Experimental Research into Noise Emission of A Gear Micropump with Plastic Rotor

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Abstract. The previous researches show that it’s possible to replace several parts of gear pump to plastic ones. This substitution leads to cost and noise reduction of the pump. Therefore, the series of acoustic experiments on a test bench were carry-out. Sound pressure levels were recorded with microphone, located in a pipe made of a vacuum rubber. Conducted experiment shows that acoustic characteristics of the micropump depend on the different material of driven rotor. Experimental result indicates that the proposed measures for replacing metal rotor to plastic one reduce micropump noise on the studied modes. The maximum achieved acoustic efficiency on equivalent level is 11 dB.

1. Introduction

Engineers pay particular attention to vibroacoustic loads in different technical objects [1, 2, 3, 4, 5], caused by constant wear. Moreover, there are exist strict requirements on noise levels [6].

The vital part of any hydraulic systems is flow sources, pumps. Positive displacement machines are most common in those systems. Among these types of machines, gear pumps are most popular. Gear pumps have a widespread use because of the simplicity of their design, low sensitivity to mechanical impurities, ease of manufacturing and low cost. Along with the advantages, there are disadvantages: a high noise level [7], high-quality requirements for the production of gears, high-pressure ripples causes the pipeline instability, cavitation processes [8]. These disadvantages are caused by different phenomena. For example, the authors [9] describe measures by pressure pulsations and vibrations loading reduction, which lead to high noise level. Kollek [10] shows that the fluid trapped between gears is the main reason of gear pump noise. Other papers were devoted to the instability of pipeline caused by high-pressure ripples [11, 12]. These articles provide numerical models of vibrations in pipeline due to pressure ripples.

Nomenclature

\( b \)  
face width (mm)

\( E \)  
Young's modulus (MPa)

\( d_{in} \)  
initial diameter (mm)

\( f \)  
operator

\( f_{sh} \)  
shaft frequency (Hz)

\( f_{sech.1,2} \)  
first and second teeth frequency (first and second harmonic) (Hz)

\( k \)  
harmonic number

\( m \)  
module of the wheel (mm)
Polymeric materials (PM) are used in mechanical engineering more and more due to higher than steel and aluminum loss factor $\eta$ [13]. A strength limit $\sigma$ of several existed PM is over 500 MPa while Young’s modulus $E$, in comparison with steel, is considerably lower [14]. These properties have been causing inevitable substitution of traditional materials (TM) of mechanical engineering from 70teens [15] till nowadays [16].

The papers show possibility PM instead TM implementation with appropriate efficiency for hydraulics [17, 18] as well as for different parts of external and internal gear pumps [18, 19]. Moreover, PM application leads to pumps noise and vibration reduction [20, 21].

The main PM advantages for mechanical engineering are increased chemical resistance [14, 22], the ability to work under lubrication lack [23], high enough loss factor $\eta$ [15, 24].

In this paper authors assessed acoustic efficiency from plastic rotor implementation in a gear micropump. Only the driven rotor was substituted.

### 2. Experimental study

The PEEK was chosen as the material for driven rotor [14], on the basis of it enormous properties in contrast to other PM’s. The comparison of PEEK (driven gear) and steel 42Cr4 (driver gear) shown in [13].

Sound pressure levels emitted by the micropump with plastic driven rotor were recorded by microphone, a signal processing module NI usb-4431 and PC with installed LabView software. In addition, a flow rate, inlet and outlet pressure of the micropump were collected with the flowmeter, pressure transducer, vacuum gauge and portable registration module.

The acoustic characteristics of the micropump had measured for the following configurations of drive and driven rotors: “steel-steel” and "steel-PEEK".

These rotors packages were studied on a gear micropump. A number of modes were formed as a combination of outlet pressure and shaft speed. Selected modes are presented in Table 1.

| Characteristics     | Unit    | Value 1 | Value 2 | Value 3 | Value 4 |
|---------------------|---------|---------|---------|---------|---------|
| Shaft speed, $n$    | (rpm)   | 1000    | 1500    | 2000    | 2500    |
| Outlet pressure, $P_{out}$ | (bar) | 3       | 6       | 9       | 12      |

The algorithm of the experiment is:

- Set the shaft speed by frequency drive and outlet micropump pressure by a throttle.
- Register a pressure and flow rate.
- Record an acoustic signal.
The experiments were carry-out on a hydraulic test bench. This test bench was based on previous one, which was designed earlier [25]. The hydraulic system scheme is illustrated in Figure 1.

**Figure 1.** (a) scheme of the test bench: 1 – air filter, 2 – tank, 3 – valve, 4 – preliminary filter, 5 – vacuum gauge, 6 – gear micropump, 7 – motor, 8 – frequency drive, 9 – microphone, 10 – measuring system, 11 – laptop, 12 – pressure transducer, 13 – portable registration module, 14 – flowmeter, 15 – pressure gauge, 16 – throttle, 17 – fluid level gauge, 18 – temperature gauge; (b) scheme of the microphone arrangement.

This system provides an opportunity to measure the flow under different operating conditions, a shaft speed and output pressure, while the oil temperature is kept constant. Sound pressure levels were recorded with microphone, located in a pipe made of a vacuum rubber. A thickness of the pipe is 9 mm (Figure 1).

3. **Results and discussion**
The collected data were carefully processed. Then an acoustic efficiency caused by the implementation of plastic rotor instead the steel one were calculated, thoroughly analyzed and presented:

- For shaft and teeth frequencies depended on the micropump outlet pressure (Figure 2).
- As equivalent efficiency depended on the shaft speed (Figure 3(a)).
- As equivalent efficiency depended on the micropump outlet pressure (Figure 3(b)).
Figure 2. Acoustic efficiency $\Delta L = f(f_{sh}, f_{teeth1}, f_{teeth2})$ on main working process frequencies at $n=2000$ rpm.

The teeth frequency is determined as (1):

$$f_{teeth} = k f_{sh} = k \frac{n z}{60}$$  \hfill (1)

The Figure 2 shows that acoustic efficiency on shaft frequency is slightly higher. The efficiency strictly depends on outlet pressure of the micropump. This tendency observed on other shaft speeds.

Figure 3 depicts the results of equivalent acoustic efficiency like shaft speed $\Delta L_{eq} = f(n)$ and output pressure $\Delta L_{eq} = f(P_{out})$ function as a difference between a noise emitted from "steel-steel" and "steel-PEEK" packages:

Figure 3. (a) An acoustic efficiency $\Delta L_{eq} = f(n)$; (b) An acoustic efficiency $\Delta L_{eq} = f(P_{out})$.

The equivalent acoustic efficiency at low shaft speeds (1000 and 1500 rev/min) rise sharply (Figure. 3(a)). At 2000 and 2500 rev/min the efficiency increased slightly. As was closely observed (Fig. 3(b)), there is a strong correlation between acoustic efficiency and outlet pressure of the micropump on the 1000 rpm and 1500 rpm. Apart from that, there is no strict dependence between acoustic efficiency and outlet pressure of the micropump on the 2000 rpm and 2500 rpm.

The sound pressure level did not register on working mode $n=1000$ rpm and $P_{out} = 12$ bar due to low micropump delivery.

The volumetric efficiency and the theoretical delivery [26] for pumps with teeth number $z = 8…16$ should be determined as (2):

$$\eta_v = \frac{Q_{act}}{Q_{theor}} = \frac{Q_{act}}{6.5 d_{in} m^3 n}$$  \hfill (2)
Figure 4, shows the volumetric efficiency of the gear micropump versus the output pressure, for two configurations.

![Volumetric efficiency of the gear micropump vs the output pressure at n=2500 rpm.](image)

**Figure 4.** Volumetric efficiency of the gear micropump vs the output pressure at n=2500 rpm.

The inlet micropump pressure was registered by a vacuum gauge. The maximum value was 0.8 bar at n=2500 rpm and $P_{\text{out}}=3$ bar. This value was not taken into account in the equation (2) as additional leakage to a suction area [27]. Thus, theoretical volumetric efficiency, presented in figure 4 is higher than it is.

It is necessary to emphasize the fact that volumetric efficiency because of plastic rotor implementation, as expected, are lower in comparison with steel rotor package [28].

The volumetric efficiency $\eta_v$ of gear pumps often expected in a range from 0.8 till 0.95 [29]. In current research volumetric efficiency were under value 0.8 at 6 bars. Nevertheless, these results are suitable for pumps with elements made of plastics [22, 28]. For example, the Tuthill company produces gear pumps with rotors made of PEEK and maximum outlet pressure $P_{\text{out}}=16$ bar. Therefore it clearly demonstrates an importance of outlet pressure increasing for pumps made of plastics.

According to Bashta [26] a volumetric coefficient of the pump is affected on its total length of the gaps. The declining of the ratio of gaps length to theoretical delivery leads to volumetric coefficient increase. Hence, the low pump delivery leads to the lower volumetric coefficient. Thus, it is recommended to run the pump at a high shaft speeds. This hypothesis is supported by the obtained experimental results: volumetric efficiency $\eta_v=0.53...0.67$ were achieved at outlet pressure $P_{\text{out}}=12$ bar, instead expected ($\eta_v=0.8...0.95$) [27]. The maximum volumetric efficiency $\eta_v=0.67...0.92$ was recorded at highest shaft speed (n=2500 rpm) for "steel-steel" package. The tendency to volumetric efficiency growing is observed in all studied range of shaft speeds. Starting from n=1000 rpm the volumetric efficiency rising up on 0.075 for each 500 rpm.

4. Conclusion

Fluid power machines are commonly used in the design of the hydraulic driving and systems of machines and appliances. Development prospects of the machines are still open. Together with the improvement of their efficiency and outlet pressure limits, it is possible to achieve a noise emission declining.

The carried-out experiment provides the results, which firmly establishes the relationship of acoustic efficiency to rotor materials in gear pumps. This is specifically referred to plastic materials. The achieved acoustic efficiency is 2...8 dB depends on outlet pressure on the main working process frequencies of the gear micropump at n=2000 rpm, and 2...11 dB on equivalent level depends on outlet pressure and shaft speeds.

The volumetric efficiency of the gear micropump depended on outlet pressure was $\eta_v=0.53...0.87$ for "steel-PEEK" package. The principal cause of this wide range value was random side gaps in the micropump during it assembling.
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