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SELECTED ADVERSE OPERATIONAL EFFECTS OF HYDROSTATIC SYSTEMS

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Abstract: *This paper discusses the operational and environmental aspects of hydrostatic systems. Requirements which such systems must meet and criteria for evaluating the latter are specified. The noisiness of operation of hydrostatic systems and the reduction of their environmental impact have become new major criteria. The interrelationship between pressure pulsations, mechanical vibrations and the noise (especially low-frequency noise) emitted to the environment is identified. Possible effective passive and active ways of reducing the adverse impact of hydrostatic systems are indicated.*

Keywords: Hydraulic pumps, Hydraulic drives, Noise, Infrasound, Pressure pulsation.

1. Introduction

Even though the current rapid advances in the technology and design of machines and devices equipped with hydrostatic systems bring about positive effects such as new areas of application, improvement of operational properties (e.g. hydraulic and mechanical efficiency), they are accompanied by certain (often unknown before) dangers related to problems in the construction, material and operational areas (e.g. operation in new environmental conditions). Foremost among them are dangers connected with vibroacoustic processes, i.e. mechanical vibrations and noise. The most noxious to the environment and most difficult to combat is low-frequency noise. Unfortunately, the latter has not been explicitly defined yet. In the literature on the subject the term low-frequency noise which applies to the frequency range of 10-250 Hz is increasingly commonly used. A subgroup of low-frequency sounds and vibrations are infrasounds. Infrasounds and low-frequency sounds are produced by, e.g., thunders, avalanches, tornados, aurora borealis, volcanos, earthquakes, waterfalls and rough seas. The infrasound level measured during storms and tsunamis reaches 140-145 dB. The frequency of the infrasounds produced by nature practically stays within the range of 0.01-20 Hz. Standard DIN 45680; 1997 is used in Germany to assess noise in rooms. The standard recommends to assess noise in one-third octave bands within the range of 8-100 Hz for 16 hours of day-time operation and 1 hour of night-time operation, and the levels should not exceed the values specified in Tab. 1.

In order to comply with the above restrictions the following three principal methods of reducing the noisiness of machines and devices are used:

- operational methods – consisting in removing the causes of noise or reducing noise emission through remedies applied to the noise source,
- passive methods – limiting the area of propagation of sound waves from the source of their emission through sound scattering and absorption,
- active methods – using secondary sound sources to suppress primary source noise.

The noisiness requirements set for contemporary machines cannot be satisfied using solely passive methods. The best results in noise reduction are achieved through the simultaneous use of operational, active and passive methods.

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Tab. 1: Permissible infrasound levels in environmental noise exposure (acc. to DIN 45680 1997).

Frequency Hz	**8**	**10**	**12.5**	**16**	**20**	**25**	**31.5**	**40**	**50**	**63**	**80**	**100**
Pressure level, dB, Leq (day)	108	100	91.5	84	76	68	60.5	53	45	38.5	38	38.5
Pressure level, dB, Leq (night)	103	95	86.5	79	71	63	55.5	48	40	33.5	33	33.5

2. Effect of noise on human body

Research has shown that exposure to infrasounds the level of which exceeds 180 dB can be fatal, two-minute exposure to infrasounds at the level of 150-172 dB is tolerated by healthy persons, whereas many hours of exposure to the level of 120-140 dB causes fatigue and can cause health disorders.

Changes in the condition of the organ of hearing caused by exposure to infrasounds and low-frequency noise can be permanent or temporary. According to different researchers, the auditory threshold shift, generally from 0 do 25 dB, quickly disappears within 30 min after the exposure ceases. Exposure to infrasounds can cause disorders of the organ of balance, manifesting themselves in: vertigo, nystagmus, body position stability disorders and changes in the internal ear. The symptoms are most severe after exposure to infrasounds with a frequency of 7 Hz and at levels above 120 dB. At very low frequencies also vibrations of the chest, breathing arrhythmia, the feeling of gagging, a headache, a cough, vision disorders and fatigue occur.

3. Effect of vibrations on hydrostatic components and systems

The user of a machine with a hydrostatic drive should be aware that supporting structure vibrations with a frequency of up to 100 Hz can occur and can result in the excitation of the control elements of hydraulic valves, such as overflow valves, distribution valves and proportional valves. The excitation of the elements which control hydraulic valves is due to the coincidence of the frequency of external mechanical vibrations with the frequency of the free vibrations of the control elements in the form of, e.g., a ball, a cone or a slide. The excitation of the elements which control valves is reflected in the amplitude-frequency spectrum of the pressure pulsation of the working hydraulic system. Fig. 1 shows the effect of external mechanical vibrations acting on a conventionally electrically controlled distribution valve (the direction of forcing consistent with the direction of slide movement). The pressure pulsation was measured with a PCB-ICP piezoelectric sensor located just before kinematically forced distribution valve.

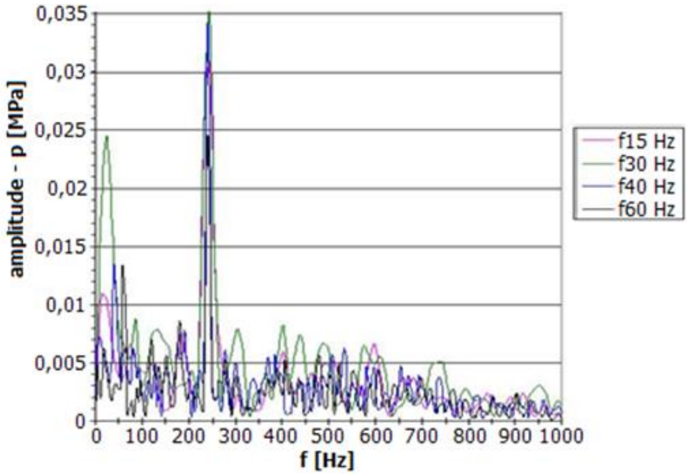

Fig. 1: Amplitude-frequency spectrum of pressure pulsation in hydraulic system with conventionally electrically controlled single-stage slide valve forced with frequency f = 15, 30, 40 and 60 Hz. Mean pressure 2 MPa, mean flow rate 6.5 dm3/min.

The result presented in Fig. 1 indicate that there is a relationship between some pressure pulsation spectrum components and the external mechanical vibrations acting on the selected hydraulic valves. In the spectrum this manifests itself in the occurrence of harmonics corresponding to the frequencies of the external mechanical vibrations.

Broadband pressure pulsation dampers are used to reduce pressure fluctuations and spikes in hydraulic systems. Such dampers are particularly effective in the low-frequency (infrasound) range. A broadband pressure pulsation damper consists of a passive chamber damper with an internal conduit, and an active damper. Exemplary amplitude-frequency pressure pulsation spectra (which were measured with PCB-ICP piezoelectric sensor located right behind the displacement pump) for a hydraulic system with and without a damper are shown in Fig. 2.

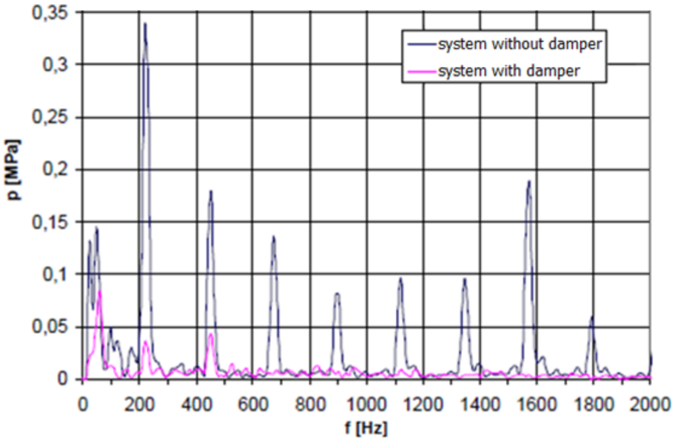

Fig. 2: Comparison of amplitude-frequency spectra for system with and without broadband pressure pulsation damper for mean pressure of 5 MPa.

The diagram shows that the broadband pressure pulsation damper reduces pressure pulsation several fold, which translates into a reduction in the system acoustic power level by 4-11 dB.

Since the displacement pump is the noisiest component of a hydraulic system, when investigating the effect of pressure pulsations on noise emission one should analyse the acoustic characteristics of the most commonly used hydraulic pumps, i.e. gear pumps. Fig. 3 shows a relationship between acoustic pressure L_m and forcing pressure for six gear pumps. One of them was a conventional pump widely used in industry, three were low-pulsation pumps made by leading manufacturers and the other two were pumps with a lowered acoustic emission level, developed jointly by Wrocław University of Science and Technology and the PHS HYDROTOR S.A. company. Both the low-pulsation pumps and the pumps with a lowered acoustic emission level are characterized by lower output fluctuation nonuniformity during operation than the conventional pump. As it is clearly evident in Fig. 4, they are characterized by noise emission lower by as much as 2-5 dB than acoustic pressure level L_m.

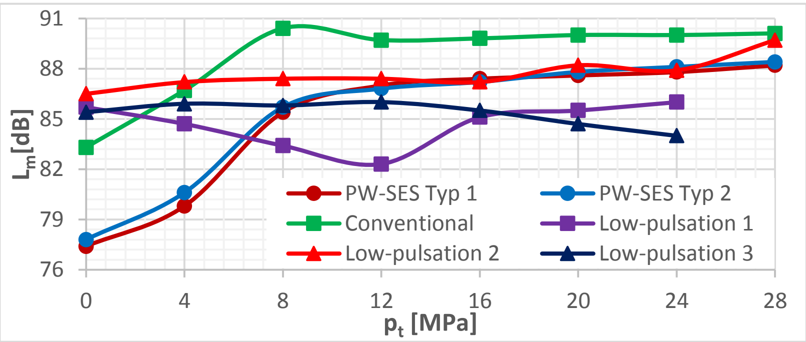

Fig. 3: Acoustic pressure level L_m depending on pressure at 1500 rpm.

It is precisely because of the connection between the output nonuniformity and noise emission of the gear pumps in hydraulic systems that operational methods consist mainly in changes to the design of the noisiest component, i.e. the hydraulic pump. Among hydraulic pumps, multi-piston pumps and external gear pumps are characterized by the highest noise emission. Therefore, the simplest operational solution seems to be to use a pump characterized by the lowest sound emission. However, this is not usually possible because of the inadequate performance of such pumps, their price and operating costs.

Investigations aimed at identifying the place of noise generation in a gear pump were carried out at Wrocław University of Science and Technology. They consisted in measuring sound intensity in the direction perpendicular to the investigated surfaces. The measurements were performed by means of a dualmicrophone sound intensity probe made by B&K. The measurement results in the form of a sound intensity distribution on the surface of the pump are shown in Fig. 4. The sound intensity distribution on the surface of the pump casing, determined using the radiosity method, indicated a local increase in sound generating vibrations in the region of the pump's rear cover on the driving wheel axis and on the casing in the area of the forcing chamber. This is evidence of the transmission of sound generating vibrations originating mainly from the pump's drive and from the pulsations of the working medium.

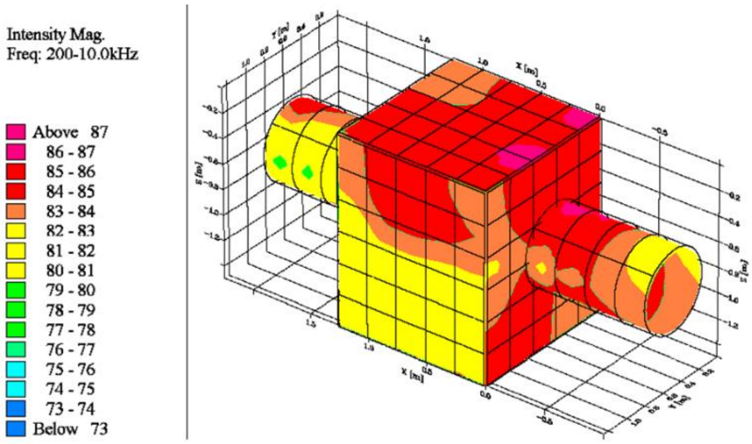

Fig. 4: Sound intensity distribution on surface of PZ-4 series pump for its rated operating parameters.

4. Conclusion

The results of the investigations done by the authors as well as by other researchers demonstrate that mechanical vibrations characterized by a wide frequency spectrum, including below 100 Hz, occur in machines with a hydrostatic drive. Also hydraulic valves are subjected to such vibrations. The overall results presented in Fig. 2 indicate that external mechanical vibrations cause changes in the amplitude-frequency spectrum of pressure pulsations in the hydraulic system incorporating the investigated valve. This is due to the fact that the frequencies of the external mechanical vibrations are close to the eigenfrequencies of the controlling element (the distribution valve slide). As a result, the latter falls into resonance. In the case of the conventionally electrically controlled single-stage distribution valve, the frequency of external vibrations at which the maximum amplitude of pressure pulsations occurs in the investigated system is about 30 Hz. The pressure pulsations generated in this way can be transmitted from the place of their origin (the vibrating hydraulic valve) via hydraulic conduits to farther system components and machines. Moreover, they can contribute to lower precision of the working units and greater nonuniformity of their operation and can shorten service life.

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