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DETERMINATION OF FREQUENCY CHARACTERISTICS OF A PROPORTIONAL PRESSURE VALVE BY STEP RESPONSE

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Abstract. *The paper presents a method for determining frequent characteristics of proportional hydraulic pressure valve by experimental and calculating method. The method is based on measuring the response of the system driven by step function at the input and it is applied to electro-hydraulic pressure control valve. The measurement has been done by the system for data acquisition based on a PC, whereas the calculation and obtainment of frequent characteristics have been done by MATLAB.*

Key words: *proportional hydraulic pressure valve, frequency characteristics, step input, MATLAB*

1. INTRODUCTION

Frequency method is widely used for analyzing and synthesizing engineering systems. It is well known that this method can be applied to studying the systems of different physical nature (electrical, mechanical, hydraulic, etc.) and that it enables dynamic characteristics of these systems to be studied, too. In order to apply this method in actual practice, it is necessary to identify the frequency function of system transfer because of the amplitude and phase frequency characteristics. This paper presents the results obtained for proportional pressure valve which is often used in modern electro-hydraulic systems. Its properties have a relevant influence on the quality and reliability of the system, so identification of frequency characteristics is useful not only in designing phase but in the system application as well. The measurement and calculation have been done by acquisition system and MATLAB programme.

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2. Theoretical Setup

The algorithm for defining frequency function of system transfer $W(j\omega)$ is based on the following characteristic of its complex transfer function $W(s)$:

$$W(s) = L\left(\frac{dy_h(t)}{dt}\right) \tag{1}$$

where $y_h(t)$ is the system response ($y_h(0_+) = 0$) to the unit step input [1,2].

If the following is assumed for step response $y_h(t)$:

$$\lim_{t\to\infty} y_h = const \tag{2}$$

then frequency transfer function can be written [1] in the following form based on (1):

$$W(j\omega) = \int_0^\infty e^{-j\omega t} \cdot dy_h(t) \tag{3}$$

If integral (3) is approximated by the sum by final increment $\Delta y_h(t)$ instead of differential $dy_h(t)$ and if the range of integration is limited to the interval of increment, in accordance with (2), the following is obtained:

$$W(j\omega) = \sum_{n=1}^{N} \Delta y_h(t_n) \cdot e^{-j\omega t_n} \tag{4}$$

where N is total of sampling points $y_h(t)$ in which the increment $\Delta y_h(t_n)$ is calculated, where the increment is

$$\Delta(t_n) = \Delta\, y_h(t_n) = y_h(t_n) - y_h(t_{n-1}) \tag{5}$$

Furthermore, series of points of frequency axis ω_1, ω_2,..... ω_M is sampled in order to define the value of frequency transfer function $W(j\omega_1)$, $W(j\omega_1)$,....., $W(j\,\omega_M)$.

Matrices are used for presenting complex transfer functions in sampling points in order to do the calculation by a digital computer.

Using (4), the matrix equation is written as:

$$\begin{bmatrix} W(j\omega_1) \\ \vdots \\ W(j\omega_M) \end{bmatrix} = \begin{bmatrix} e^{-j\omega_1 t_1} \cdots & e^{-j\omega_1 t_N} \\ \vdots & \\ e^{-j\omega_M t_1} \cdots & e^{-j\omega_M t_N} \end{bmatrix} \begin{bmatrix} \delta(t_1) \\ \vdots \\ \delta(t_M) \end{bmatrix} \tag{6}$$

i.e.,

$$\overline{W} = E \cdot D \tag{7}$$

In order to determine complex vector $\overline{W}$ having length M (the values of transfer function $\overline{W} = [(j\omega_1)\dots(j\omega_M)]^T$) by means of matrix equation (7), it is necessary to experimentally define the vector D having length N ($D = [\delta(t_1)...\delta(t_n)]^T$) and to calculate complex matrix E whose dimensions are (MxN). It depends on the vector of sampling points $T=[t_1...t_n]$ and frequency vector $\Omega=[\omega_1 ... \omega_i]$.

Matrix E and multiplication (7) are generated in this study by means of MATLAB programme in PC.

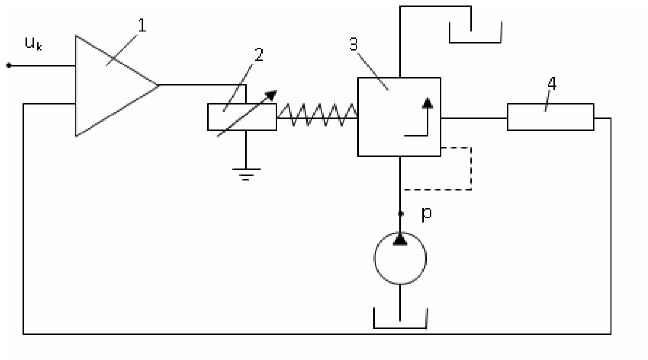

Fig. 1. Proportional pressure servo valve

3. MEASUREMENT AND CALCULATION

The method presented in the paper has been applied to determination of frequency characteristics of the system composed of a proportional electro-hydraulic pressure valve and accompanying elements. The electro-hydraulic servo system is presented in Fig. 1. It consists of one hydraulic pressure control valve (3), a proportional electro-magnet (2), an electronic amplifier (1) and displacement sensor (4).

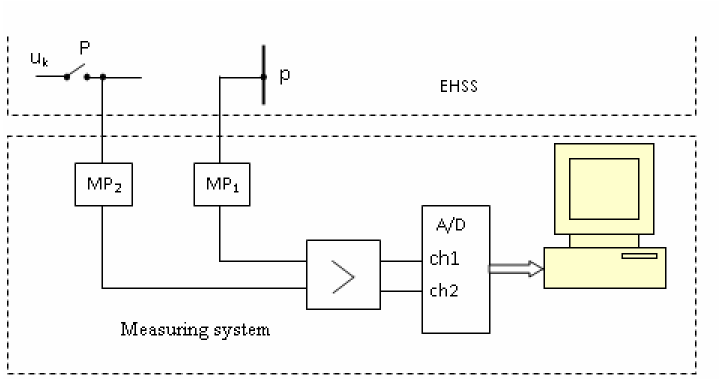

Fig. 2. Measuring system and connection to proportional valve

Input signal $U_u(t)$ (DC voltage 0-10V) is applied to amplifier input (1) which provides current signal to proportional magnet (2) of electro-magnetic valve (3). Hydraulic pressure p at the valve (3) is obtained in accordance with the displacement of magnet anchor (i.e. in proportion to current intensity, i.e. the magnitude of input voltage). The reached displacement is measured by displacement sensor (4) and the signal feedback applied to the amplifier input (1) is provided, so dynamic properties related to the feedback system are achieved.

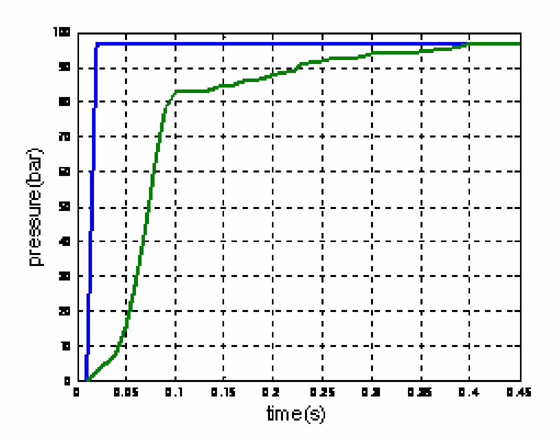

Fig. 3. Input voltage and preassure response

Input signal (U_u) and output signal (p) of the proportional valve are measured to determine frequency characteristics. The measuring system (Fig.2) consists of measuring convertors MP_1 and MP_2 of mesuring amplifier and acquisiton system which records the change of these signals. Heaviside step function is formed by momentary closing of the switch P. Time-dependent system response to the step input (Fig. 3) is obtained by sampling interval Δt, and it changes like total number of sampling points N. The results obtained by sampling interval of 0.01 sec and for $N = 45$ are shown in Figure 3.

Increment vector D is identified based on the response to the step input presented in Figure 3. Numerical file holds the data and they are used for calculating frequency characteristics. The programme developed in MATLAB reads the file containing data D, generates matrix E, vector Ω, and calculates the complex vector W in accordance with equation (8).

MATLAB programme has useful functions which make it easy to obtain frequency response of linear time-invariant system. Traditional approach to frequency analysis uses Bode diagrams to determine magnitude and phase changes depending on frequency logarithm [3-5].

Amplitude frequency characteristic is defined by means of *abs* MATLAB while the magnitude is defined in decibels on the basis of the well known definition:

$$A = 20 \log \frac{A_n}{A_0} \tag{8}$$

where $A_n = abs(W(j\omega))$ and $A_0 = A_n(0)$.

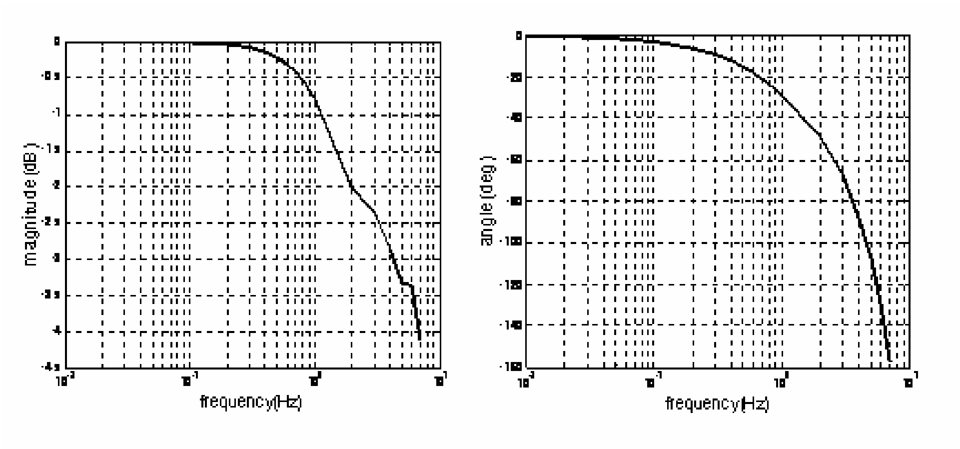

Fig. 4. Amplitude and phase frequence charactheristics

Phase frequency characteristic is defined by MATLAB function *angle*. Amplitude and phase frequency characteristics for the above described proportional valve are shown in Figure 4. It can be seen that the boundary frequency for the valve is over 4Hz (magnitude -3dB), which is satisfying enough for application of these proportional valves which are expected to be robust and reliable during operation. Therefore, the designers get important information on dynamic characteristics of these valves and their application.

4. CONCLUSION

The paper presents the results of experimental and calculating method which identifies frequency characteristics of electro-hydraulic proportional pressure valve. The method is automated by a PC which is used for data acquisition, calculation and presentation of diagrams by means of MATLAB programme. The diagrams obtained this way enable engineers to understand dynamic behaviour and stability of the analysed system.

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ODREĐIVANJE FREKVENTNIH KARAKTERISTIKA PRPORCIONALNOG VENTILA PRITISKA KORIŠĆENJEM ODSKOČNOG ODZIVA

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U radu je prikazan jedan postupak za određivanje frekventnih karakteristika proporcionalnog hidrauličkog ventila pritiska primenom eksperimentalno računskog postupka. Postupak se zasniva na merenju odziva sistema pobuđenog odskočnom funkcijom na ulazu i primenjen je na elektrohidraulički ventil za regulaciju pritiska. Merenje je obavljeno sistemom za akviziciju podataka baziranom na PC računaru, a računski deo i dobijanje frekventnih karakteristitka urađeno je programom MATLAB.

Ključne reči: *Proporcionalni hidraulički ventil pritiska, frekventne karakteristike, step pobuda, MATLAB*