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IMPACT OF SUCTION SPACE LEAKS ON THE DISCHARGE PRESSURE PULSATION OF POSITIVE DISPLACEMENT PUMP

Wpływ nieszczelności przewodu ssawnego na pulsację ciśnienia w linii tłocznej pompy wyporowej

Abstract: *This paper presents the results of the experiments related to measuring the impact of the suction space leaks in the gear pump on the pressure pulsation, resulting in the aeration of hydraulic fluid. The research authors claim that it is possible to detect leaks in the suction line, causing aeration of the hydraulic fluid, by recording and analyzing the pressure pulsation in the positive displacement pump discharge line. The measurements were performed for six leakage values, five discharge pressure settings and under constant hydraulic fluid temperature. The obtained results were analyzed in the time and frequency domains. The results of experimental research confirmed the author's thesis.*
Keywords: suction space leaks, discharge pressure pulsation, gear pumps, fluid aeration

Streszczenie: *W artykule przedstawiono wyniki badań eksperymentalnych związanych z pomiarem wpływu nieszczelności przestrzeni ssącej na zmianę przebiegu pulsacji ciśnienia pompy wyporowej, spowodowane zapowietrzeniem cieczy hydraulicznej. Autorzy badań twierdzą, że istnieje możliwość wykrycia nieszczelności przewodu ssawnego, powodującego aerację cieczy hydraulicznej przez rejestrację, a następnie analizę przebiegu pulsacji ciśnienia w linii tłocznej pompy wyporowej. Eksperyment przeprowadzono dla sześciu wartości nieszczelności oraz pięciu nastaw ciśnienia tłoczenia przy stałej wartości temperatury cieczy hydraulicznej. Zarejestrowane wyniki badań przeanalizowano w domenie czasu oraz częstotliwości. Wyniki badań eksperymentalnych potwierdziły postawioną przez autorów tezę.*
Słowa kluczowe: nieszczelności linii ssawnej, pulsacja ciśnienia linii tłocznej, pompy zębate, aeracja cieczy

1. Introduction

Despite the rapid development of drive techniques, the users of hydrostatic drives constantly suffer from failures caused by the aeration of the working fluid. The presence of air in the system not only poses a serious threat to the operation correctness of the system elements such as pumps, valves and receivers but also affects the physical and chemical properties of the medium, such as increased compressibility, accelerated oxidation, reduced greasing properties and accelerated chemical decomposition of enriching additives [1–5]. The fluid aeration also reduces the drive's hydraulic stiffness [6, 7] and, consequently, lowers the accuracy of hydraulic actuators' positioning, particularly in the systems with servo-hydraulic and proportional valves [8]. It may even cause a loss of stability in the hydraulic and electrohydraulic servo drives. Furthermore, the aeration increases noise levels and drive vibrations [6, 9–11]. The aforementioned reasons motivate our current research on analyzing the phenomena related to the presence of air in hydraulic systems.

In the paper, we report on the experiments conducted concerning the analysis of a leaking suction pipe, causing the aeration of the hydraulic fluid and its influence on the pressure pulsation of the discharge line. As a result, it was hypothesized that it is possible to detect the aeration of hydraulic fluid by recording and analyzing the discharge pressure pulsation.

2. Measurement stand and plan of experiments

The hydraulic diagram of the measurement system shown in Fig. 1. stand consists of a gear pump with external gearing (Parker Hannifin, series PGP511) with the efficiency of 12 l/min, driven with the asynchronous AC motor with the nominal rotation speed of 1470 rev/min and throttle valve 9N600S (hydraulic resistance setting). We used the HDA 4748-H-0009 and HDA 4748-H-0250 fast-pressure transducers mounted on the suction and discharge lines of the pump. Additionally, the connector for aeration nozzles was mounted in front of the pressure converter. The temperature of the working fluid (mineral oil HLP46, according to DIN51524) was 45±2°C. The measurements were recorded using the diagnostic recorder HMG3010. Since the air was being introduced to the medium, the liquid from the drain pipe was first put into the buffer container for venting and then moved to the main container before each series of measurements.

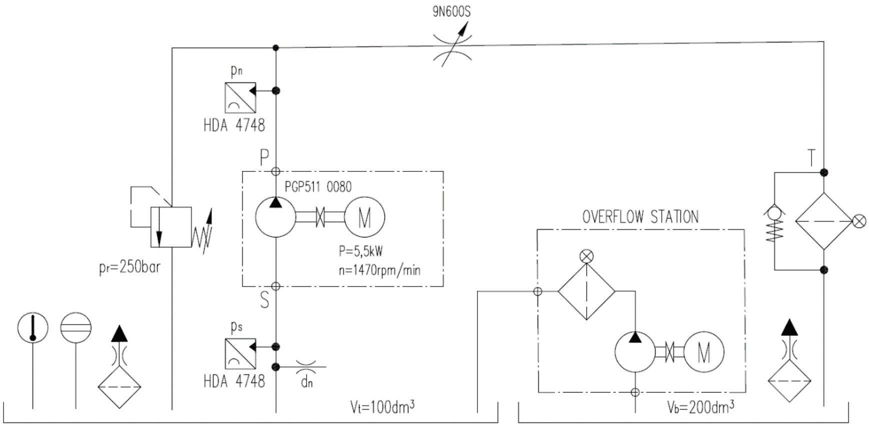

Fig. 1. Simplified diagram of the measurement stand

Figure 2 shows a measurement stand with aeration nozzles.

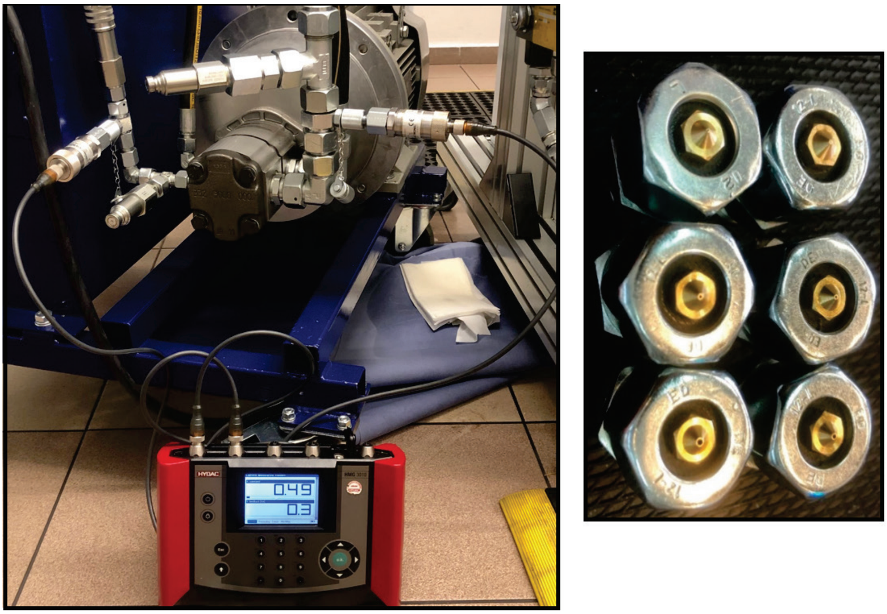

Fig. 2. Measurement stand with aeration nozzles

The experiments were carried out according to the information shown in Table 1. The pressure in the discharge line and the diameter of the nozzle throughout the experiments were changed. The fluid pressure pulsations were compared before aeration and after setting different levels of aeration.

Table 1

Experimental plan

No	Test designation	Nozzle diameter φd_n [mm]	Nominal pressure p_n [MPa]	No.	Test designation	Nozzle diameter φd_n [mm]	Nominal pressure p_n [MPa]
1	BA25		2,5	21	A05_25		2,5
2	BA50		5	22	A05_50		5
3	BA100	0,0	10	23	A05_100	0,5	10
4	BA150		15	24	A05_150		15
5	BA200		20	25	A05_200		20
6	A02_25		2,5	26	A08_25		2,5
7	A02_50		5	27	A08_50		5
8	A02_100	0,2	10	28	A08_100	0,8	10
9	A02_150		15	29	A08_150		15
10	A02_200		20	30	A08_200		20
11	A03_25		2,5	31	A1_25		2.5
12	A03_50		5	32	A1_50		5
13	A03_100	0,3	10	33	A1_100	1	10
14	A03_150		15	34	A1_150		15
15	A03_200		20	35	A1_200		20
16	A04_25		2,5				
17	A04_50		5				
18	A04_100	0,4	10				
19	A04_150		15				
20	A04_200		20				

The aeration of the suction pipe was analyzed in the time and frequency domains. The time domain analysis was conducted to establish the peak-to-peak discharge pressure, affecting the fatigue of hydraulic system components and causing increased noise and vibration levels. The frequency domain analysis was performed to identify the pump's frequency response abnormalities, indicating possible working fluid aeration [2, 3, 12].

The sampling frequency of the signals recorded during the experiments was 10 kHz. The average pressure values were determined within the 500 ms time window, while to perform the FFT analysis, we used 16384 samples analyzed in the function of the Hamming window.

3. Results and discussion

The results of the pressure pulsation measurements in the time domain are visualized in Fig. 3.

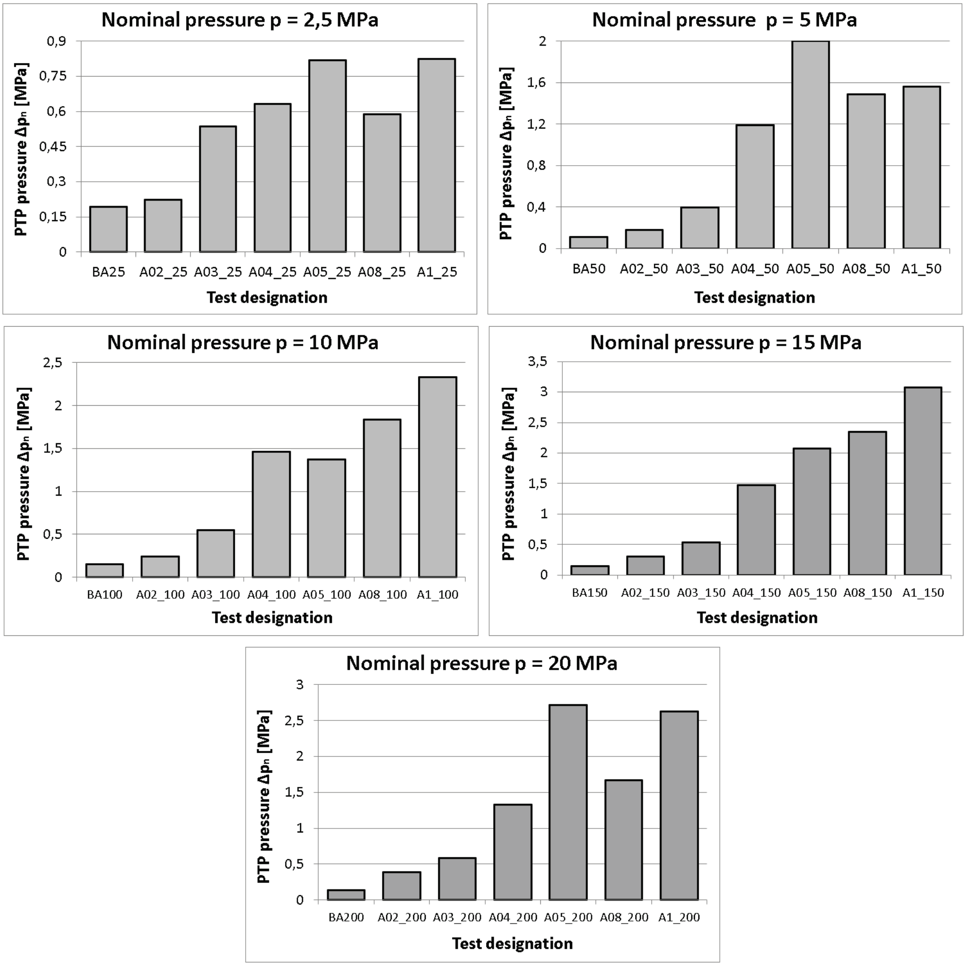

Fig. 3. The visualization of the impact of aeration on the pressure pulsation (time domain analysis), Δp - peak to peak pressure

It was observed that for the hydraulic fluid before aeration, the pressure pulsation values were not greater than 0,2 MPa. Furthermore, the waveforms were regular and periodic. The time intervals between successive pressure pulses, depending on the drive rotation speed, its sliding and the number of discharge pump elements, was between 3,3 ÷ 3,4 ms.

The aeration of the suction pipe significantly increased pressure pulsation value of the discharge line. The effect was proportional to the increase in the input pressure and the diameter of the aeration nozzle. The pressure pulsation value for the measurement denoted by A1_150 (Δp_{A1_150} = 3,073 MPa) increased over fifteen times compared to the value for the fluid without aeration. The pressure pulsation waveforms after aeration were irregular and aperiodic.

The authors have also observed significantly increased noise levels of the pump for the larger diameters of the nozzle and greater pressure values in the discharge line.

The selected pressure pulsation waveforms in the function of time are shown in Fig. 4.

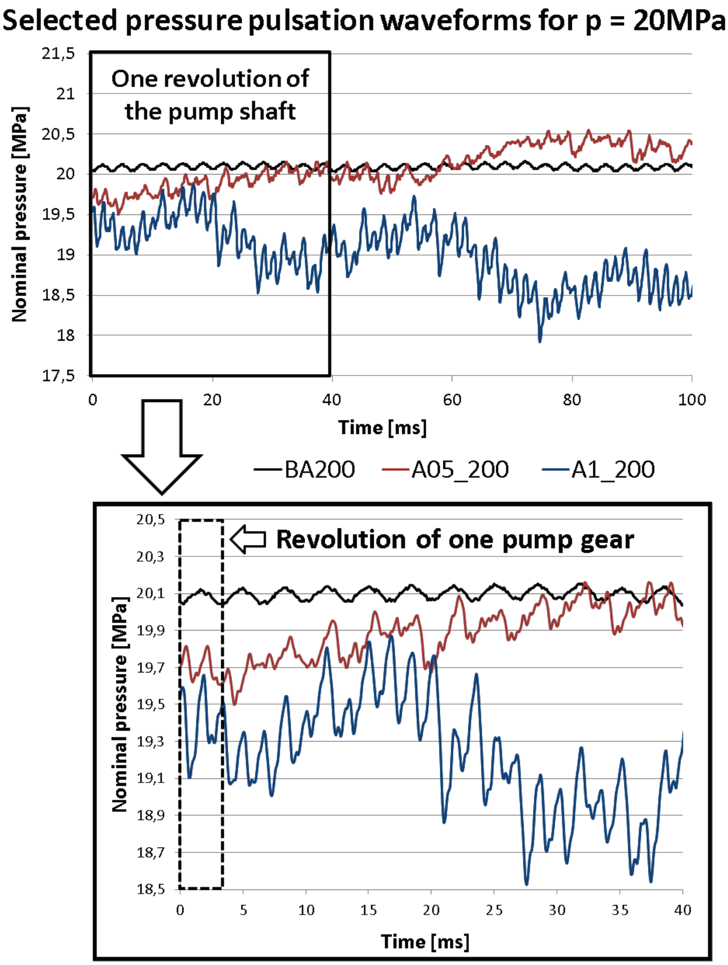

Fig. 4. Selected pressure pulsation waveforms (experiments BA200, A05_200, A1_200)

The gear wheels of the positive displacement pumps, series PGP511, were equipped with 12 teeth. So, the frequency of teeth entrance into the buttress, equivalent to the frequency of the expected pump performance pulsation f_p, was equal to ~300 Hz. The frequency f_p was related to the frequency of the centrifugation of the pump shaft f_n [2, 3]. The selected results of pressure pulsation measurements, analyzed in the frequency domain, are visualized in Fig. 5. The dominant pressure peaks resulted from pump shaft centrifugation with frequency $f_n = \sim 25$ Hz, and from entering successive gear teeth into the pressing phase $f_p = \sim 300$ Hz.

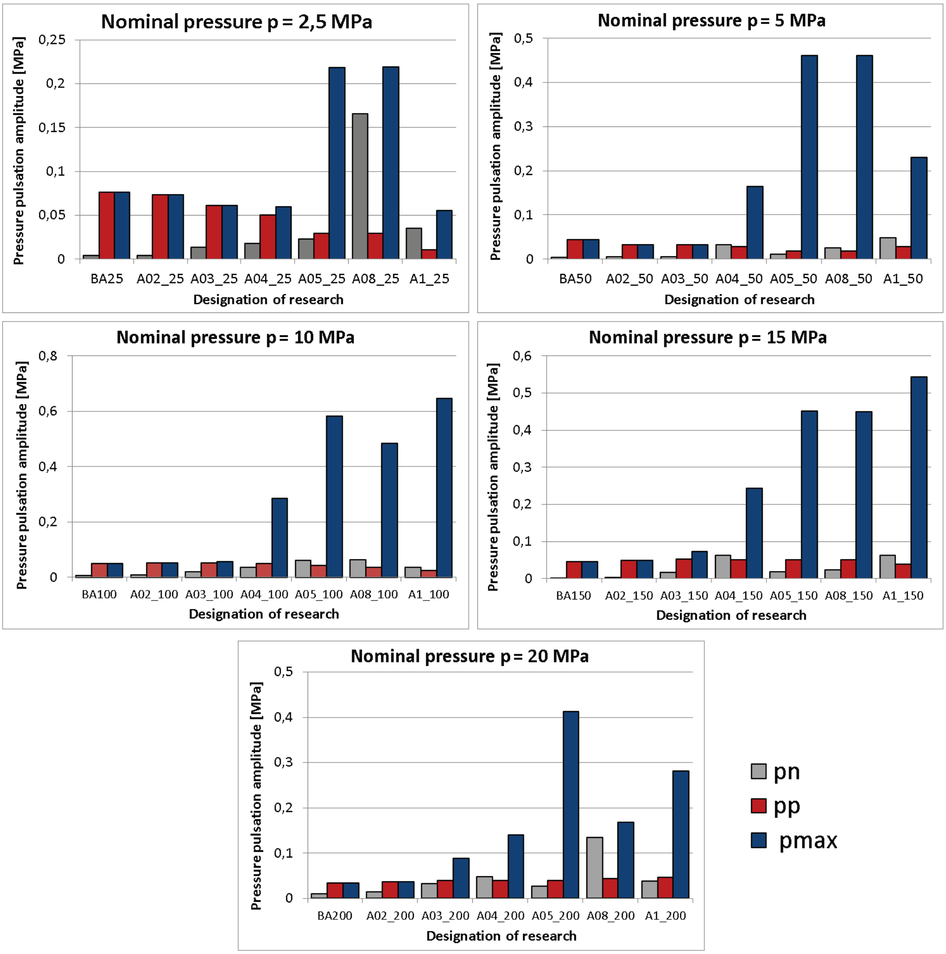

Fig. 5. The visualization of the impact of aeration on the pressure pulsation (frequency domain analysis), pn - amplitude of pressure pulsation for frequency of shaft rotation, pp - amplitude of pressure pulsation for gear-mesh frequency, pmax - maximum amplitude of pressure pulsation observed on pressure spectrum for specific conditions

Figure 6 shows the selected pressure pulsation spectra analyzed in frequency domain.

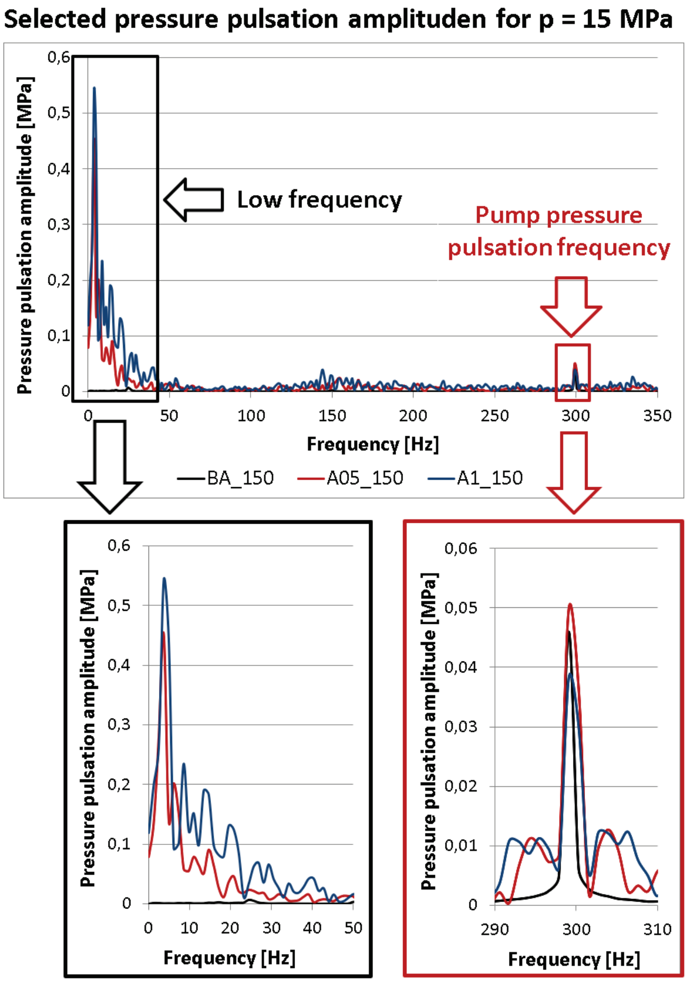

Fig. 6. Selected pressure pulsation spectra (experiments BA150, A05_150 and A1_150)

The experimental results confirm a relationship between the air leaks of the suction line of the positive displacement pump and the pressure pulsations at its discharge. It was also noticed that the vacuum on the suction line of the tested pump was constant and did not depend on the degree of aeration of this line.

Consequently, the air is supposed to flow through the aeration nozzles depending on their cross-sectional area. The results indicate that the most significant increase in the discharge pressure pulsation amplitudes appears for the cross-sectional areas corresponding to the aeration nozzles of diameter 0,2-0,5 mm. In the same range, we can also observe the linear dependency of the cross-sectional area of the suction line leaks on the pressure pulsation amplitudes. The discharge pressure pulsation amplitude is less sensitive to further increase in the cross-section of the aeration nozzles – for diameters from 0,5 mm to 1 mm.

To conclude, based on the obtained results, it seems that even a small leak in the suction pipe or other element closing the suction space of the discharge pump (for the given PGP511 pump being approximately equal to 0,2 mm^2) is enough to cause significant discharge pressure pulsations. Moreover, further enlarging the leak does not necessarily result in the linear increase of the pressure pulsation amplitude. It does not mean, however, that the aeration level of the working fluid remains unchanged. Further studies are required to establish the dependency between the size of suction line leak and the relative aeration of the working fluid.

Furthermore, it was also observed that in the case of the non-aerated fluid, the pressure pulsation amplitude caused by the instantaneous change of pump performance resulting from gear mesh is much larger than the pulsation resulting from the eccentricity of pump gear wheels. The increased pressure value leads to the increased pressure pulsation amplitude resulting from the rotational shaft speed. The maximum pressure pulsation amplitude is achieved at the gear-mesh frequency (300 Hz). No pressure pulsations of the non-aerated fluid are observed in the low frequencies range (below 20 Hz).

For the analyzed pressure values in the discharge line, the maximum pressure pulsation amplitudes are observed for the low-frequency values. The significant increase in pressure pulsation, caused by the working fluid aeration, accelerates the fatigue effects of the hydraulic system components.

4. Conclusions and summary

The conducted experiments confirmed the hypothesis that there is a strong dependency between the discharge pressure pulsation of the positive displacement pump and the aeration of the hydraulic fluid caused by air leaks in the suction line.

Based on the analysis of pressure pulsation waveforms in the time domain, we have observed a significant increase (by order of magnitude) in peak-to-peak pressure values.

It was observed that for the aerated working fluid, the frequency resulting from joining the successive working chambers of the pump to the discharge line is not dominant in the pressure pulsations (for a gear pump, the frequency is equivalent to the gear-mesh frequency). In these cases, the dominant elements are the low-frequency discharge pressure pulsations, appearing below or at 8 Hz. Such observations can be easily made using industrial pressure sensors, whose pressure signal bandwidth is much wider. Moreover, it was noted that the pressure signal can be recorded with a much smaller sampling frequency (at least three times larger than the expected pulsation frequency resulting from working fluid aeration). This should make it easier to archive the data recorded by the sensors monitoring the operation of the positive displacement pumps.

On the whole, a similar test should also be performed for positive displacement pumps of other types. In the future, we plan to confirm or reject the aforementioned conclusions based on the study of vane and multi-piston pumps working in the conditions of discharge line aeration.

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