INFLUENCE OF SETTING THE SELECTED PARAMETERS OF HYDRAULIC SYSTEMS ON PRESSURE PULSATION OF GEAR PUMPS

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Summary
The article presents results of preliminary experimental tests regarding pressure pulsation of the gear pump with external gear design, series PGP511 manufactured by Parker Hannifin. A cycle of measurements was carried out in relation to the selected parameters of system's operation, such as: rotational speed of the pump shaft, pumping pressure and capacitance change (i.e. hydraulic capacity) of the pressure line. The obtained curves have been analyzed in terms of time and frequency.

Keywords: pressure pulsation, gear pumps, hydrostatic drive

WPŁYW NASTAW WYBRANYCH PARAMETRÓW UKŁADU HYDRAULICZNEGO NA PULSACJĘ CIŚNIENIA POMPY ZĘBATEJ

Streszczenie
W artykule przedstawiono wyniki wstępnych badań eksperymentalnych pulsacji ciśnienia pompy zębatej o zazębieniu zewnętrznym, serii PGP511 produkcji Parker Hannifin. Cykl pomiarów przeprowadzono w odniesieniu do wybranych parametrów pracy układu, takich jak: prędkość obrotowa wału pompy, ciśnienie tłoczenia oraz zmiana kapacytancji (tj. pojemności hydraulicznej) linii tłocznej. Uzyskane przebiegi zostały przeanalizowane w dziedzinach czasu oraz częstotliwości.

Słowa kluczowe: pulsacja ciśnienia, pompy zębate, napęd hydrostatyczny

1. INTRODUCTION

Development of modern hydrostatic systems is not connected only with the increase in density of transferred power and efficiency improvement of the selected elements of hydraulic systems, but it also involves reduction of vibration emission levels (with mechanical or hydraulic sources) [2, 8]. Vibration resulting from pressure pulsation, caused by unbalanced flow rate of the hydraulic fluid from the pump to the system, causes accelerated wear of working elements, limitations in accuracy of positioning receivers and increased emission of noise [1, 2, 5].

One of more popular design solutions of displacement pumps in the hydrostatic drive systems are gear pumps with external gear design.

Pumps of this type, despite the fact of the complicated run of the pumping process and the necessity of compensating capacity losses (losses between gear teeth, circumferential capacity loss, peripheral and front capacity loss), they are often used in hydrostatic drive systems of stationary and mobile machines [11]. The article presents test results for the gear pump PGP511B0060CS4D3NE5E3S carried out with regard to pressure pulsation.

The scope of tests included a series of experiments enabling identification of the correlation between pump pressure pulsation and the following factors:

- geometric, volumetric and operating parameters of the pressure line (influencing capacitance, inertance and hydraulic resistance),
- rotational speed of the pump shaft,
- setting pumping pressure.

The obtained curves of pumping pressure pulsation [6, 7, 9, 10] have been analyzed in terms of time and frequency. The time analysis was carried out in order to determine the peak-to-peak value of pumping pressure that influences fatigue wear of the hydraulic system elements and is responsible for generating raised levels of vibration and noise. The frequency analysis was carried out in order to identify the irregularities of frequency response of the examined gear pump, which may be used to diagnose the operating condition of the pump.

2. PUMP CAPACITY FLUCTUATION MODEL OF EXTERNAL GEAR PUMPS

Pressure pulsation of gear pumps result from temporary displacement volume changes connected with changes in the position of gearwheels.

According to [5] capacity fluctuation of external gear pumps with identical gearwheels, results from the change in temporary flow output Q, as expressed by the formula:

$$Q = B \cdot \omega \cdot \left(r_2^2 - r_t^2 - u^2\right) \tag{1}$$

where:

- B – face width of gearwheels [mm],
- ω – angular velocity of the pump shaft [rad/s],
- r_w – tooth tip radius [m],
- r_t – pitch radius (rolling) [m],
- u – gear mesh points on the pressure line [m].

Adopting geometric data close to the data of the examined pumps (number of teeth z = 12, module m=2 mm, gear correction coefficient x = 0,3, tooth depth coefficient y = 1, pressure angle α_0 = 20°), theoretical capacity fluctuation has been determined (Fig. 1). Subsequently, amplitude spectrum of capacity fluctuation was determined (sampling frequency f_s = 10kHz, number of samples 8192) with pump shaft rotational speed of n = 732,5 rpm (Fig. 2).

In the model described by the authors, internal leakage in the pump was not taken into consideration.

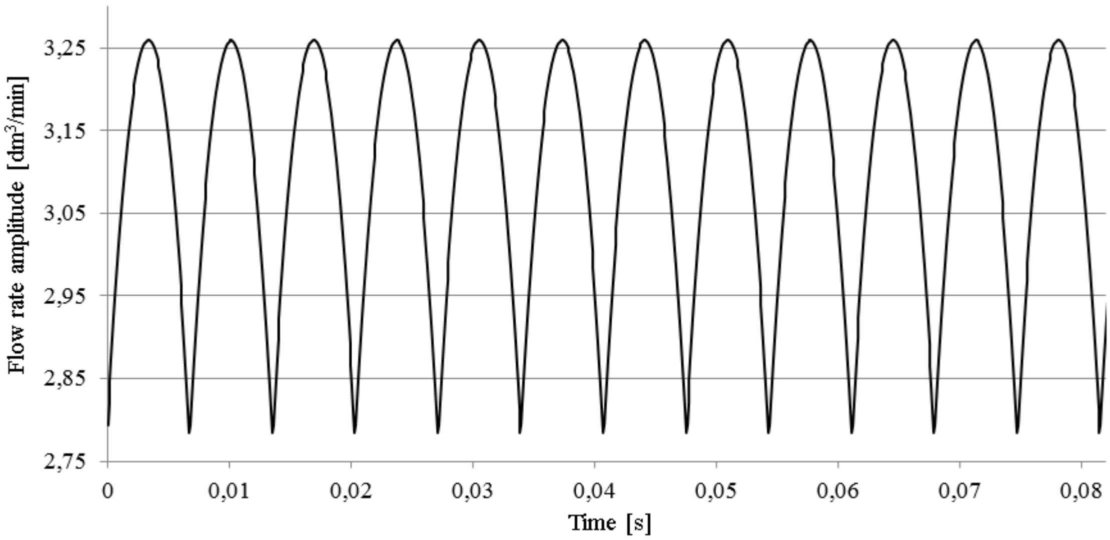

Fig. 1. Curves of theoretical temporary pump capacity fluctuation

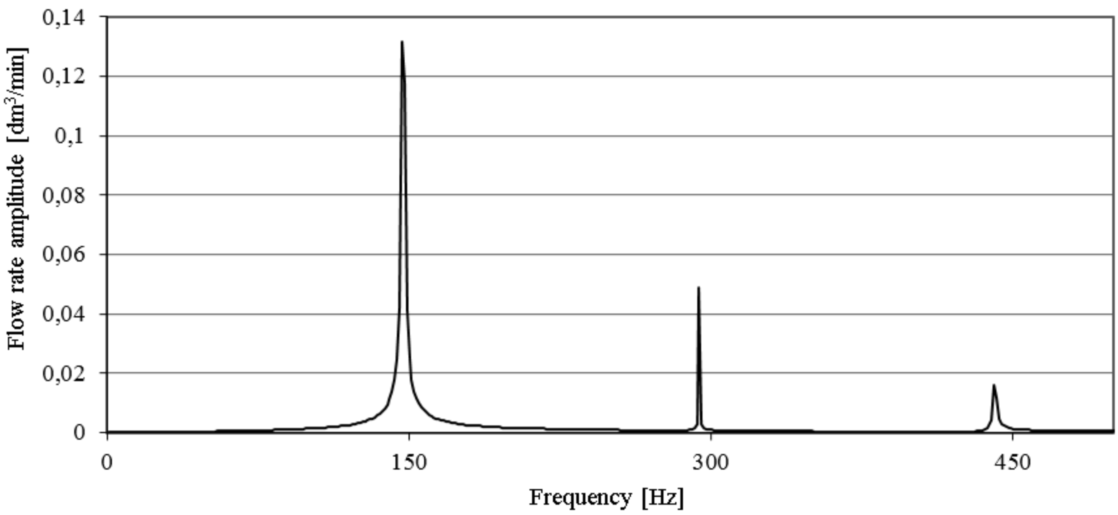

Fig. 2. Frequency spectrum of theoretical temporary pump capacity fluctuation

3. MEASURING STATION AND EXPERIMENT PLAN

Measuring system (Fig. 3) has been composed of a gear pump with external gear design (series PGP511B0060CS4D3NE5E3S, manufactured by Parker Hannifin) powered by asynchronous AC motor with frequency converter, throttle valve 9N600S (setting of pressure in the circuit) and Parker Elite WP 22,5MPa 20mm (3/8”) 1SC flexible hoses. Increased hydraulic capacity (capacitance) of the pressure line was achieved by using additional flexible hoses between the pump and throttle valve. A SCPT-160-C2-05 pressure sensor was installed by the pressure flange of the pump. During the experiment, temperature of working fluid was 30°C. Results of the experiment were acquisition using ServiceMaster Plus device.

A series of measurements were carried out according to table 1. Variable parameters included pressure, rotational speed of pump shaft (volumetric flow rate) and capacitance of pressure line.

4. RESULTS OF EXPERIMENTAL TEST

Operating principle of displacement pumps, involving periodical changes of working space capacity, is the reason of capacity fluctuation and pumping pressure fluctuation (connected with temporary flow rate).

Gearwheels of Parker Hannifin PGP511 displacement pumps are fitted with 12 teeth, hence the frequency of moving from the suction to the pressure side (equivalent to the frequency of the expected pump capacity fluctuation f_p), can be calculated as follows:

$$f_p = \frac{i \cdot n}{60} \quad [Hz] \tag{2}$$

where:

i – number of teeth in a gearwheel,

n – rotational speed of the pump shaft [rpm]

Frequency f_p may be modulated by the frequency of pump shaft rotation f_n, which is most commonly caused by run-time or assembly errors. This effect might also be caused by leakage at one pair of teeth of the interacting wheels.

Table 2 presents foreseen values of pressure peaks frequency resulting from the pump shaft rotation and subsequent rotors entering the pumping phase.

Selected curves of pressure pulsation as a function of time are presented in Fig. 4 and 5.

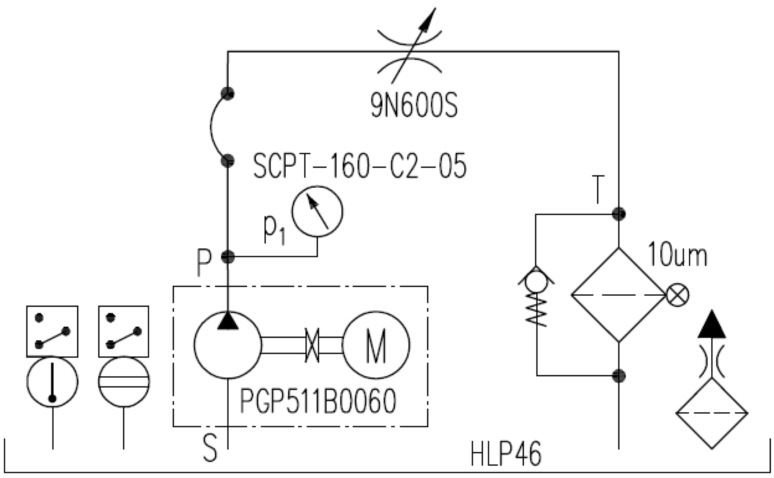

Fig. 3. Simplified schematic diagram of the measuring station

Tab.1. Parameters of the research experiment

Designation of study	Pressure in the discharge line p [bar]	Speed of the pump shaft n [rpm]	Additional capacitance in the discharge line V [dm^3]
P1	45	731	none
P2	90	697	
P3	45	1432	
P4	90	1472	
P5	45	731	0,24
P6	90	697	
P7	45	1432	
P8	90	1472	

Tab.2. Qualitative parameters achieved as a result of the conducted experiment

Designation of study	Discharge pressure pulsation							
	p_{max} [bar]	p_{min} [bar]	Δp [bar]	Δp [%]	f_n [Hz]	p_{n_max} [bar]	f_p [Hz]	p_{p_max} [bar]
P1	45,41	44,99	0,44	0,96	12	0,05	143	0,14
P2	90,38	89,8	0,62	0,69	11,2	0,06	135	0,12
P3	45,28	44,93	0,35	0,77	24,4	0,04	292	0,04
P4	90,25	89,90	0,35	0,39	23,7	0,05	283	0,04
P5	45,75	45,33	0,42	0,92	11,9	0,02	143	0,14
P6	90,36	89,81	0,55	0,60	11,2	0,04	135	0,16
P7	45,58	45,17	0,40	0,89	24,4	0,02	292	0,08
P8	90,61	90,26	0,36	0,39	23,7	0,02	283	0,07

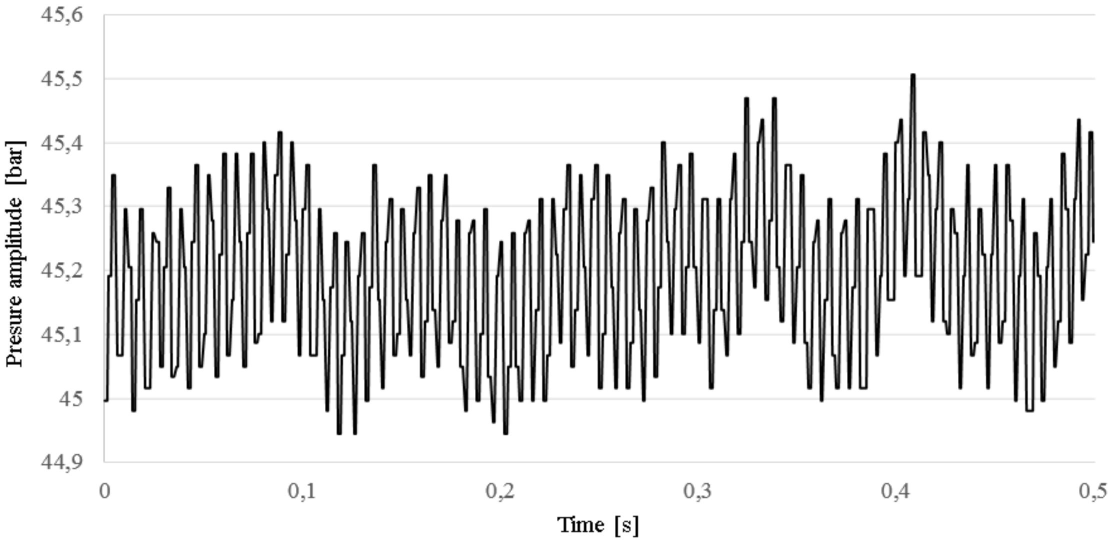

Fig. 4. Curves of pressure pulsation for the experiment P1 (n=731 rpm, p=45 bar, no extra capacitance)

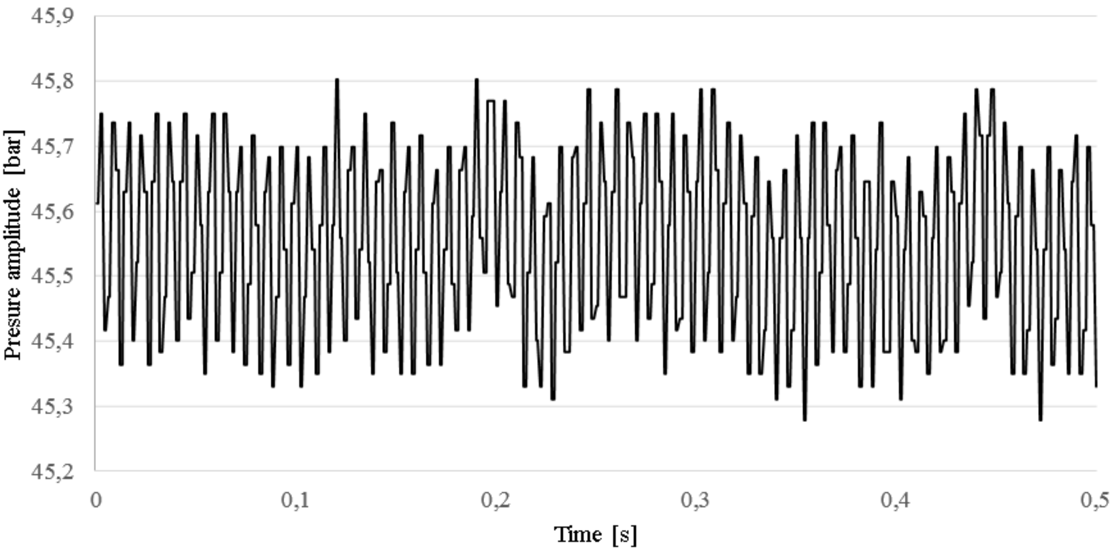

Fig. 5. Curves of pressure pulsation for the experiment P5 (n=731 rpm, p=45 bar, extra capacitance with the capacity of $V=0,24dm^3$)

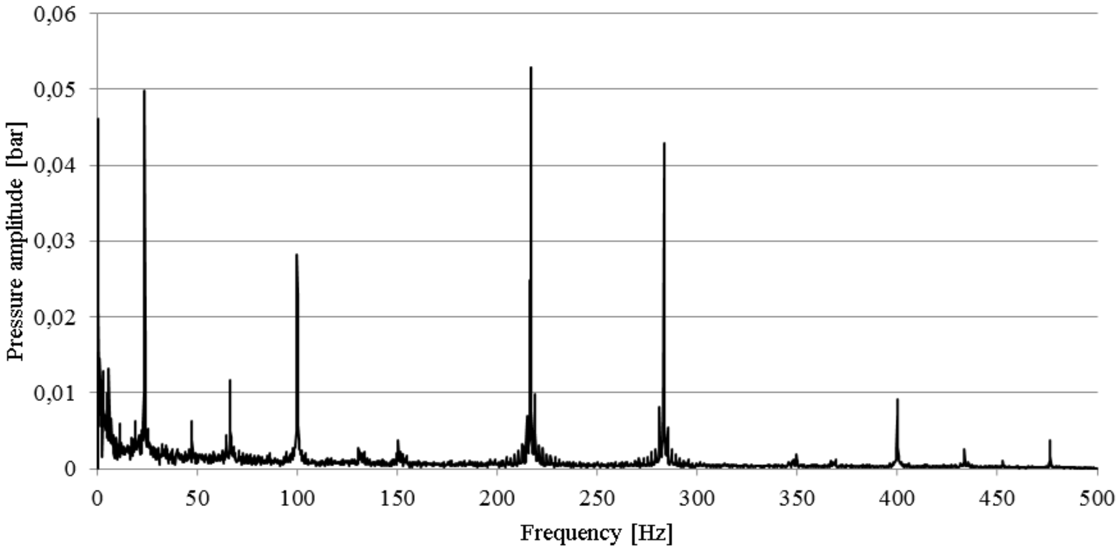

Fig. 6. Frequency spectrum of pressure for experiment P1 (n=731 rpm, p=45 bar, no extra capacitance)

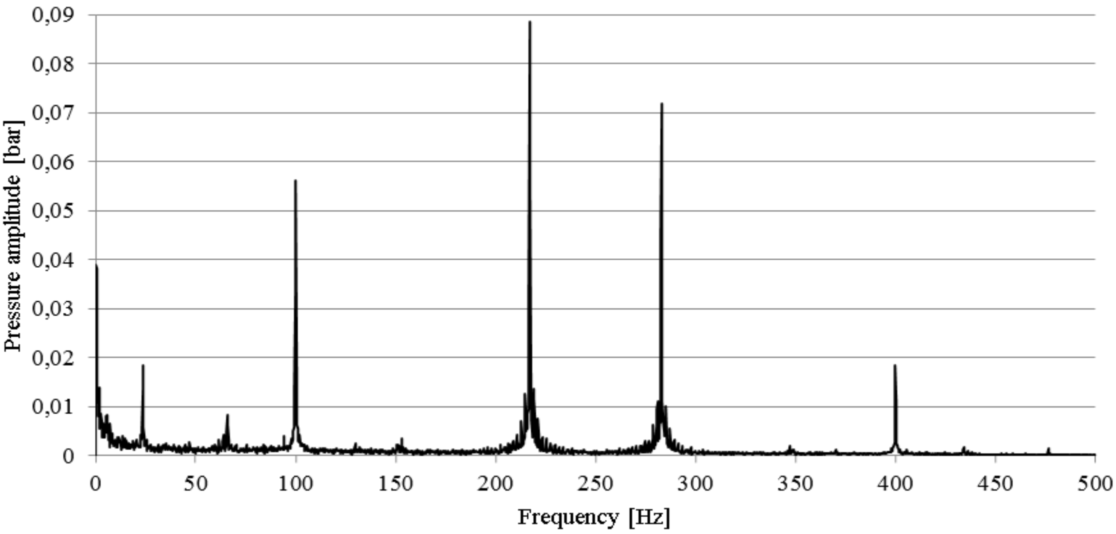

Fig. 7. Frequency spectrum of pressure for experiment P5 (n=731 rpm, p=45 bar, extra capacitance with the capacity of $V=0,24dm^3$)

Frequency of sampling signals registered during the experiments was 1kHz. 8192 samples analyzed in the rectangular window function were taken for the FFT-based data processing. Frequency spectrums were subject to being averaged with four time windows.

5. CONCLUSIONS

Teeth damage was not observed on time courses. The fact is supported by the lack of periodically recurrent (one shaft rotation) significant pressure drops.

Amplitude of pressure pulsation resulting from temporary change of pump capacity caused by the teeth engagement is much higher than pulsation resulting from the pump gearwheel eccentricity.

Increasing rotational speed of the pump, and at the same time pressure pulsation frequency, results in the reduction of pressure pulsation amplitude. Since rotational speed of the pump does not influence the temporary geometric efficiency, the observed phenomenon shall be explained by the phenomenon connected with damping the pressure pulsation caused by compressibility of hydraulic fluid.

Value of the average pumping pressure practically does not influence the pulsation amplitude.

It follows that pump leakage within the limits specified by the producer does not influence pulsation of the examined pump.

Increasing the length of pressure line (extra capacitance) does not influence pressure pulsation connected with the teeth engagement at low rotational speed of pump shaft. However, with nominal rotational speed pressure pulsation was enhanced along longer pressure line. The presented conclusion contradicts the claims that the longer pressure line is the lower pressure pulsation values. The observed phenomenon requires running extra tests.

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