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COMPARISON OF THE EFFICIENCY OF SELECTED HYDRAULIC SOURCES

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Abstract: *This article compares the efficiency of three selected hydraulic sources: a fixed displacement pump with a relief valve, a pressure compensated pump, and a pump with Load-Sensing control. The study investigates how pump speed reduction impacts the efficiency of each source. An experimental circuit was used to measure input power and output power, evaluating efficiency across varying flow rates and pressure drops. The analysis determines which hydraulic source exhibits the highest efficiency and whether efficiency gains from speed reduction are consistent across different loads.*

Keywords: Axial piston pump, efficiency, pressure compensated pump, Load-Sensing

1. Introduction

Improving efficiency in hydraulic systems can be achieved through various methods, including the implementation of variable displacement pumps with diverse control strategies. The classical hydraulic sources, which consists of a fixed displacement pump with a parallel connected relief valve, is replaced by a variable displacement pump with some option of control. In general, a fixed displacement pump with a parallel connected relief valve is not optimal in terms of efficiency, see (Levchenko 2017). Basic types of pump control include, for example, pressure compensated pump or pump with Load-Sensing control. The pump with Load-Sensing control is very effective, as mentioned by Siebert et al. (2017), or Vašina et al. (2018). In their study, Chirita et al. (2018) compare the efficiency of a hydraulic source consisting of a fixed displacement pump with parallel connected relief valve with a hydraulic source consisting of a pump with Load-Sensing control. Their results show that a hydraulic source consisting of the pump with Load-Sensing control achieves 26 % higher efficiency than a source consisting of fixed displacement pump with parallel connected relief valve. Even higher efficiency can be achieved by controlling the pump speed. In their study, Ge et al. (2017) addressed this and concluded that reducing the pump speed can increase efficiency by 10 %. Lovrec et al. (2009) in turn investigate the increase efficiency of fixed displacement pump with variable pump speed. In their study, they mention that it is advantageous in terms of efficiency, but they cite problems with lubrication at low pump speed as a disadvantage for speed control. Kolář et al. (2024) reached similar conclusions in their study. In this paper, the efficiencies of three selected hydraulic sources are compared. These are a fixed displacement pump with a parallel connected relief valve (FP), a pressure compensated pump (PC) and a pump with Load-Sensing control (LS). The dependence of input power, output power and efficiency on the flow rate in the experimental circuit and pressure drop at the proportional relief valve, which is the load in the hydraulic circuit, is compared. Subsequently, a comparison of the efficiency of the selected hydraulic sources at reduced pump speed is performed. Reducing the pump speed can have a significant effect on reducing the input power and thus increasing the efficiency of the system.

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2. Methods

This section presents the measurement methodology and mathematical formulation of the variables.

2.1. Experimental circuit

An experimental circuit was design and assembled for the measurements, see Fig. 1. The main part of the circuit is an axial piston pump (HP) with swash plate. The pump is equipped with pressure control valve (VP) and flow rate control valve (VQ). The source of mechanical energy for the pump is an asynchronous electric motor (M) to which a frequency converter (FC) is connected to adjust the pump speed. A relief valve (RV) is connected in parallel to the pump. In the circuit is also a throttle valve (TV), which adjusts the flow rate. Behind the throttle valve (TV) is a proportional relief valve (PRV), which adjusts the load. The circuit continues with a cooler (C) that keeps the fluid temperature constant and a filter (F) that keeps the fluid purity. The fluid is mineral oil ISO HV VG 46. The circuit is complemented by sensors of the pressure (PS1, PS2, PS3) of the flow rate (FS), of the torque (TS), of the speed (SS) and of the temperature (TeS).

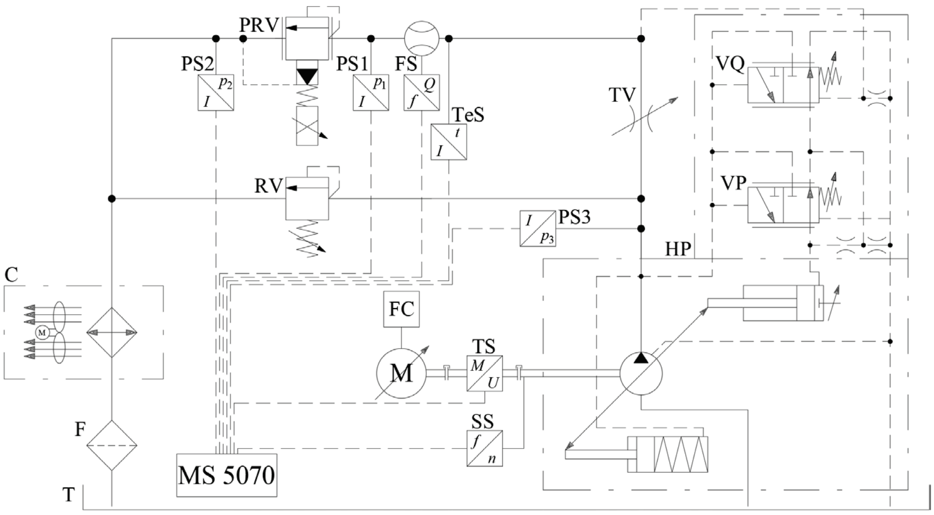

Fig. 1 Experimental circuit

The circuit can be used to measure all three selected hydraulic source variants. For the FP variant, the both control valves (VP, VQ) are out of service, for the PC variant are out of service the relief valve (RV) and the flow rate control valve (VQ) and for the LS variant are out of service the relief valve (RV) and the flow control valve (VQ). The throttle valve (TV) adjusts the flow rat e in the circuit. Subsequently, the load in the circuit is increased by the proportional relief valve (PRV). Flow rates were set to Q = (4; 8; 12; 16; 20) $dm^3 \cdot min^{-1}$ and pressure drops were set to Δp = (20; 40; 60; 80; 100; 120) bar.

2.2. Monitored variables for evaluation

The monitored variables are input power, output power and efficiency.

The input power is defined according to (1):

$$P_{in} = 2 \cdot \pi \cdot n \cdot M, \tag{1}$$

The pressure drop at the proportional relief valve is defined according to (2):

$$\Delta p = p_1 - p_2, \tag{2}$$

The output power is defined according to (3):

$$P_{out} = Q \cdot \Delta p, \tag{3}$$

The efficiency is defined according to (4):

$$\eta = \frac{P_{out}}{P_{in}}, \tag{4}$$

where n is speed, M is torque, Q is flowrate, p_1 is pressure at the inlet to the PRV, p_2 is pressure at the outlet to the PRV, Δp is pressure drop at the PRV, P_{out} is output power, P_{in} is input power and η is efficiency.

3. Results

From the measurement, the dependencies of the input power P_{in} and output power P_{out} were evaluated on the pressure drop Δp and on the flow rate Q for the selected hydraulic sources, see Fig. 2 (a), (b), (c). The dependence of the efficiency was also evaluated on the pressure drop Δp and on the flow rate Q for the selected hydraulic sources, see Fig. 2 (d).

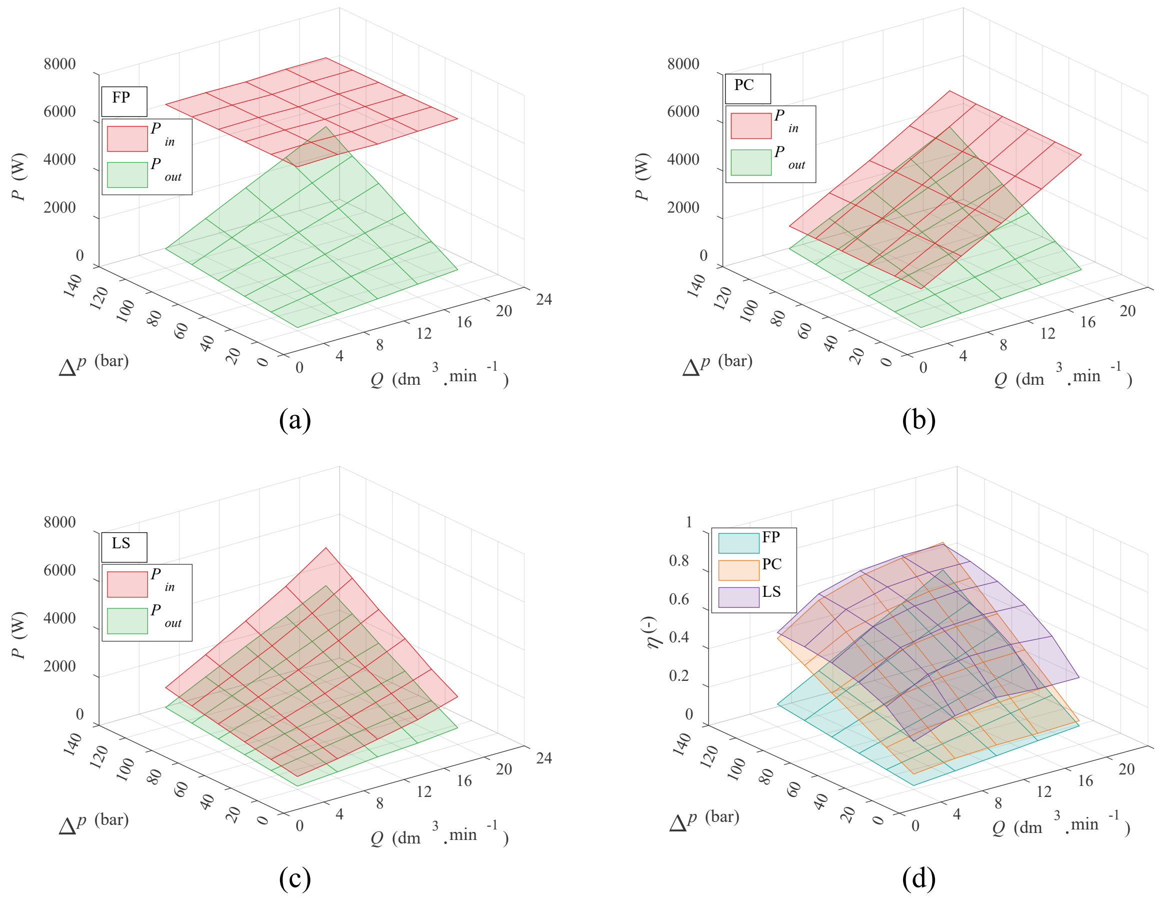

Fig. 2 Dependence of the input power and of the output power on the pressure drop and on the flow rate for: a) FP, b) PC, c) LS; d) Dependence of the efficiency on the pressure drop and on the flow rate

In the Fig. 2 (a), the input power P_{in} is constant for increasing pressure drop and for increasing flow rate Q, too. Fig. 2 (b) shows the input power P_{in} is constant only in the case of increasing pressure drop Δp and it increases with increasing flow rate Q. Fig. 2 (c) shows the input power P_{in} increases with increasing pressure drop Δp and it increases with increasing flow rate Q, too. In the Fig. 2 (d), it can be seen that the highest efficiency is achieved for the pump with Load-Sensing control.

Furthermore, the dependence of the efficiency η was evaluated on the pressure drop Δp at the flow rate $Q = 4\ dm^3 \cdot min^{-1}$ for speeds $n = 1500\ min^{-1}$ and $n = 500\ min^{-1}$, see Fig. 3.

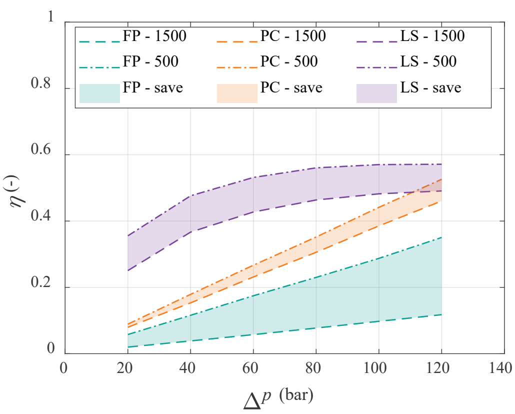

Fig. 3 Comparison of the efficiency of selected hydraulic sources at different speeds

In the Fig. 3, it can be seen that the efficiency η increases with increasing pressure drop Δp at the proportional relief valve, and it can also be seen that the efficiency η increases with decreasing speed n. For the FP and the PC variants, it can be seen that the efficiency improvement increases with increasing pressure drop Δp. In contrast, for the LS variant, the efficiency improvement is constant.

4. Conclusions

In this study, the efficiency dependence of selected hydraulic source sis evaluated. From the measurement it can be seen that the highest efficiency is achieved in the variant of the pump with Load-Sensing control. On the other hand, the lowest efficiency is achieved when is used a fixed displacement pump with a parallel connected relief valve. In the case of the fixed displacement pump with the parallel connected relief valve, the input power is constant for the increasing pressure drop at the proportional relief valve and for the flow rate, too. In the case of the pressure compensated pump, the input power is only constant with increasing pressure drop at the proportional relief valve and it increases with increasing flow rate. In the case of the pump with Load-Sensing control, the input power increases with increasing pressure drop at the proportional relief valve and in increases with increasing flow rate, too. If the speed is reduced, the efficiency of the whole system increases. For the fixed displacement pump with the parallel connected relief valve and for the pressure compensated pump, it can be seen the efficiency improvement increases with increasing pressure drop at the proportional relief valve. In contrast, in the case of the pump with Load-Sensing control, it can be seen that the efficiency improvement is constant for increasing pressure drop at the proportional relief valve.

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