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Experimental investigation on adaptive Helmholtz resonator for hydraulic system

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ABSTRACT

The pressure pulsation of the gas turbine fuel system may lead to instable combustion in low-emission combustor chamber. The fundamental frequency of the pump varies greatly while the engine mode changes. It is necessary to use a special adaptive Helmholtz resonator tuned to the pump speed. In this work the adjustable element of the resonator was a volume of a cavity. This study focuses on experimental investigation of the tunable resonator efficiency in the interested frequency band. The experimental set up was consisted of a pump, a fuel cooling system, a resonator with a piston to change the volume of the cavity, and the imitation the fuel system. During the tests, the pressure pulsation before the resonator and after it as well as pressure pulsation after the pump without the resonator were acquired. The volume of the cavity also was varied from minimum to maximum limits. The efficiency of the adaptive Helmholtz resonator was estimated using insertion loss factor. The frequency characteristic of the adaptive resonator efficiency represents a monotonically decreasing curve. The experimental data verified the theoretical calculation with high accuracy. The adaptive Helmholtz resonator provides much higher attenuation of pressure pulsation than unregulated one in entire frequency range.

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1. INTRODUCTION

A pump is a main source of pressure pulsations of the working fluid in a hydraulic system, which greatly reduce reliability and resource of the pipelines and hydraulics [1]. Moreover, pressure fluctuations of the gas turbine fuel system can cause instable behavior in the overall system, which may lead to instable combustion in low-emission combustor chamber.

There are several types of pulsation attenuators. The most preferred type in this case is resonator-type pressure pulsation damper, i.e. Helmholtz resonator, because of its lack resistance to the stationary flow of working fluid and high efficiency. However, efficiency of reducing pressure pulsations using the unregulated Helmholtz resonator greatly reduces if its natural frequency is not equal to the frequency of pressure pulsations of working fluid. In turn, the frequency of pulsations depends on the fundamental frequency of the pump, which varies greatly while the engine mode changes.

There are many experimental investigations on Helmholtz resonators in systems with a gas working fluid that can be applied to the hydraulic systems. For example, one of the methods to increase the frequency band of attenuation is to use different Helmholtz resonator array configurations [2, 3]. Another method is to use 3 degrees of freedom Helmholtz resonator, which is investigated by G. Changbin, J. Zongxia [4]. However, these methods are not suitable due to a strong increase in the mass of the unit. Another way is development a special adaptive Helmholtz resonator tuned to the pump speed. An adaptive Helmholtz resonator in hydraulic systems has been studied by e.g. L. Kela [4 5], G. Kim, K. Wang [6]. In this work the adjustable element of the resonator was a volume of a cavity, since this method is the most technologically advanced and capital saving.

However, at the moment a small amount of research is devoted to the effectiveness of Helmholtz resonator with respect to hydraulic systems, especially aircraft hydraulic systems. Therefore, this study focuses on experimental investigation of the tunable resonator efficiency in the interested frequency band.

2. TEST RIG

2.1 Circuit diagram for the test rig

The circuit diagram for the test rig is presented in Figure 1. The test rig consists of 2 main blocks:

-the working fluid preparation block;

-the block of the main pump unit (with the adaptive Helmholtz resonator).

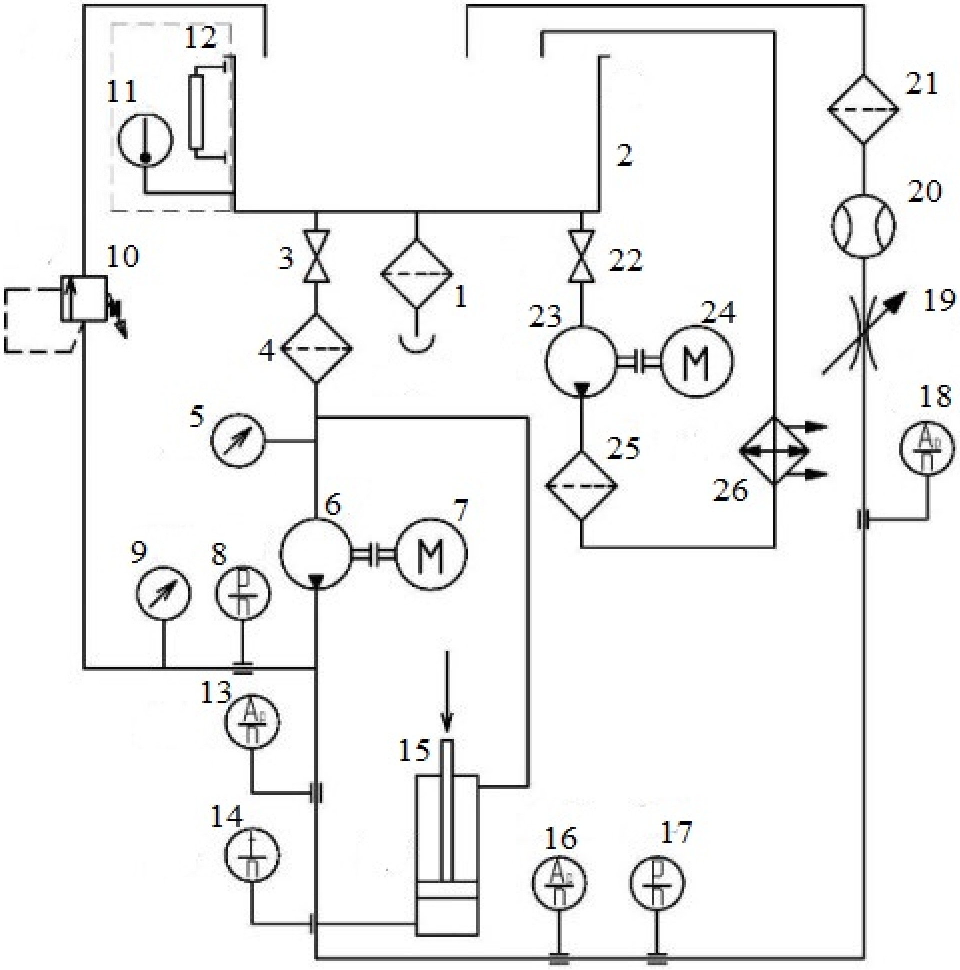

Figure 1. Circuit diagram for the test rig. 1 – oil-tank hopper, 2 – hydraulic tank, 3 – cutoff valve, 4 – filter, 5 – vacuum gauge, 6 – gear pump, 7 – electric motor, 8 – pressure transmitter, 9 – manometer, 10 – adjustable relief valve, 11 – thermometer, 12 – level indicator, 13 – pressure pulsation detector, 14 – electronic temperature transmitter, 15 – hydraulic cylinder with a ballscrew actuator, 16 – pressure pulsation detector, 17 – pressure transmitter, 18 – pressure pulsation detector, 19 – adjustable choke, 20 – flowmeter, 21 – filter, 22 – cutoff valve, 23 – gear pump, 24 – electric motor, 25 – filter, 26 – water heat exchanger.

The test rig is equipped with a hydraulic tank with a volume equal to 150 l. The tank is equipped with a level indicator with a Filtrec FL2TM12 thermometer to monitor the temperature and level of the working fluid. The working fluid used in the test equipment is a Gazpromneft Hydraulic Hlp 46 mineral hydraulic oil.

The test rig is presented in Figure 2.

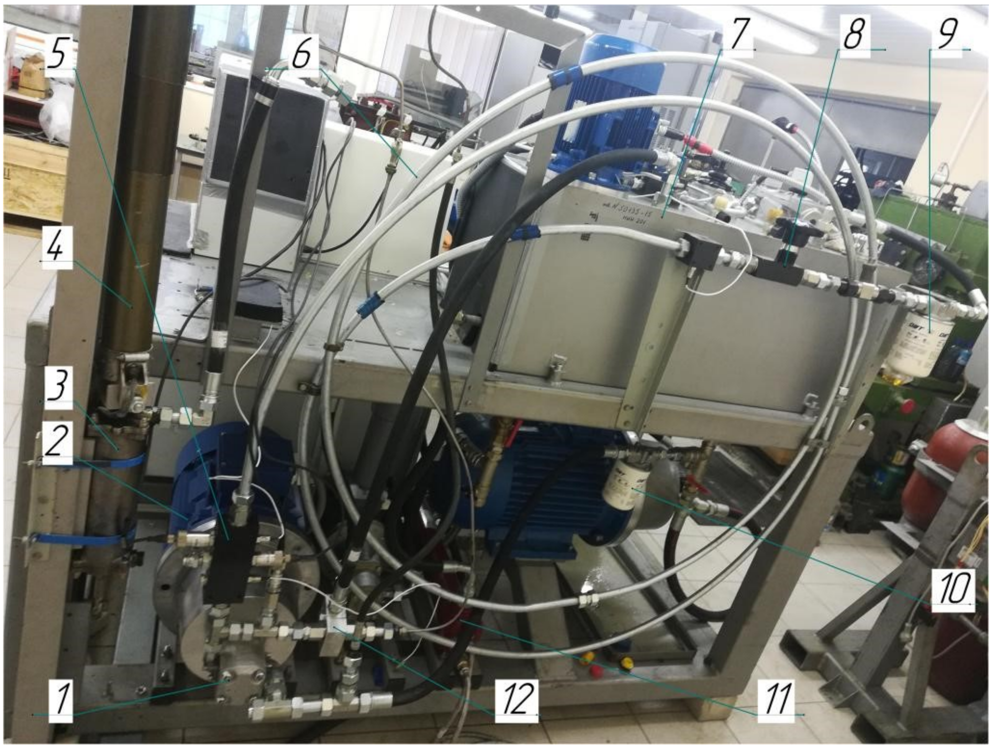

Figure 2. Test rig. 1 – the main gear pump, 2 – the pump motor,3 – the adaptive Helmholtz resonator, 4 – the ballscrew actuator, 5 –the data-transmitter unit, 6 – the acoustic load, 7 – the hydraulic tank, 8 – the adjustable choke, 9 – the outlet filter, 10 – the inlet filter, 11 – the adjustable relief valve, 12 - the working fluid preparation block.

2.2 Working fluid preparation block

A Bosch Rexroth AZPG-22-032-RCB20MB gear pump is used for pumping working fluid. The pump shaft is driven by an AIS 90L2 electric motor. Working fluid preparation block is equipped with a OMT SA081-715-S4 water heat exchanger to maintaining and regulating the temperature of working fluid. A Bosch Rexroth ABZFD-S0080-10H-420-1X/M-B pressure filter is installed for the working fluid filtration.

3.1 The block of the main pump unit

The main pump was a Bosch Rexroth AZPF-12-014RCB20MB gear pump. The pump shaft was driven by an AIS 160M4 B01 electric motor. The length of the main pipeline was 9 m. A Duplomatic RSN5/30 adjustable choke was installed at the exit from the pipeline to adjust the pressure at the outlet of the main pump unit. To filter the working fluid in the test rig, a OMT OMTI05CNA filter was installed in the suction line and a OMT OMTI05GNR filter was installed in the drain line were used. For protection against overpressure at the outlet of the pump unit, a Duplomatic CR5/22N adjustable relief valve was used.

The adaptive Helmholtz resonator was made of the hydraulic cylinder which inner diameter is 0.078 m. The nozzle and the pipe section to the main pipeline act as a resonator neck, the cylinder piston side acts as a cavity of the Helmholtz resonator. The inner diameter of the neck is 8 mm, the length of the neck is 120 mm. The volume of the cavity was varied by the hydraulic-cylinder rod which moved by the ballscrew actuator. The minimum value of the cavity was 0.0795 l, the maximum value was 0.5478 l. This hydraulic cylinder with the ballscrew actuator is presented in Figure 3.

Figure 3. The adaptive Helmholtz resonator

The hydraulic test rig was designed in such a way that the test rig allows determining both the static parameters of the working fluid and the dynamic parameters of the gear pump and the adaptive Helmholtz resonator. Thus, the measuring instruments included a Hydac HDA 4748-H pressure transmitter, a Hydac ETC 4548-H electronic temperature transmitter and a Hydac HMG 3000 portable data recorder. A vacuum gauge and two manometers were used to visually monitor the pressure at the pump inlet and outlet.

3. TEST PROCEDURE

The adaptive Helmholtz resonator was tuned to the frequency of the lower tooth harmonic of the pulsations of the gear pump. The efficiency of the adaptive Helmholtz resonator was estimated using the insertion loss factor K_{IL}, which represents the ratio of the amplitude of pressure pulsation in the circuit without a resonator to the amplitude of pressure pulsation in the circuit with the resonator [7]. The insertion loss factor was experimentally determined for three values of the cavity volume: with maximally extended rod, with 0.75 from the maximum extended rod and with 0.5 from the maximum extended rod.

During the tests, pressure pulsation in the cross-section before the resonator and after it as well as pressure pulsations after the pump without the resonator were acquired. The volume of the cavity also was varied from minimum to maximum limits.

The temperature of the working fluid was maintained at 30±2°C. The pressure of the working fluid also remained constant and was maintained with the throttle at the outlet of the pipeline simulating the hydraulic load. The average pressure level was 2.5 MPa.

The registration of pressure transducers readings was carried out on a personal computer using the analog-to-digital conversion. The sampling rate was 10 kHz, the recording time was 2 sec. Such parameters of the registration of pressure transducers readings make it possible to analyze the recorded pulsations in the frequency range from 0.5 to 2500 Hz, because the studied frequencies of the lower tooth harmonics of the pulsations of the gear pump are located above 80-100 Hz.

Further, Fourier analysis of the recorded signal was performed. The short time Fourier transform with an overlap of 99.95% was performed using the Hanning window. The number of Fourier spectral lines was 2048. Thus, the spectrum was averaged over 37952 windows, which ensured the accuracy of the Fourier transform of the order of 0.003%. Since the recorded signal is random, the power spectral density of the analyzed signal was calculated.

3. RESULTS

The expected effectiveness of reducing the pressure ripple using the adaptive Helmholtz resonator used in the experiment was evaluated by automated program for calculating dynamic characteristics of the adaptive resonator.

The results of experimental data processing and their comparison with the results of the mathematical modeling are presented in Figure 4.

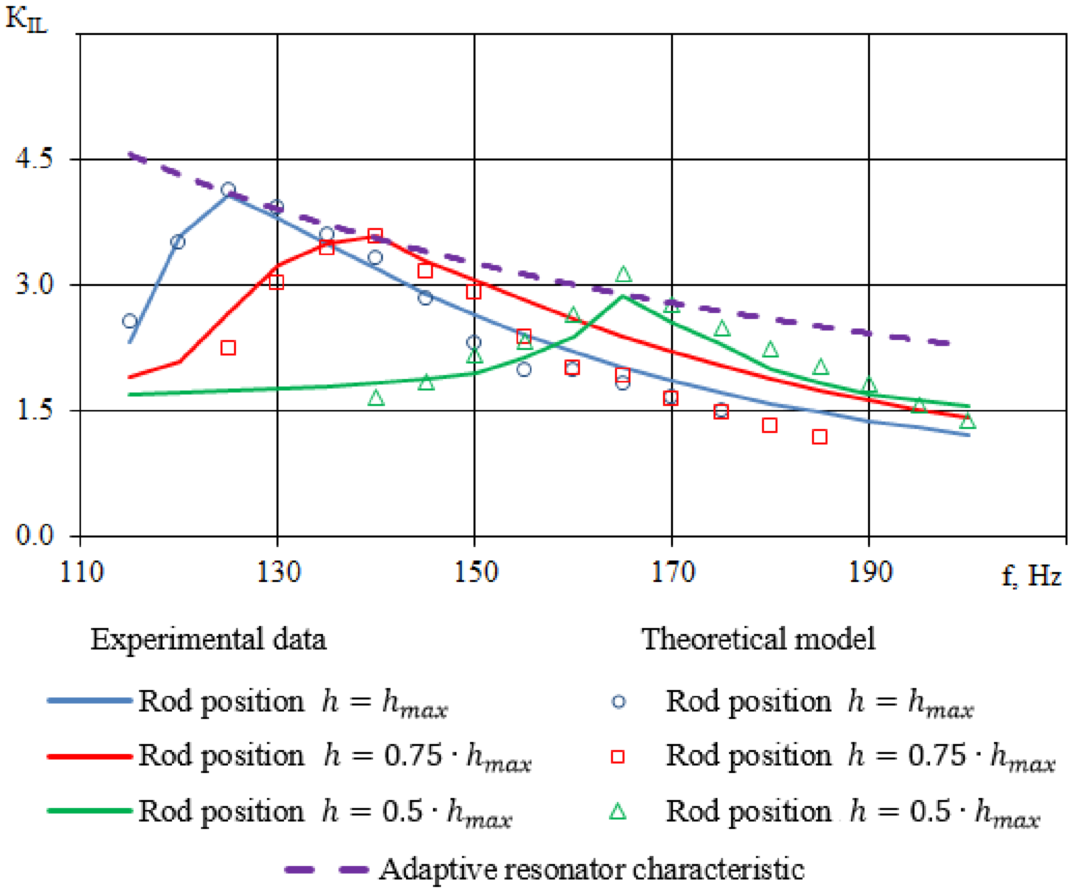

Figure 4. The frequency dependence of the insertion loss factor of the adaptive Helmholtz resonator

A comparison of the calculated and experimental values of the insertion loss factor shows their good convergence. Adequacy of the theoretical model was confirmed by Fishers' ratio test, which was equal to 1.24 at the test significance equal to 1.91.

As can be seen from Figure 4, the frequency characteristic of the adaptive resonator efficiency represents a monotonically decreasing curve. On the subresonance frequencies, the efficiency of the adaptive absorber increases more than three times compared to the unregulated resonator, on the supperresonance frequencies – more than half times. Thus, the adjustment of the Helmholtz resonator by changing the volume of its cavity allows to increase its efficiency in entire frequency range.

4. CONCLUSIONS

As a result of research the adaptive Helmholtz resonator has been developed and experimentally investigated. For experimental research, the hydraulic test bench was designed. The experimental data were compared with calculated values of the insertion loss factor and the adequacy of the theoretical model was confirmed by Fishers' ratio test. This study proved, that the investigated adaptive Helmholtz resonator provides much higher attenuation of pressure pulsations than the unregulated one in entire frequency range. Such technology can be widely used in aviation industry while reducing dynamic loads and ensuring the stability of low-emission combustion chambers. In addition, the adaptive Helmholtz resonator can be widely used in the petroleum, chemical and other industries.

5. ACKNOWLEDGEMENTS

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