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DYNAMIC PROPERTIES OF PRESSURE COMPENSATED PUMP

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Abstract: *The aim of the study is to evaluate the dynamic properties of a variable displacement pump. It is a pressure compensated axial piston pump with swash plate. The dynamic properties will be evaluated for transient response. The transient response will be induced by the rapid closure of the directional valve located at the pump outlet. The consequence of the directional valve rapid closure is the regulation of the displacement. The main motivation of this paper is to determine, if the pump speed and the set pump displacement affect the control time in and the overshoot. A methodology for measuring the dynamic properties during the transient response is presented in this paper. The experimental circuit used to measure the dynamic properties is described. Subsequently, the time dependence of the pressure at the pump outlet is evaluated when the directional valve at the pump outlet is rapidly closed. The measurements are then used to evaluate the overshoot and the control time in as a function of the pump speed and the pump relative displacement. The results will be further used to create a mathematical model of a pressure compensated pump.*

Keywords: Dynamic properties, pressure compensated pump, overshoot, control time in.

1. Introduction

Pressure compensated pumps are used in many industrial applications. Pressure compensated pumps are used in energy saving systems as shown in (Vašina et al., 2018). The pressure compensated pump works on the following principle. When the pressure in the circuit reaches to the value set on the pressure compensator, the pump displacement is regulated to the minimum value. From this perspective, two basic states can be defined for the pressure compensated pump. In the first state, the pressure at the pump outlet has not reached the value, which is set on the pressure compensator. The pump displacement is maximal and the pump generates the maximal flow rate. In the second state, the pressure at the pump outlet has reached the value, which is set on the pressure compensator. The pump displacement is minimal and the pump generates the minimal flow rate. This minimal flow rate covers the flow losses of the pump to maintain a constant pressure at the pump outlet. If there is a sudden increase in hydraulic resistance in the circuit, the pressure will also increase. This can be demonstrated, for example, by the rapid closure of the directional valve at the pump outlet. The decrease of pump displacement occurs over a certain settling time. In the meantime, the pressure at the pump outlet also rises above the value, which is set at the pressure compensator. In terms of the transient response, it is desirable to avoid pressure peaks in the system and to keep the settling time as short as possible. The dynamic properties of a pressure compensated pump are examined by (Mondal et al., 2022; Mondal et al., 2018). They investigate how the closing speed of the valve at the pump outlet affects the pressure peak. From their results, it can be observed that as the closing time increases, the pressure peak in the system decreases, but the settling time increases. Subsequently, (Saleh et al., 2006) examine whether the pump speed has an effect on overshoot and settling time. They concluded that as the pump speed increases, the overshoot increases and the settling time decreases. The knowledge of these properties is important for the development of the mathematical model of pressure compensated pump.

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2. Methods

An experimental circuit was designed and assembled to measure the dynamic properties of the pressure compensated pump. A scheme of the circuit is shown in Fig. 1. The main part of the circuit is the pressure compensated pump (HP+PC). The pump has a set screw, which can be used to limit the displacement. The source of mechanical energy for the pump is the electric motor (M). The electric motor speed is control by a frequency converter (FC). A relief valve (RV) is connected in parallel to the pump to ensure the safety function. The pump is loaded by a proportional relief valve (PRV). A directional valve (DV), which is located before the proportional relief valve, is used to close the pump outlet. In order to keep the oil viscosity constant, a cooler (C) is placed in the circuit. A temperature of 53 °C ± 1 °C is maintained in the circuit. The oil purity is maintained by the filter (F). The circuit is further contained a pump outlet pressure sensor (PS), a flow rate sensor (FS), a speed sensor (SS) and a temperature sensor (TeS). The tank (T) is a reservoir for the oil.

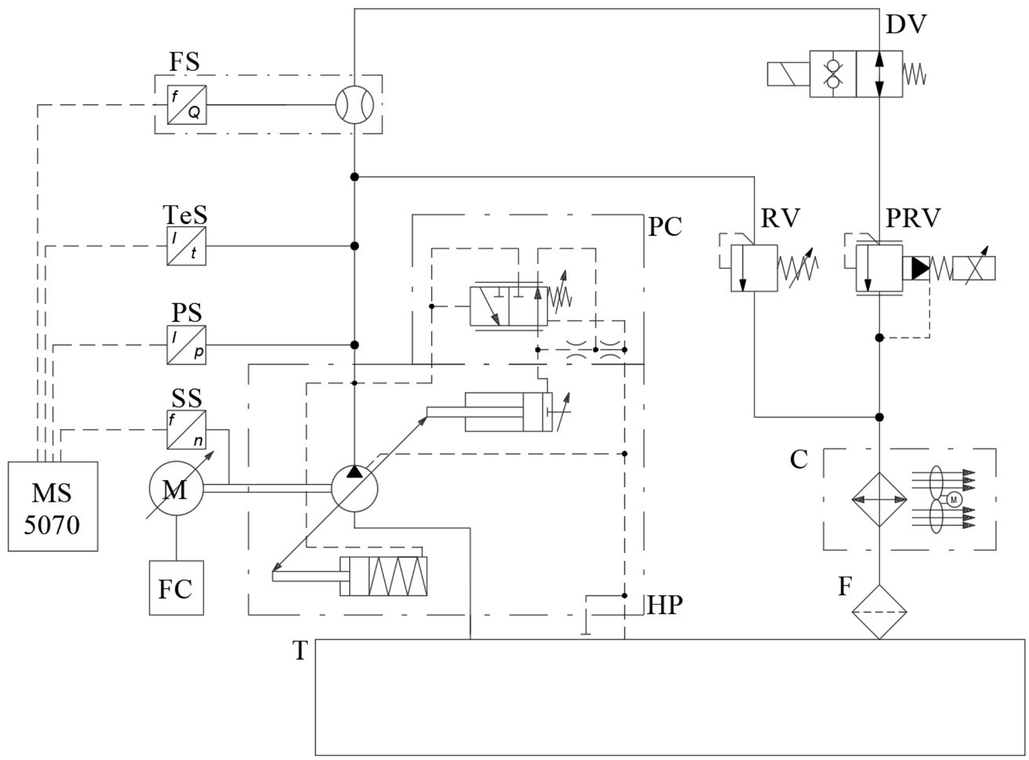

Fig. 1: Experimental circuit scheme.

Measurement procedure

The relief valve (RV) was fully open. The directional valve (DV) was closed and at the pressure compensator (PC) was set the maximal pressure. The speed of electric motor (M) was set to value n = 1 500 min^{-1}. The pressure at the relief valve was set to value p_{RV} = 250 bar. The pressure at the pressure compensator was set to value p_{PC} = 110 bar. Then the directional valve (DV) was opened. The pressure at the proportional relief valve was set to value p_{PRV} = 40 bar. Then, time recording of the variables was performed with a time of 3 s and a sampling rate of 0.0001 s. At time t = 0.5 s, the directional valve (DV) was closed. This process was repeated for pump speed n = (1 250; 1 000; 750; 500) min^{-1} and pump relative displacement β = (0.75; 0.50; 0.25). The pump relative displacement β is the ratio between the set pump displacement and the maximal pump displacement.

3. Results

If the directional valve is closed rapidly, a transient response will occur. The result of the transient response is a pressure peak, which is determined by the kinetic energy of the oil, the oil bulk modulus, the oil viscosity, etc. (Bureček et al., 2015; Hružík et al., 2017). In this research, the time dependencies of pressure

p at the pump outlet during the rapid closure of the directional valve were evaluated. The control time in t_{SE} was evaluated from each time dependence. The control time in t_{SE} is the time, which is elapsed from the moment, when the directional valve is closed to the moment, when maximal pressure is reached at the pump outlet, see (RE 92 712). Subsequently, the pressure peak p_{max} was evaluated from each time dependence. Furthermore, the time dependencies of pressure p at the different pump speeds n are shown in Fig. 2a and also the time dependencies of pressure p at different pump relative displacements β are shown in Fig. 2b. In Fig. 2a is shown an example of the control time in t_{SE} (s) and pressure peak p_{max} (bar) evaluation. Subsequently, the overshoot x (%) was evaluated for each pressure peak p_{max}, according to:

$$x = \frac{p_{max}}{p_{PC}} \cdot 100 - 100, \tag{1}$$

where p_{max} is the pressure peak (bar) and p_{PC} is the pressure set at the pressure compensator (bar).

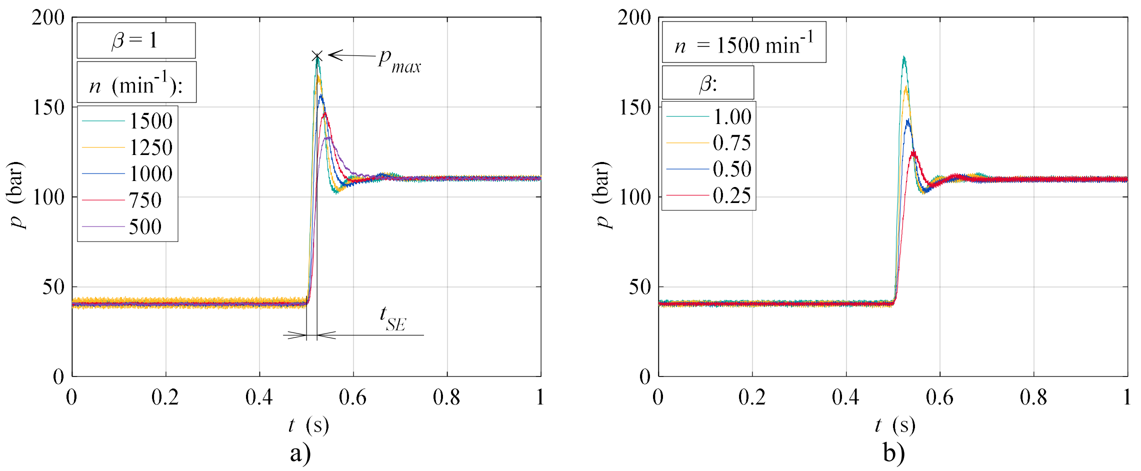

Fig. 2: Time dependencies of pressure p:
a) for different pump speeds n, b) for different pump relative displacements β.

The dependencies of the control time in t_{SE} on the pump speeds n at the different pump relative displacements β were evaluated, see Fig. 3a. Subsequently, the dependencies of overshoot x on the pump speeds n at the different pump relative displacements β were also evaluated, see Fig. 3b.

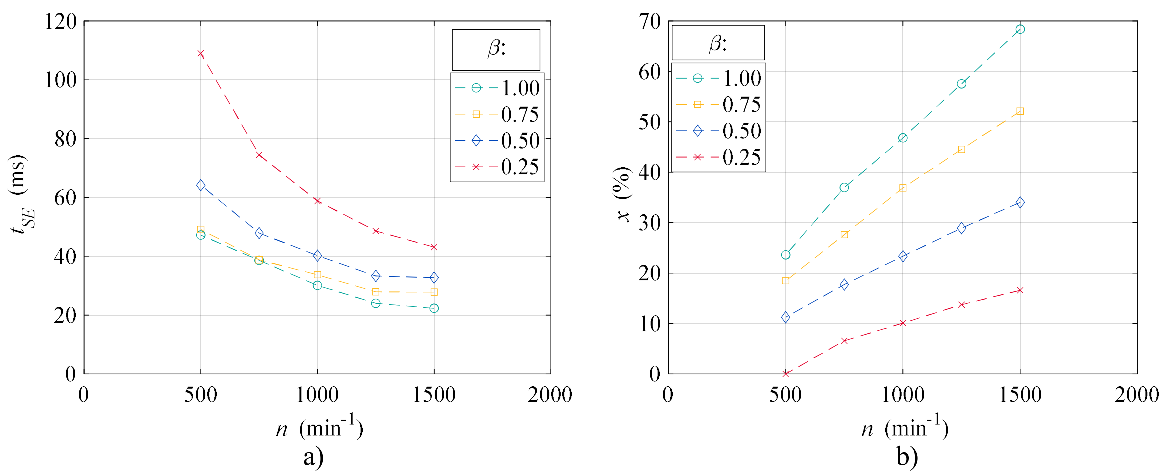

Fig. 3: Dependencies on the pump speeds n at the pump relative displacements β:
a) of the control time in t_{SE}, b) of the overshoot x.

Fig. 3a shows the control time in t_{SE} decreases with an increasing pump speed n and the control time in t_{SE} decreases with an increasing pump relative displacement β. Fig. 3b shows the overshoot x increases with an increasing pump speed n and the overshoot x increases with an increasing pump relative displacement

β. These evaluated control times in t_{SE} can be burdened with a deviation of up to 3 ms, which is due to the effect of different closing times of the directional valve at different flow rates Q.

In Tab. 1 are evaluated values of control time in t_{SE} and overshoot x at different pump speeds n and different pump relative displacements β.

	n = 1 500 min^{-1}		n = 1 250 min^{-1}		n = 1 000 min^{-1}		n = 750 min^{-1}		n = 500 min^{-1}	
	t_{SE} [ms]	x [%]	t_{SE} [ms]	x [%]	t_{SE} [ms]	x [%]	t_{SE} [ms]	x [%]	t_{SE} [ms]	x [%]
β = 1.00	22.3	68.4	24.0	57.5	30.1	46.8	38.6	37.0	47.2	23.6
β = 0.75	27.8	52.1	27.9	44.5	33.7	36.9	38.8	27.6	49.1	18.5
β = 0.50	32.7	34.0	33.3	28.9	40.2	23.3	47.9	17.7	64.2	11.2
β = 0.25	43.1	16.6	48.6	13.7	58.8	10.1	74.5	6.6	109.0	0.0

Tab. 1: Evaluated values of control time in t_{SE} and overshoot x.

4. Conclusions

The aim of this study was to assess the effect of the pump speed and pump relative displacement on the dynamic properties of the pressure compensated axial piston pump with a swash plate. The measurements were carried out at different pump speeds and different pump relative displacements. The main monitored variables were control time in and overshoot. It was found, when the pump speed increases the control time in decreases and the overshoot increases. It was also found, when the pump relative displacement increases the control time in decreases and the overshoot increases. The results will be used to develop and verify the mathematical model of the pressure compensated pump. Also, the results can be used to compare the dynamic properties of pressure compensated pumps of other design types. In the future, the time dependence of torque on the pump shaft will be measured.

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