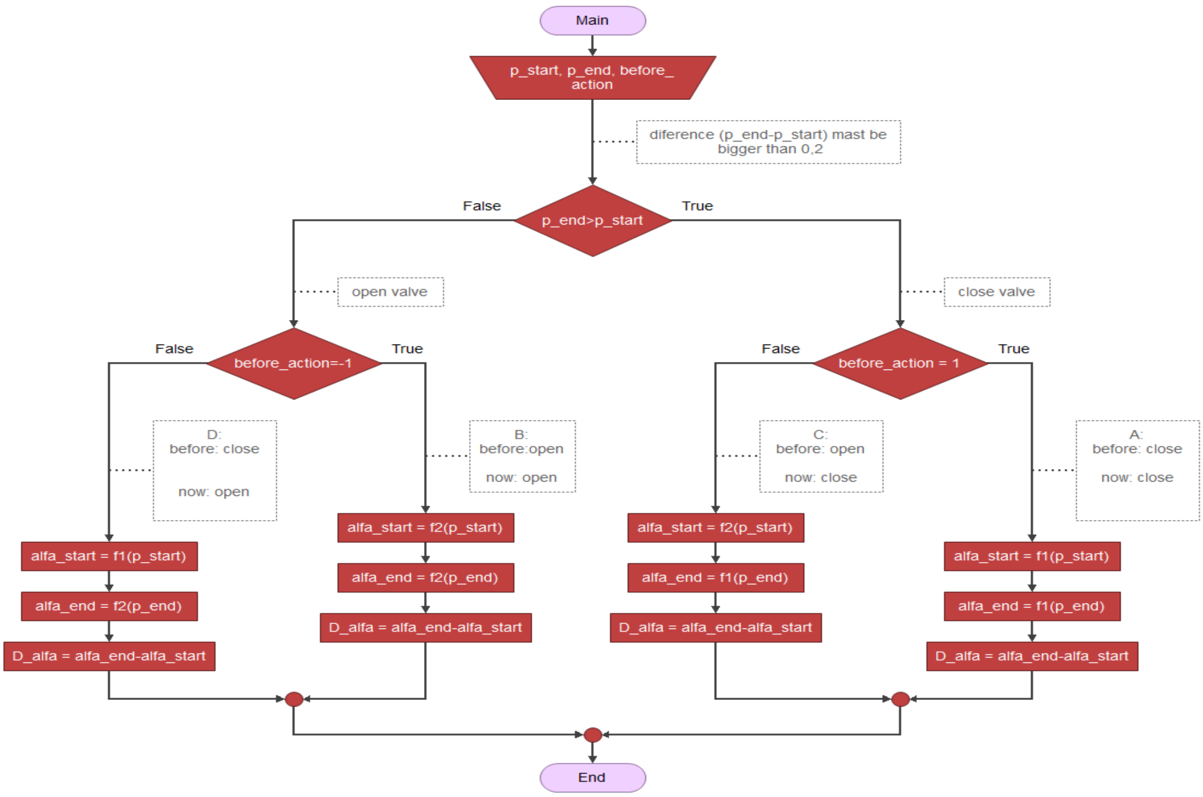

Fig. 7. *Control algorithm*

Using the previous algorithm, by closing and opening the valve, it is possible to achieve the desired pressure in the system. To achieve the desired pressure in the system the only prerequisite is to know the current value of the pressure in the system.

CONCLUSION

In the paper, the procedure for the butterfly valve characteristic determination is described. The valve, which was constructed for 10 different positions, is used. The entire range of pressure change is achieved using only 3 positions of the valve, so the valve characteristic was not possible to measure.

For moving the valve, stepper motor in micro-stepping mode was used. The stepper motor enables over 1000 different positions, which provides almost continuous valve rotation (provided by the minimum rotation angle of 0.1125°). Dependency of pressure against angle of rotation is obtained by measuring. Difference between curves of valve closing and opening was spotted, in other words, existence of hysteresis was determined.

Interpolation function of valve closing was calculated using the measured values. Because of the similarity of the curves of valve closing and valve opening, the same interpolation function was used for both.

Algorithm, which enables automatic pressure regulation by following specific actions on the valve, was created.

All measurements were conducted at the frequency of 30 Hz. Determination of valve characteristics in the frequency range of 10-50 Hz is planned in the further research. Goal of the research is acquiring a unified interpolation function that could be used for all working regimes in which the pump system works. A completely automated system could be achieved using the unified interpolation function, by manipulating the valve into position that sets the system into the desired duty point on the characteristic p=f(q). Second part of the research will be dedicated to reducing the hysteresis of the valve by replacing the elastic coupling with a more rigid coupling.

ACKNOWLEDGEMENTS

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