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Dynamics and Vibroacoustics of Machines (DVM2014)

Exploration of acoustic characteristics of gear pumps with polymeric pinion shafts

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Abstract

The previous researches show that it is possible to replace several parts of gear pumps to polymeric ones. This substitution leads to cost and noise reduction of the pump unit. Therefore, the series of experiments on test bench SVNSH-08 with the use of acoustic camera Norsonic Nor848 for the analysis of acoustic characteristics was carry-out. Measuring system - portable 12-channel signals analyzer LMS SCADAS Mobile (SCM05) was used. Conducted experiment shows that acoustic characteristics of the pump unit depend on different material drive and driven rotor. Experimental result indicates that the proposed measures for replacing metal pinion shafts to polymeric reduce pump unit noise on the test modes.

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Keywords: gear pump; acoustics; polymeric materials; mechanical noise; gear; pinion shaft;

1. Introduction

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, high quality requirements for the production of gears, high pressure ripples causes the pipeline instability. These disadvantages are caused by different phenomena. For example, the authors [1] describe measures by pressure

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pulsations and vibrations loading reduction, which leads to high noise level. Kollek [2] 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 [3,4]. These articles provide numerical models of vibrations in pipeline due to pressure ripples. A vibroacoustic interaction of pipeline and fluid was modelled by the authors. Nonetheless gear pumps are widely used in many industries, including chemical, oil and gas ones. Aggressive media negatively affect the elements of pumping units. In this regard in the production of this type of pumps the flow channel is made of chrome-nickel, high-alloyed silicon/chromium cast iron and titanium alloys. Analogues of such alloys can serve as polymeric materials and polymeric composite materials (the PM and PCM). Hoskins [5] presents a study of the dynamic behavior, in terms of noise emission, of polymeric gears. The polymeric composite materials are not considered. This research takes into account the tribological noise generated as a result of the interacting tooth flanks. This problem can be solved by the lubrication. Dearn [6] presents a study of the role of materials in the generation of noise made by plastic gears. Sound levels were recorded for gears running in various running combinations. In this research only the gears were examined and real working conditions with lubrication are not reproduced.

Attempts to investigate the workflow and vibro-acoustic characteristics of gear pumps with polymer gears have been made earlier [7, 8 and 9]. These articles show that such experiments need some change and technological improvements. In the paper [7] the authors used low strength materials for their study and that led to gear-shaft failure. There are several researches devoted to strength analysis [10] and improvement of load - carrying capacity [11]. But object of study first of them is not a gear pump. Second research provides the gears studies without working fluid.

To increase strength characteristics of gears several composite materials are used [12]. In this study unreinforced and reinforced polymer materials are compared. Experiments are carried out not as a pump but as gears only.

Successful attempt to create a pump with plastics gears was provided by Krawczyk [13]. This approach is similar, but the construction of the gears is differing.

As known, the nature of noise in gear pumps has a mechanical and hydrodynamic character [14]. One of the hydrodynamic noise reasons is the cavitation. Stryczek [15] provides measure to decrease noise caused by this phenomena. Another reason is the pressure ripples. To reduce acoustic noise induced by the pressure ripples the pressure mufflers are used. The authors [16] present the main points of design methodology of a hydrodynamic noise silencer in a hydraulic system. The studies have focused on the development of measures for mechanical noise decreasing.

2. The technology and the process of the production of polymeric rotors

At the moment, the use of the polymer-shaft gears (Fig. 1) instead of metal is promising, as it leads to: weight loss, reduction of noise and vibration, improving the tribological properties of the interacting elements.

Computer calculation of the strength of the shaft-gear only gives the stress distribution and bearing forces, but does not provide any information about fatigue and wear of material. Such calculation is presented by Stryczek [17, 18]. That is why it is necessary to make an experimental set of the polymer pinion shafts to carry-out a series of experiments.

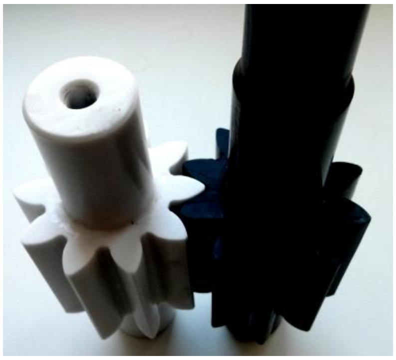


Fig. 1. Polymeric pinion shafts.

Technological process occupies an important part on the way of detail from development to experiment. The production of polymeric pinion shafts is cheaper than the production of metal ones (the manufacture of blanks, cutting, hardening of the teeth, etc.), that can significantly reduce the cost of the polymeric pinion shafts.

The polymer pinion shafts have been made by chill-casting with ProtoCast-85R material. The chill mold has been made by casting of metallic pinion shafts. This manufacturing method has been chosen because of its availability, low cost and short manufacture time of the product with satisfactory mechanical properties of the material. External state of gears has been rated as satisfactory: outside the friction and contact surfaces seams and minor irregularities have taken place. Furthermore, due to thermal shrinkage diameters heads and tooth troughs differed from metal by 0.38% in the lower side. The diameters on the seat cylinders differed from metal by 0.29%.

3. Experimental studies

For the experiment test rig SVNSH-08 has been used (Fig. 2). The SVNSH-08 is the test rig for a hydraulics test run. It consists of: hydraulic tank, filter, motor, pump, needle valve, analog and digital sensors.

The technical elements of the test rig are shown in Tables 1, 2 and 3.

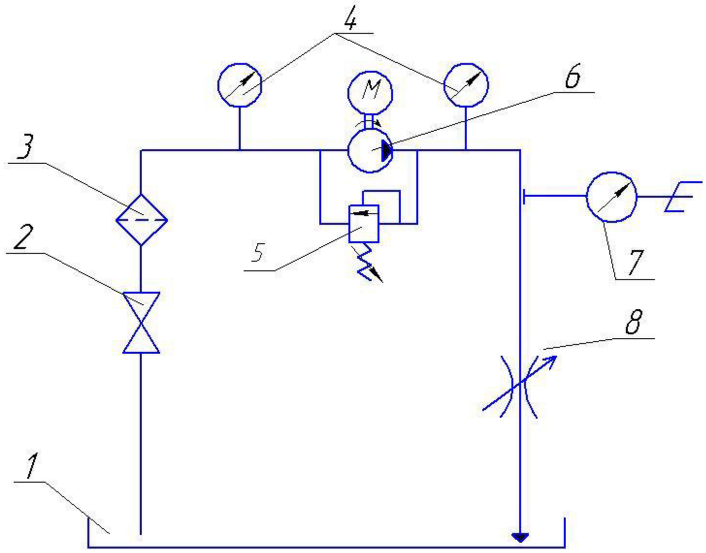


Fig. 2. Test rig SVNSH-08:
1 - tank, 2 - isolation valve, 3 – filter, 4 – analog manometers, 5 - safety-valve, 6 – electrical motor and pump, 7 - pressure fluctuations sensor, 8 – needle valve

Flow source is gear pump NMSH-5-25-4 0.4/25. Pressure fluid is hydraulic oil HLP-46.

Table 1. Main characteristics of the pump.

Characteristics	Unit	Value
Flow, at least	(L/min)	67
Outlet pressure	(bar)	25
Rotation	(rpm)	1450
Pump efficiency	(%)	81.5
Pump power, at least	(kW)	30.8

Handled medium		Oil, petrol
Working temperature	(°C)	70

At the outlet of the pump pressure fluctuations of working fluid and static pressure have been measured. For the pressure measurement analog manometer has been used. Pressure fluctuations have been measured by the pulsation sensor PCB HM101A. The main technical characteristics of the pulsations sensor PCB HM101A are shown in Table 2.

Table 2. Main technical characteristics of the pressure fluctuations sensor PCB HM101A.

Characteristics	Unit	Value
Full-scale range (± 5V)	(bar)	34.5
Response (± 1mV/psi)	(mV/bar)	145
Maximum pressure (static)	(bar)	345
Accuracy grade	(bar)	0.0007
Resonating frequency	(kHz)	≥400
Error measurement	(%)	0.5

The pump unit noise levels has been recorded by acoustic camera Norsonic Nor848. Technical characteristics of the acoustic chamber are:

- Number of microphones - 256 pcs
- The maximum sound level - 110 dB
- Frequency response of microphones - 20 Hz-20 kHz
- Frequency response of acoustic card - 100 Hz to 7 kHz
- The sampling rate of 44.1 kHz

As the measuring system the portable 12-channel analyzer vibration and acoustic signals LMS SCADAS Mobile (SCM05) has been used. SCM05 – is an instrument for pre-signal conditioning, data acquisition and signal processing in a wide range. Main technical characteristics are presented in Table 3.

Table 3. Specifications analyzer SCM05 (Belgium).

Characteristics	Unit	Value
Number of channels		12
Max number of channels		40
Sizes	(mm)	340x78x295
Mass	(kg)	6.2
Temperature range	(°C)	-10…+55
Conformance of the requirement MIL-STD 810F:		
Vibration and shock	(g)	till 60
Humidity	(%)	up to 95
Tachometer channel (stationary)		2
Channel of generator output signal (stationary)		2
PC connection		Ethernet

The acoustic characteristics of the pump have been measured for the following configurations drive and driven rotors:

- "metal- metal "
- "polymer- polymer "

- "metal - polymer"

Different modes have been worked out which formed a combination of speed and output pressure. A number of pressures have been taken from the GOST 19027-89. Modes are shown in Table 4.

Table 4. Test modes.

Characteristics	Unit	Value		
Rotation, n	(rpm)	100	200	300
Outlet pressure, Pout	(bar)	2.4	4	10

The algorithm of the experiment:

- Set the rotation speed of the motor shaft
- Set the pressure in the system (by using the needle valve)
- Pressure fluctuations and acoustic signal registration

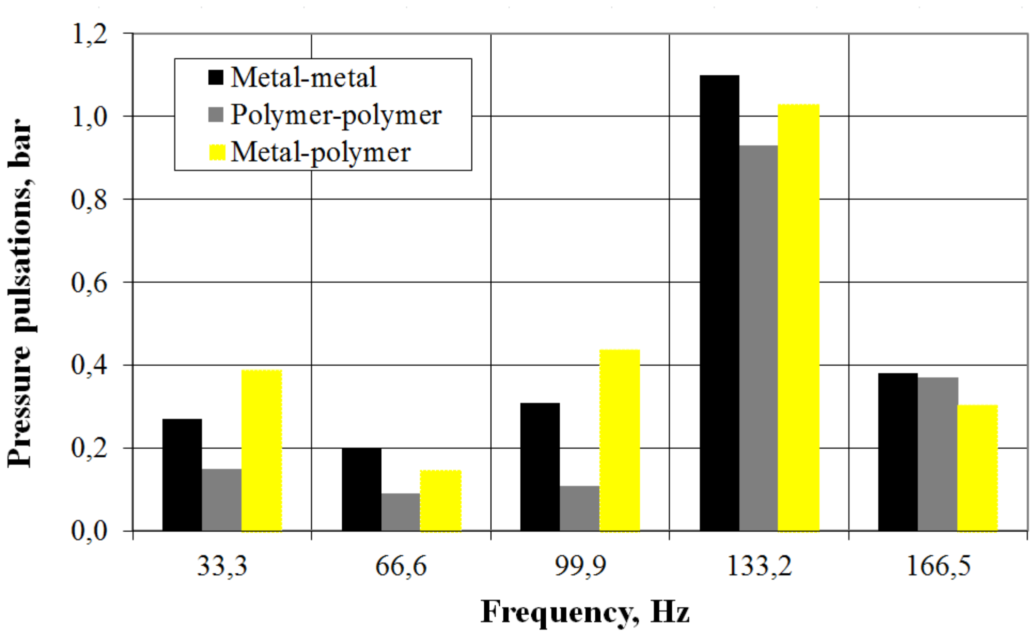
4. Experimental results

During the experiment, in the arrangement of the "polymer" drive rotor could not stand on the load mode: n = 300 rpm, Pout = 10 bar. Material fracture occurred on the shaft, outside the sealed cavity. Combined loading has been the reason - bending combined with torsion. It happened because of excessive play of the shaft in the bush due to shaft heat set in the seats field. By increasing the pressure in the output chamber and the shaft was "clamped" in the bush (Fig. 3). This was the reason to stop the experiments. The appropriate conclusions were drawn and further experiments will be carried out taking into account the existing gaps.

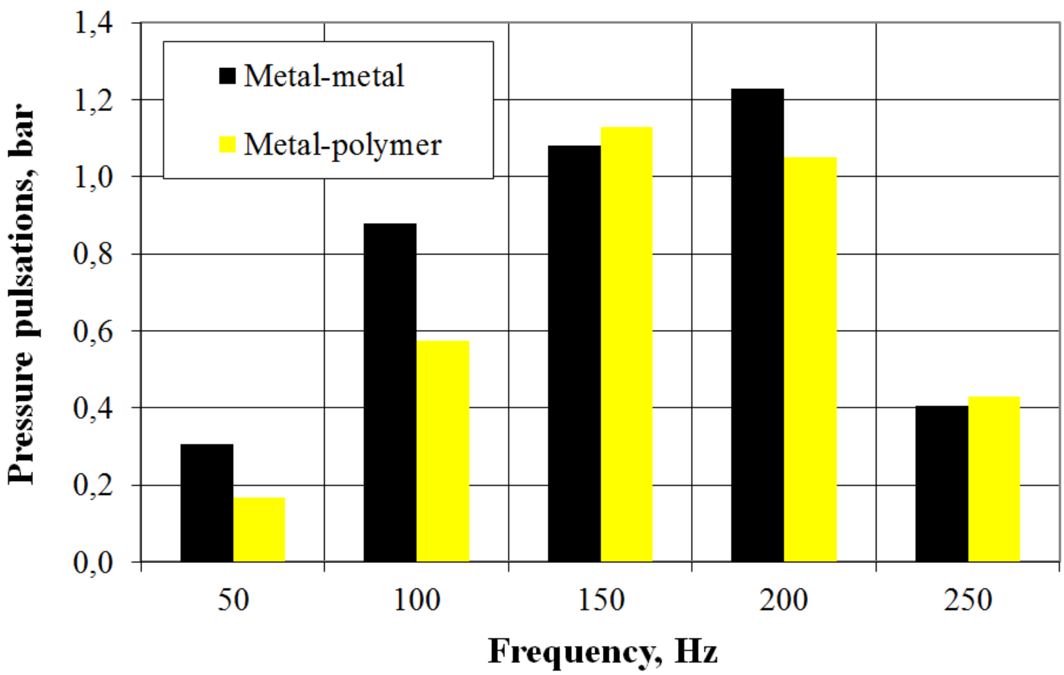
Fig. 3. Breakdown of polymer pinion shaft.

In conducting further experiments PM/PCM with improved strength characteristics are needed.

The radial and side clearances have been increased because the pinion shaft dimensions have been decreased. As a consequence the leakages have increased. The pressure fluctuations spectra of the pump outlet at the various modes are shown in Fig. 4.



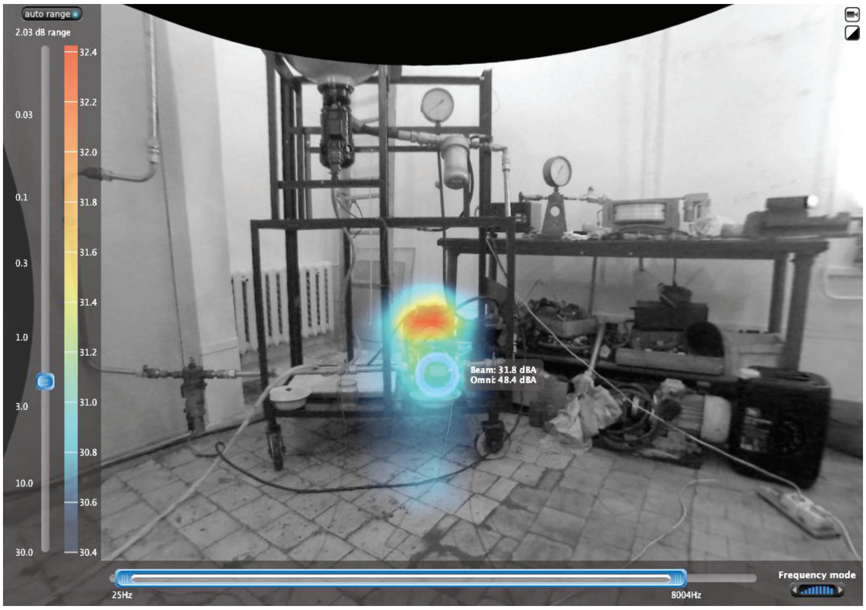
(a) n = 200 rpm, Pout = 2.5 bar



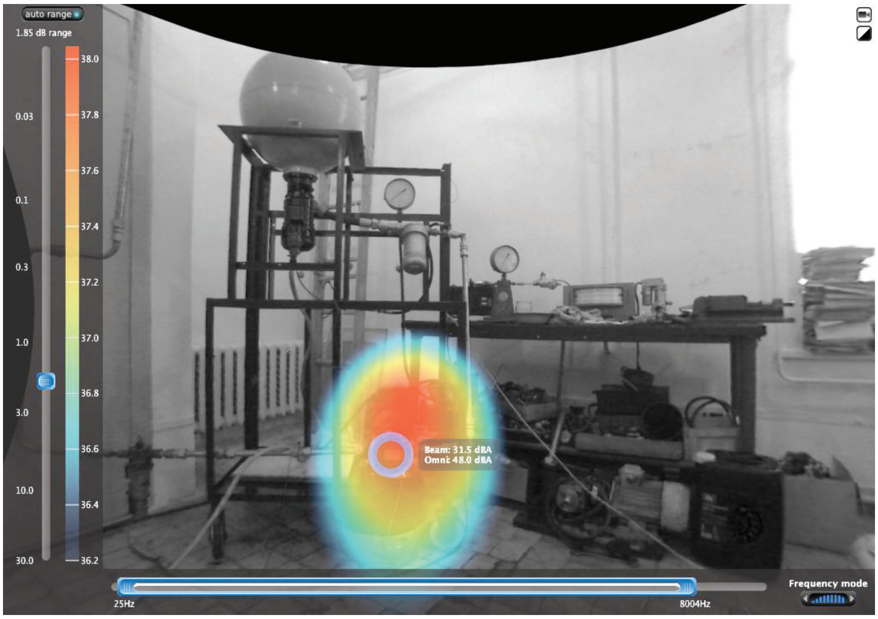
(b) n = 300 rpm, Pout = 10 bar

Fig. 4. The spectrum of the pressure pulsations at the pump outlet: (a) n = 200 rpm, Pout = 2.5 bar; (b) n = 300 rpm, Pout = 10 bar.

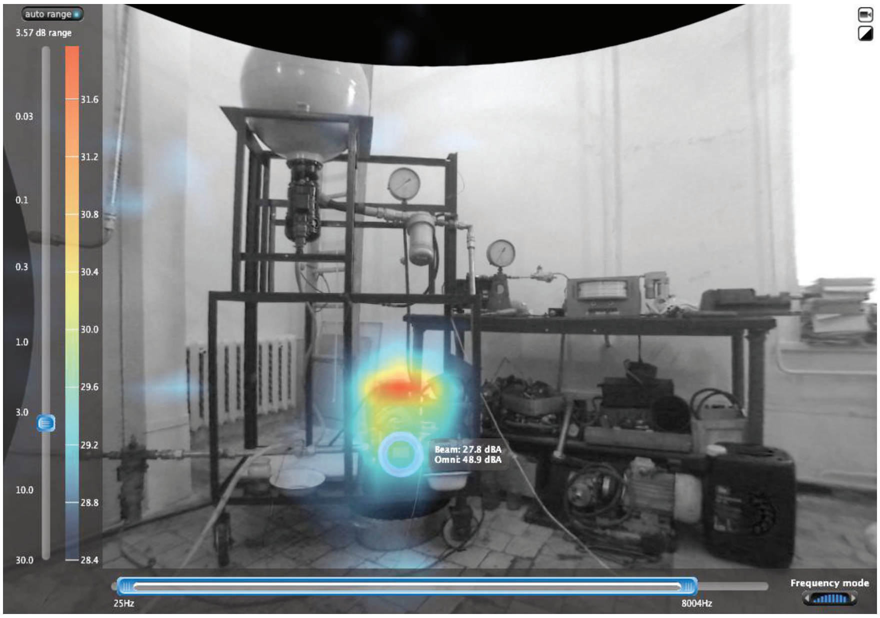
The sound pressure levels of the pump performance at the various configurations drive and driven rotors are shown in Fig. 5.



(a) n = 100 rpm, Pout = 4.2 bar (metal/metal)



(b) n = 100 rpm, Pout = 4.2 bar (metal/polymer)



(c) n = 100 rpm, Pout = 4.2 bar (polymer/polymer)

Fig. 5. The sound pressure level of the pump: (a) n = 100 rpm, Pout = 4.2 bar (metal/metal); (b) n = 100 rpm, Pout = 4.2 bar (metal/polymer); (c) n = 100 rpm, Pout = 4.2 bar (polymer/polymer).

Figure 5 shows, that gear pump with polymeric pinion shafts generates less noise (27.8 dBA) then other combinations (31.8 dBA and 31.5 dBA) at the same performance regime. These noise levels are measured far from the pump. In an acoustic camera plane (Beam on Fig. 5). Thus the noise levels are much lower than the levels which recorded by means of virtual microphones, which are located near the pump (Omni on Fig. 5). The sound pressure level of the pump against rotating speed is shown in Fig. 6.

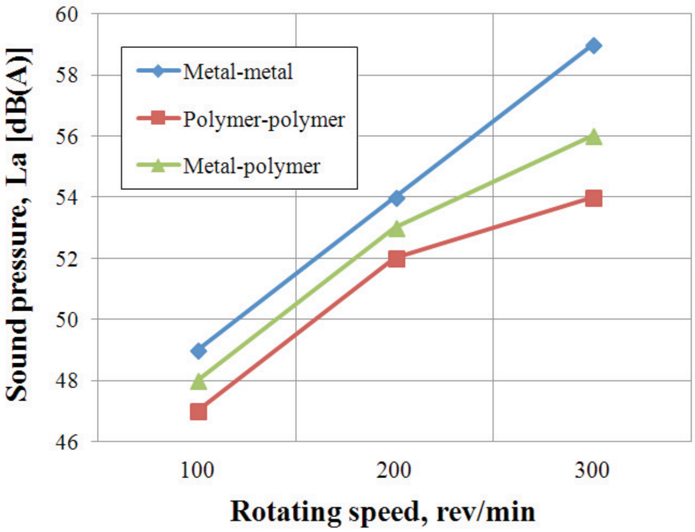


Fig. 6. The sound pressure level of the pump against rotating speed (at 4,2 bar).

Figure 6 shows, that noise increases if rotating speed increases. It is typical for all pinion shafts combinations. Moreover, the intensity of the sound pressure level increasing while the pair of "metal+metal" performance is higher than any combination with using a polymer. It should be noted that these dependencies were obtained in experimental values of pressure and rotating speed, which significantly differ from performance mode.

Preliminary analysis of the efficiency increasing by using of the polymeric materials suggests that the basic modes of the pump operation in combination with the use of polymeric pinion shafts will have greater effect in the sound pressure level reducing. More loaded experiment (n=300 rpm, Pout= 4.2 bar) was conducted without a configuration “polymer-polymer”. The spectrum of the sound pressure level of the pump unit is shown in Fig. 7.

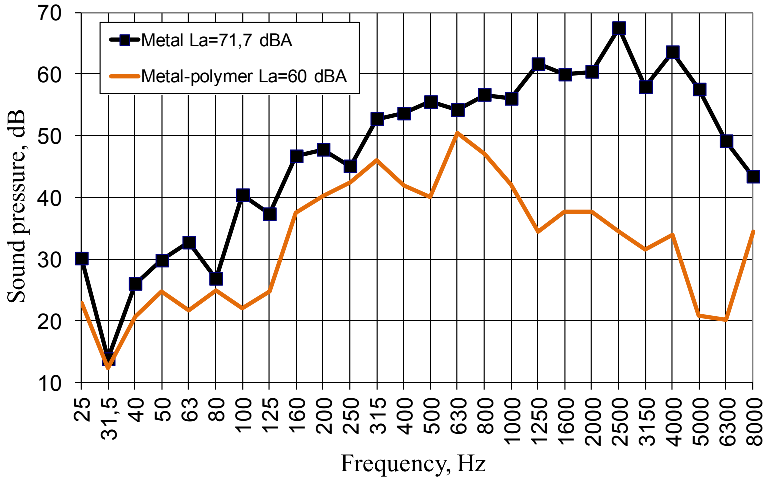


Fig. 7. The sound pressure of the pump unit with metal and polymer pinion shafts on mode: n = 200 rpm, Pout = 10 bar.

The measurement results of the sound pressure level on different configurations shows that the arrangement "polymer-metal" is better both in the frequency range and the scale A.

5. Discussion and conclusions

Conducted in this research experiment is a trial. Nonetheless two main results are obtained. Firstly, the gear pump noise level decrease when metal gears substitute on polymer ones. Secondly, pressure pulsations are lower after polymer gears were installed.

Fig. 5 shows that gear pumps with polymeric gears are quieter than metal ones because their low modulus makes them resilient when the teeth come into contact. The coefficient of friction of unlubricated plastics gears can be very high, as much as 0.8. But in this study a problem of the tribological noise generated as a result of the interacting tooth flanks is solved by the lubrication use. It is possible to see that increasing of speed rotation leads to noise increasing (Fig. 6). This trend is observed for all considered materials. Noise spectra comparison of the pump unit with metal and polymer pinion shafts shows that polymer application is more efficient on high frequencies (Fig.7). Probably it caused by the polymer flexibility.

Pressure pulsations are decreased (Fig. 4) due to the pump leakages which caused by polymer shrinkage after the injection. It should be noticed that mold for gears casting were produced by using metal gears. The shrinkage could be calculated in a case of 3D model using for injection. Therefore decreasing of the pressure pulsations is incorrect result. This experience should be takes into account during further researches.

The main advantages of plastic over steel gears are their low weight, high resilience and their ability to run under dry, unlubricated conditions. For high volume production the cost of plastic gears is low if manufactured by injection moulding.

Experiments show that the use of polymeric materials for rotor gear pump leads to noise reduction. On the one hand polymeric materials have a lower density than metal and they are more manufacturable. On the other hand, polymeric materials have lower tensile strength and much lower durability than the metal ones. Hence, polymeric materials are inappropriate for the manufacture of heavy duty pumps. Nonetheless there are a lot of systems with low loaded pumps.

The use of polymeric materials can reduce the weight and noise emission such devices as missiles (ballistic and space), torpedoes, underwater vehicles. Due to the low reactivity polymer pumps can be used in the chemical industry rather than metal ones. This requires the completion of construction and a careful selection of materials.

The using of the polymeric pinion shafts decreases the pump sound pressure level. More precise working regime data will be carried out in further experiments.

In a view of the identified deficiencies of the polymer pinion shafts the following ways to improve the results of the experiment will be taken:
- Improvement of the manufacture method of the product;
- The use of stronger and more wear-resistant plastics: polyamide 6, polyamide 66, POM, PPS, PEEK, etc. [19];
- The combined production of the drive shaft pinion: the shaft will be made from a metal and the gear will be made from a polymer. Therefore requires detailed elaboration of the casting process combined metal-polymer.
- Producing our own mold and a punch for a simple combination of polymers.
- The three-component non-contact laser-based vibration sensor should be used [20].

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