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EXPERIMENTAL INVESTIGATIONS OF THE VIBRATION OF HYDRAULIC MICROHOSES

M. Bocian*, M. Lubecki, M. Stosiak*****

Abstract: *Vibration is a common phenomenon in mechanical systems. But it can have many adverse effects on the functioning and durability of mechanisms. Particularly dangerous is resonance, i.e. the superimposition of the excitation frequency on the free vibration frequency of an element. Both flexible and rigid tubes belong to the hydrostatic drive's elements most susceptible to resonance. In their case, excitations most often originate from fluctuations in working fluid pressure and also from the vibrations of the other elements of a machine incorporating a hydraulic system. One of the ways of avoiding resonance is to design such geometry and fixing of the components that their free vibration frequencies do not coincide with the excitation. This paper presents an experimental approach to determining proper frequencies. An appropriate test stand and the way of conducting the experiment are described and analyses of the measured data are carried out. Moreover, the effect of the pressure and rate of flow of the fluid in the hose on the fundamental frequency of transverse vibrations is examined.*

Keywords: microhydraulics, vibration, hose

1. Introduction

Despite the intensive development of other forms of drive (electric, mechanical, etc.) hydrostatic drive still remains the leading solution in many machines. This is owing to its particularly high transmitted power/system mass ratio and to the fact that the system components can be freely arranged on the machine. For the last ten-twenty years there has been a trend towards miniaturization of hydraulic systems whereby a new field called microhydraulics has appeared.

Microhydraulics is a hydrostatic drive division where the rates of flow of the fluid in the system do not exceed 3 l/d (Kollek et al., 2011). In order to design equipment using such a drive one needs to know not only the static characteristics of the individual components, but also their dynamic properties. One of such properties is the behaviour of objects during vibrations.

The components of a hydrostatic drive can begin to vibrate as a result of external excitation originating from the work of the machine's other components and systems (the motor, the gears, the suspension system, the working parts) or fluctuations (due to fluctuations in pump delivery or to system transient states) in the flow of the medium in the system. Particularly dangerous is resonance, i.e. the superimposition of the excitation oscillation frequency on the element free vibration frequency, since it results in a sharp uncontrolled increase in the amplitude (and so in the velocity and acceleration) of the element vibrations and can be the cause of the more rapid fatigue wear of the unit or even its catastrophic

* Mirosław Bocian PhD, Eng.: Faculty of Mechanical Engineering, Wroclaw University of Science and Technology, Department of Mechanics, Materials Science and Engineering, Łukasiewicza 5, 50-371 Wrocław, PL, miroslaw.bocian@pwr.edu.pl

** Marek Lubecki M.Sc. Eng.: Faculty of Mechanical Engineering, Wroclaw University of Science and Technology, Department of Maintence and Operation of Logistic, Transportation and Hydraulic Systems,Łukasiewicza 5, 50-371 Wrocław, PL, marek.lubecki@pwr.edu.pl

*** Michał Stosiak DSc., PhD, Eng. Prof.: Faculty of Mechanical Engineering, Wroclaw University of Science and Technology, Department of Maintence and Operation of Logistic, Transportation and Hydraulic Systems, Łukasiewicza 5, 50-371 Wrocław, PL, michal.stosiak@pwr.edu.pl

failure. Other effects of the vibration of hydraulic components include increased noise emission and difficulties in precise controlling the receivers.

Vibration in mechanical systems, including the effect of vibrations on hydraulic and microhydraulic components, is extensively investigated in foreign and domestic literature ((Piersol, Paez, 2010; Kudźma, 2012; Stosiak, 2015). There are also many publications on the effect of vibrations and pressure fluctuations on typical hydraulic hoses (Czerwiński and Łuczko, 2015; Łuczko and Czerwiński, 2016; Paidoussis, 1998). However, in the world literature there are few works dealing with the effect of the excitation by external vibrations. Therefore, this became the subject of the present paper.

2. Methods

The commercially available hose Polyflex 2020N-012U30 made by Hannifin was used in the investigations. The hose's inside diameter was 2 mm, its outside diameter – 3.2 mm and its length – 960 mm. The hose worked in the hydraulic system shown in Fig. 1. Nine equally distant points (a_0, a_1, …, a_8), of which point a_0 was located in the place of hose fixing (ferruling) on the pump side and point a_8 in the place of fixing on the further system part side (Fig. 1), were marked along the entire length of the hose. External, vertical excitation was provided by rigidly fixing the hose in point a_3 to a vibration exciter supplied by a power amplifier, and generating excitation patterns by means of a digital function generator. Also the sweep function was used. A white noise signal was fed to the exciter to determine the excitation frequency range. Then the amplitude-frequency response was examined to determine in what frequency range the first four free vibration frequencies were situated. Hence the sweep range of 1-200 Hz, the time of 10 s and the exciter supplying voltage of 1 V were set. Fig. 2 shows characteristics of excitation as a function of frequency. Pressure fluctuation values at the beginning and end of the hose and the exciter vibration acceleration were recorded. The hose vibration velocity was recorded by a laser Doppler vibrometer whose beam was focused in point a_5. The sampling frequency was 5 kHz. The obtained traces were subjected to an FFT analysis in order to determine the hose vibration velocity amplitude-frequency responses. The Hanning window was used during the FFT analysis to obtain precise information about the frequency values. The free vibration frequencies were identified as the ones for which a considerable increase in hose oscillation velocity occurred. Measurements were performed for different values of the hydraulic parameters (pressure and flow rate) in order to examine the effect of the latter on the hose free vibration frequencies. The pressure assumed the values of: 70 bar, 100 bar and 150 bar and the rate of flow of the fluid amounted to respectively 0.2 l/min, 0.6 l/min and 1 l/min. Each measurement was preformed three times.

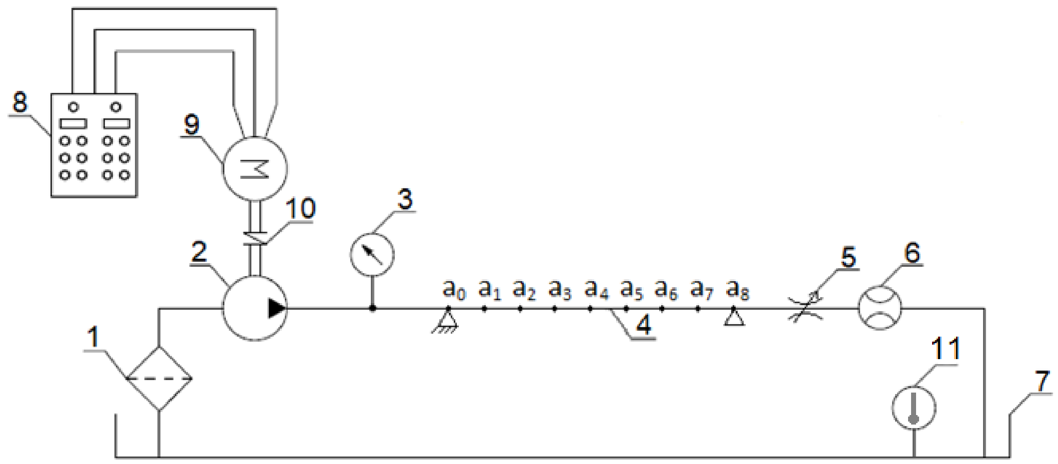

Fig. 1: Schematic of hydraulic system: 1 – filter, 2 – gear micropump, 3 – pressure gauge, 4 – tested microhose, 5 – preset throttle microvalve, 6 – flowmeter, 7 – tank, 8 – control cabinet, 9 – electric motor, 10 – torque indicator, 11 – temperature meter.

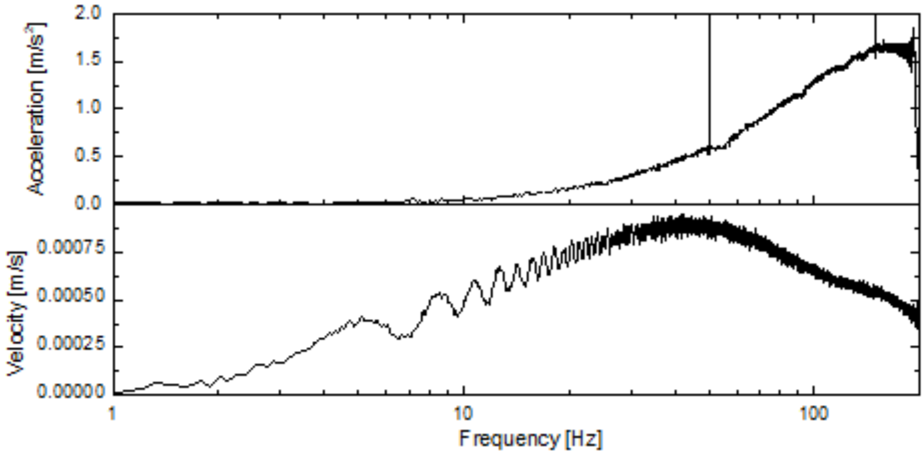

Fig. 2: Characteristics of excitation (acceleration and velocity of vibration) as a function of frequency.

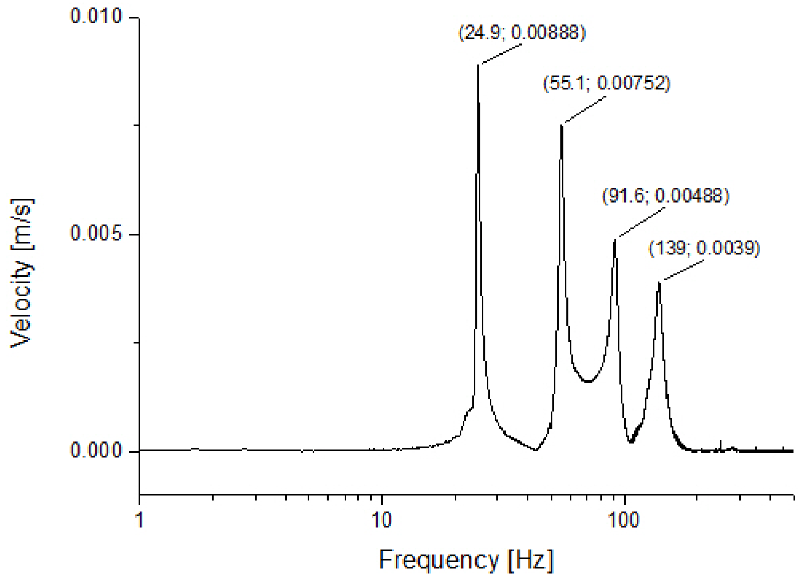

Fig. 3: Amplitude-frequency response of hose vibration velocity at switched off hydraulic system.

3. Results

The first measurements were carried out when the hydraulic system was switched off. The aim was to determine the free vibration frequencies of the hose with no effect of the flowing fluid taken into account. Figure 3 shows the vibration velocity amplitude-frequency response obtained in this way. As one can see, the fundamental free vibration frequency amounted then to f_1 = 24.9 Hz. The diagram also shows the next vibration forms with: f_2 = 55.1 Hz, f_3 = 91.6 Hz, f_4 = 139 Hz, respectively. Figure 4 shows the effect of the flow rate and the fluid pressure in the system on the base, second and third free vibration frequency of the hose. It is apparent that as a result of a pressure increase the fundamental vibration frequency shifts upwards, whereas a flow rate increase shifts this frequency downwards.

4. Conclusions

It is apparent that the successive free vibration frequencies (vibration forms) of the microhose are not integral multiples of the fundamental frequency. Hydraulic hoses are composite elements made of steel braided elastomeric materials. As a result, the whole system is nonlinear whereby the free vibration frequencies shift relative to the expected values and the resonance frequency depends on the amplitude of the vibrations. Similar trend could be observed for the second and third harmonics.

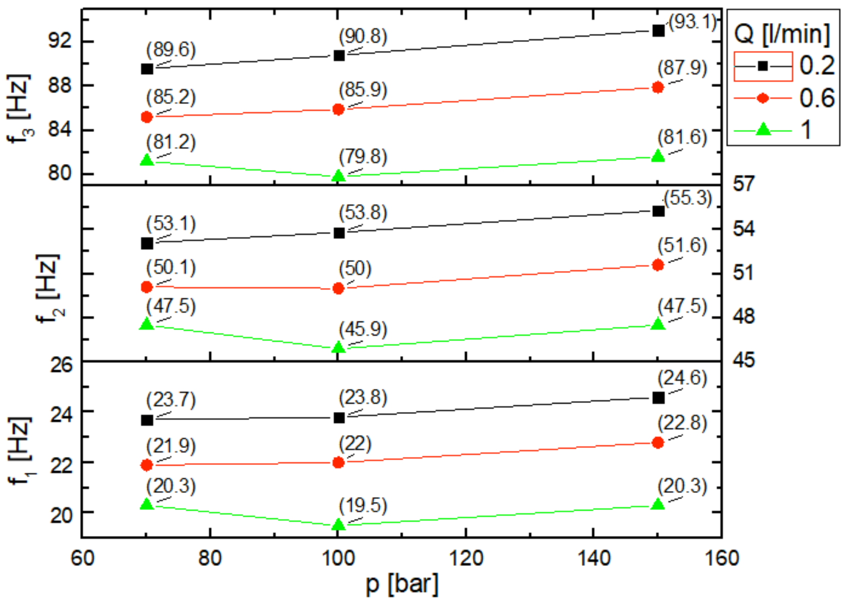

Fig. 4: Effect of pressure and flow rate in system on fundamental (f_1), second (f_2) and third (f_3) free vibration frequencies of investigated microhose.

Another important observation is that the pressure and rate of flow of the fluid through the hose have an effect on the frequency of its free vibrations. It has been found that the effect of the pressure is significantly stronger than that of the free vibration frequency. An increase of pressure shifts vibration frequencies upwards, whereas a flow rate increase shifts these frequencies downwards. A similar trend could be found when investigating conventional elastic hoses (Fiebig, Harla, 2010). In-depth analysis of this phenomena requires supplementing experimental data with a theoretical model. Bernoulli-Euler and Timoshenko beam theories could be used as a starting point for deriving such a model (Zhag, Tysseling and Vardy, 1999), which will be a subject of further investigation.

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