INVESTIGATION OF THE VIBROACOUSTICAL CHARACTERISTICS OF THE GAS-TURBINE ENGINE NK-14ST FUEL-CONTROL SYSTEM

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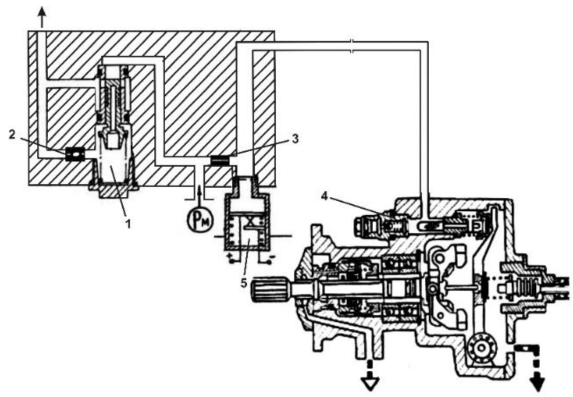
In this paper, we consider the reason of high pressure pulsation and vibration of the gas-turbine engine NK-14ST and pipe break in the fitting location of the oil pump engine-control system. The engine is intended for the gas transfer plant blower drive. NK-14ST is based on NK-12ST production engine. The engine can also be used as the power plant for hydrofoil ships. In the end of 90s, the engine-control system was modernized. Instead of the gas-measuring device DG-12 in the control system was included gas-measuring device DG-97 and an electronic control system of fuel injection. After that the high pressure pulsation and vibration was indicated in the engine tests. On the operating conditions of engine was indicated pipe break in the fitting location of the oil pump engine-control system. The experiment research of vibroacoustical characteristics of the fuel-control system units was done for the gas-turbine engine NK-14ST. The reason of the high pressure pulsation and vibration of the gas-turbine engine NK-14ST and pipe break in the fitting location of the oil pump engine-control system was defined. This is the self-oscillations of pressure reducer valve because of changing force balance of the valve. The reason of changing force balance is decrease oil consumption after removal units from the control system and increase oil pressure on the reducing valve spool on the operating conditions. The pressure pulsation and vibration abatement procedure was developed. There is a changing the acoustic load of the drain line. The experimental validation of developed procedure was done.

Keywords: pressure, pulsation, vibration, gas-turbine engine

1. Introduction

The gas-turbine engine NK-14ST is intended for the gas transfer plant blower drive. NK-14ST is based on NK-12ST production engine. The engine can also be used as the power plant for hydrofoil ships. The engine NK-14ST is designed by order of «Gasprom» as a modification of the engine NK-12ST. This engine is created on the base of engine NK-12ST and is completely interchangeable with it. The engine has improved general performance data. The change of the combustion chamber, turbo-compressor turbine, main and free turbines resulted in engine power and efficiency increase. The modified engine NK-14ST with regenerative cycle, increasing the engine efficiency up to 41.5% [1-3].

In the end of 90s, the fuel-control system was modernized. Instead of the gas-measuring device DG-12 in the control system was included the gas-measuring device DG-97 and electronic control system of fuel injection. The pressure reducer valve RK-14, gas-measuring device and pressure switch MST-15S are placed in one case and the overspeed chopper of the free turbine OG-8-4 remained in the fuel-control system (Fig. 1).



1 - pressure reducer valve RK-14; 2,3 – jets, 4 - overspeed chopper of the free turbine OG-8-4;
5 - pressure switch MST-15S.
Figure 1: The modernized fuel-control system of the gas-turbine engine NK-14ST.

Changing configuration of the engine-control system became the reason for reduction of the oil flow rate and increase oil pressure on the reducing valve spool on the operating conditions of engine. The force balance on the spool of valve and the work condition of valve are changed. After that high-pressure pulsation and vibration were indicated in the engine tests. On the operating conditions of engine was indicated a pipe break in the fitting location of the oil pump engine-control system [82, 83]. In the pipes from the injection pump to pressure reducer valve RK-14 in the oil system was detected oscillations in the frequency range 576-590 Hz. The frequency range of the oscillations didn't change despite the intensive change of the turbocompressor rotation speed [4-6].

2. The experiment research of the gas-turbine engine NK-14ST

The experiment research of the vibroacoustical characteristics of the fuel-control system units was done for the gas-turbine engine NK-14ST.

The pressure switch MST-15S and the absorbing jet were removed from the pressure reducer valve RK-14 and install the pressure pulsation sensor DD-10. The pressure pulsations are measured under engine operating conditions: idle, n: 7800 RPM, 7900 RPM, 7980 RPM, normal shutdown, emergency shutdown (after 4 min of idle). The experimental results are shown in the Table 1.

Table 1: The pressure pulsations are measured under engine operating conditions.

Engine operating conditions	Pressure pulsations		
	F, Hz	AP, MPa	n, RPM
Engine start	581 560	>3.25 2.97	6250 4880
Idle	576	3.95	6210
Idle -8000	578	>6	6500
Normal shutdown	598 552	1.22 3.2	2820 6220
Emergency shutdown (after 4 min of idle)	588	2.6	4540

The maximum of the pressure pulsation in the pressure reducer valve RK-14 was detected in the frequency range 541...598 Hz in the 6210...6500 RPM. In some cases the high pressure pulsation was detected on idle (n_{tc} =6500 RPM)

The reason of high-pressure pulsation is the changing force balance in the pressure reducer valve. The coincidence of the self-oscillations frequency and one of the natural frequencies was the reason of the resonance and the pipe bursting.

3. Semi-natural test bench for experimental research of the fuel-control system

The experiment research of the vibroacoustical characteristics of the fuel-control system units was done in the semi-natural test bench of the OAO «SKBM» (Fig. 4.2).

The test bench consist of the tank, injection gear pump, electric drive motor, pressure reducer valve RK-14, pressure pulsation damper, jets and pipelines.

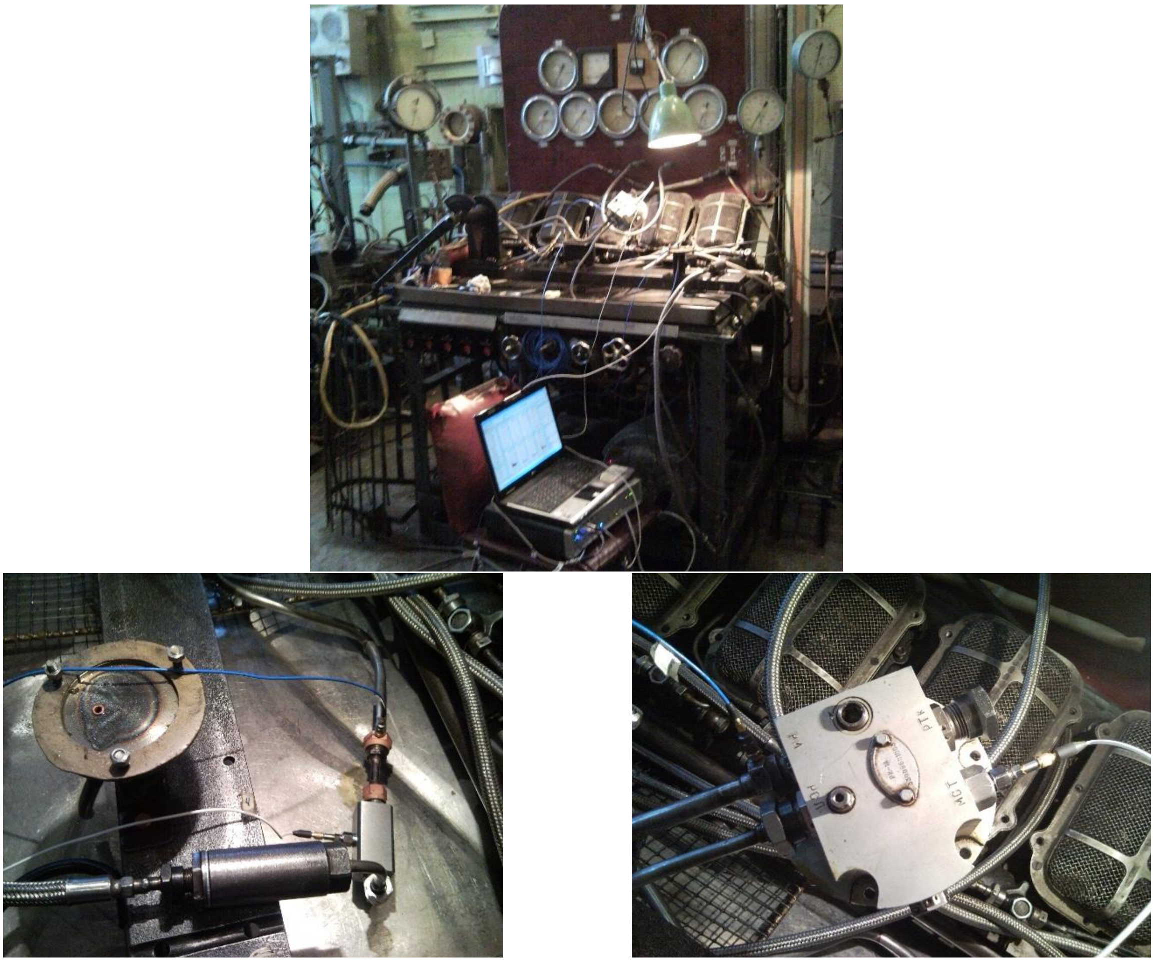


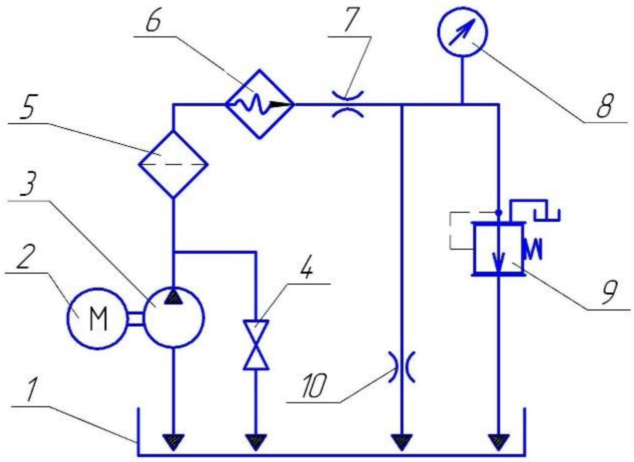
Figure 2: Semi-natural test bench of the OAO «SKBM».

The oil is served from the tank (tank capacity is 100 liter) by the injection gear pump 4020. The pressure pulsation damper located in the pipeline in the outlet of the pump. The pressure pulsation damper is used for acoustical uncoupling of the gear pump and the investigated pipeline. For the flow rate $\boldsymbol{Q}$ =25 liter per minute in the inlet of the system and the pressure $\boldsymbol{P}_{вх}$ =4 MPa, after pressure pulsation damper was installed the jet by the diameter of 2.5 mm.

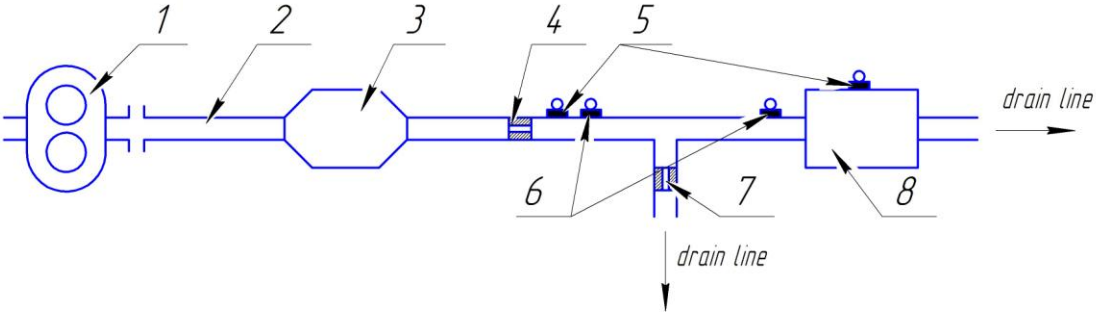
The pressure reducer valve RK-14 is used for keeping constant the oil pressure 3 MPa in the control system. When the pressure oil in the fuel control system is not to exceed 3 MPa the valve is closed. When the pressure oil became more than 3 MPa the valve spool is moving and open the oil bypass on the drain. If the pressure oil became less than 3 MPa the valve spool is moving to the normal position. The acoustic load is changed by various diameters of jets installed in the drain line between the pump and the reducer valve.

The hydraulic diagram of the semi-natural test bench is shown in the Fig. 3.

In the inlet of the pressure reducer valve and in the outlet of the pump in the pipeline were installed the pressure pulsation sensors PCB M101A06 and vibration sensors PCB M353B16. The twelve channel signal analyzer LMS SCADAS Mobile and LMS Test.Xpress are used for signal processing of test data (Fig. 4).



1 – tank; 2 – electric motor; 3 – gear pump 4020; 4 – shut down valve; 5 – low-pressure filter; 6 – pressure pulsation damper; 7 – jet; 8 – manometer; 9 – pressure reducer valve RK-14; 10 – jet in the drain line.
Figure 3: Hydraulic diagram of the semi-natural test bench.



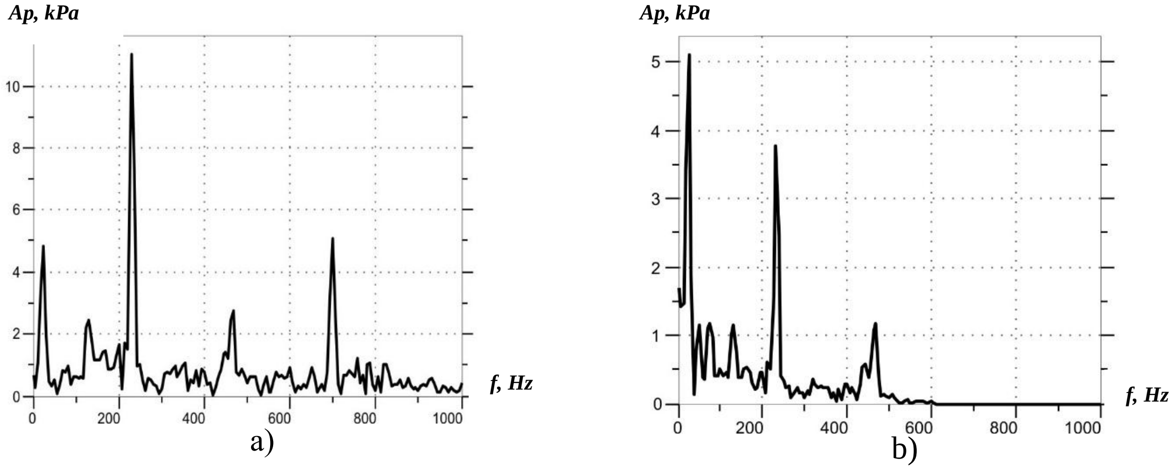
1 – gear pump 4020; 2 –pipeline; 3 – pressure pulsation damper; 4 –jet; 5- pressure pulsation sensors PCB M101A06; 6 – vibration sensors PCB M353B16; 7 - drain line jet; 8 –pressure reducer valve RK-14.
Figure 4: Measuring scheme.

The experimental research was done for the different values of the acoustic load impedance (in the non-dimensional value - acoustic load impedance/wave impedance) 14.9, 5.8, 3.7, 1.9, 1.4, 0.9 corresponds to the drain line jet diameter 0.5 mm, 0.8 mm, 1 mm, 1.4 mm, 1.6 mm, 2 mm. The signals records were on the steady-state condition.

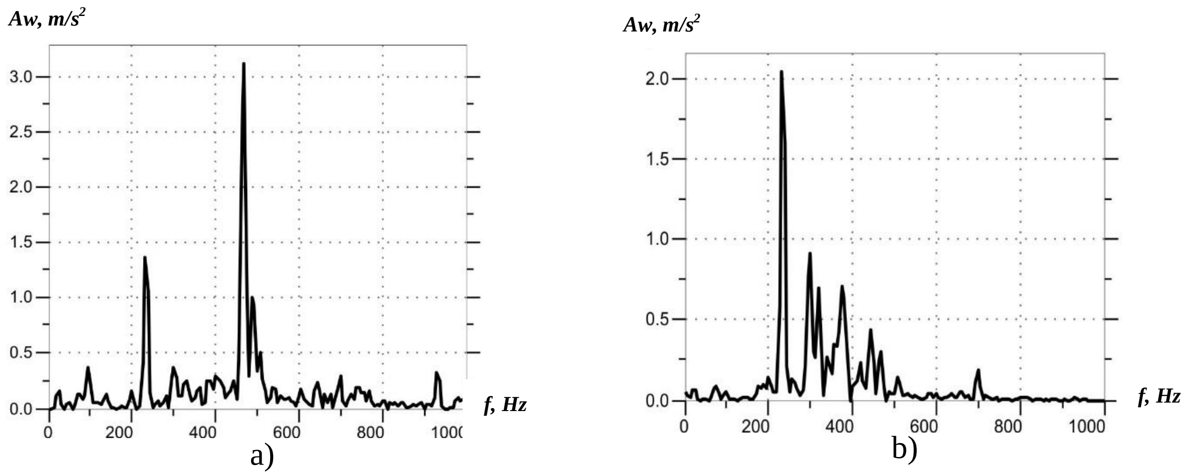
The experimental results presented in the Figs. 5, 6.

In the figures we can see the first tooth mesh frequency 242 Hz and the first rotor frequency 24 Hz. The pressure pulsation amplitude of the first tooth mesh frequency in the outlet of the pump higher than amplitude in the inlet of the pressure reducer valve. The reason of it deformation of the pressure wave because of installed jet in the drain line. The pressure pulsation amplitudes of the first rotor frequency close each other for the all presented load impedance.

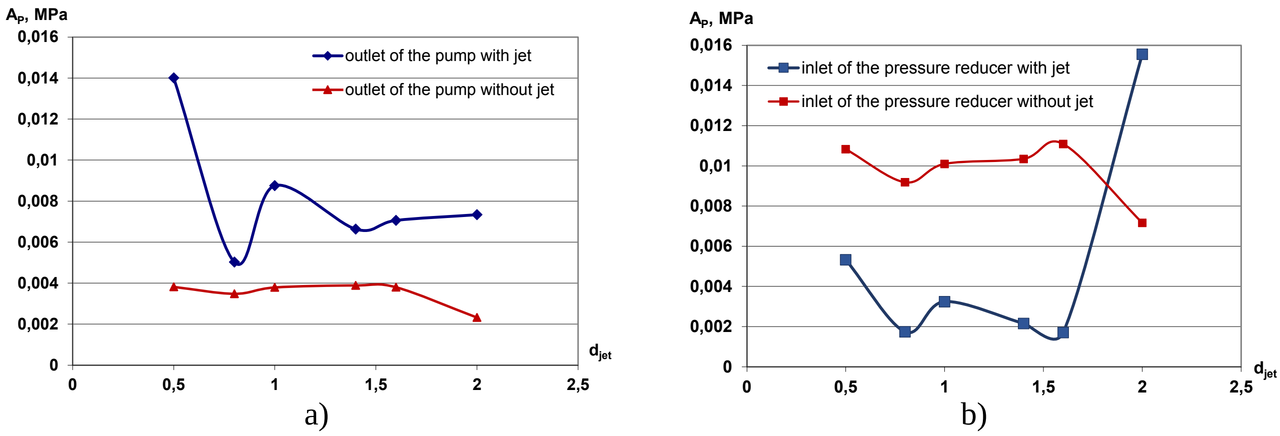
In the Figs. 7, 8 presented the amplitude of pressure pulsation and vibrational acceleration dependence of the first tooth mesh frequency from the drain line jet diameter.



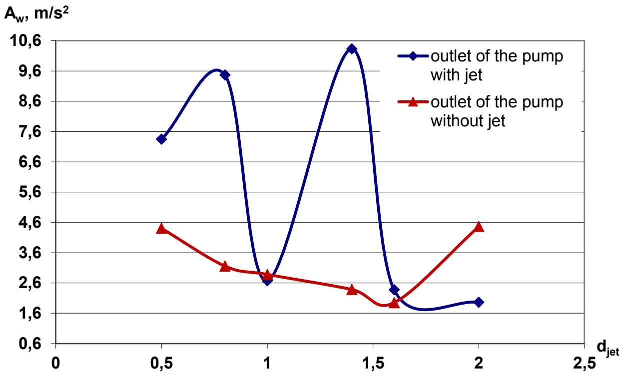
a) outlet of the pump; b) inlet of the pressure reducer valve.
Figure 5: Pressure pulsation spectrum for the non-dimensional load impedance 1.4.



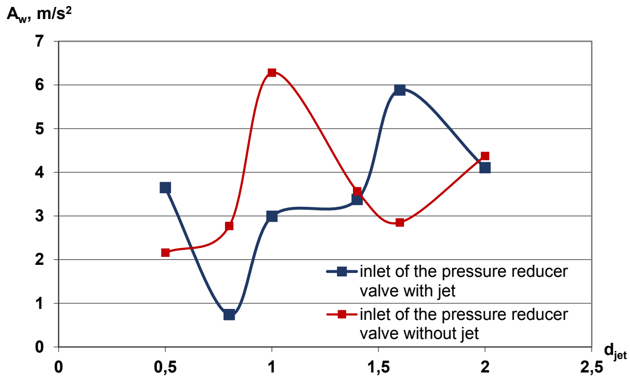
a) outlet of the pump; b) inlet of the pressure reducer valve.
Figure 6: Vibrational acceleration spectrum for the non-dimensional load impedance 1.4.



a) pump outlet; b) pressure reducer inlet.
Figure 7: Amplitude dependences of pressure pulsation of the first tooth mesh frequency from the drain line jet diameter.



a)



b)

a) pump outlet; b) pressure reducer inlet.

Figure 8: Amplitude dependence of vibrational acceleration of the first tooth mesh frequency from the drain line jet diameter.

The curves in the figures with jets and without jets in the drain line are close each other. Jets installation in the drain line between the pump and the reducer valve is not influence on the rate of curves. The minimum value of pressure pulsation corresponds to the load impedance 0.9 in the Fig. 7,b.

Changing the acoustic load impedance by installing jets in the drain line between the pump and the reducer valve provides decrease of the pressure pulsation approximately in 20 times.

Conclusion

The experiment research of the vibroacoustical characteristics of the fuel-control system units was done for the gas-turbine engine NK-14ST. The reason of high-pressure pulsation and vibration of gas-turbine engine NK-14ST and the pipe break in the fitting location of the oil pump engine-control system was defined. This is the self-oscillations of pressure reducer valve because of changing force balance of the valve. The reason of changing force balance is decrease oil consumption after removal units from the control system and increase oil pressure on the reducing valve spool on the operating conditions. The pressure pulsation and vibration abatement procedure was developed. There is the changing the acoustic load of the drain line. The different diameter of the drain line jets were investigated. Minimum value of pressure pulsation was detected with the load impedance 0.9 correspond to the drain line jet diameter 2 mm.

Changing the acoustic load impedance by installing of the drain line jets between the pump and the reducer valve provides decrease of the pressure pulsation approximately in 20 times.

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