Procedure for Studying the Natural Frequencies of the Valve Mechanism of the Internal Combustion Engine

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PROCEDURE FOR STUDYING THE NATURAL FREQUENCIES OF THE VALVE MECHANISM OF THE INTERNAL COMBUSTION ENGINE

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Operational reliability, efficiency, active safety, and environmental qualities of a car are largely determined by the operation of its engine. Therefore, the search and study of new diagnostic methods that allow quickly, as simple as possible, and reliably identifying faults is an urgent task. The justification for this statement can be carried out experimental studies of vibration of an internal combustion engine (ICE). As a result of these studies, ICE vibration was found to be acoustic in nature. It is proved that it is possible to use the directional microphone EM-8800 and the acoustic noise recorder of the 1st class Robotron 00023 as a sensitive element of the ICE valve mechanism diagnostics system. The exploratory partial survey runs on a full-scale Ford
V1.3 8-valve engine and SpectraLAB software built on a base PC using a handheld vibration analyzer. Due to this, it became possible to obtain the amplitude-frequency response over the entire audible sound range from 100 Hz to 20 kHz. Experimental studies have confirmed that the EM-8800 directional microphone has a wide dynamic range of the measured signal of 70dB and a high ultimate sound pressure level of 150 dB. It was also found that the natural frequencies of the intake and exhaust valves of the car ICE are in the frequency range of 4-5 kHz.
Keywords: *vibration diagnostics ICE, acoustic monitoring.*

Introduction

Problem Statement. Operational reliability, economy, active safety and environmental qualities of a car are largely determined by the operation of its engine. Therefore, the maintenance of engine operation and fast identification of faults is an urgent task.

Modern internal combustion engine (ICE) is a complex by design, multifunctional object, the diagnostics of which is rather difficult. In many cases, it requires the use of rather complex and expensive diagnostic equipment, and in some cases – partial disassembly of the engine to diagnose the defects of internal parts. In this case, the quality of diagnostics is largely determined by the experience and knowledge of a master diagnostician and is sometimes subjective in nature.

Therefore, the search and study of new diagnostic methods that allow quickly, as simple as possible, and reliably identifying faults is an urgent task.

Analysis of recent research and publications. The theory of vibration diagnostics of machines is presented in the works of I.I. Artobolevsky [2], V.V. Bolotin [3], F.Ya. Balitsky [3], A.V. Barkov [5] and other domestic and foreign researchers.

The problem area of research is as follows:

- main sources of vibration of machines and equipment;
- influence of defects on the vibration of machines and equipment;
- balancing of rotors in the process of operation of machines;
- mathematical and software for expert and automatic vibration acoustic diagnostics;
- vibration acoustic monitoring and diagnostics systems of machines and equipment.

The construction of mathematical models in solving the problems of diagnostics of gear transmissions are covered in the works of F.Ya. Balitsky, A.H. Sokolova, O.I. Kosariev, Yu.H. Barynov and others. Research in the field of diagnostics of rolling bearings were carried out by V.A. Avakian, R.A. Kollot, B.H. Marchenko, M.B. Myslovych, as well as a number of foreign scientists.

In the last decade a new generation of the systems of automatic machines diagnostics by vibration has appeared, which combined the best properties of both monitoring and diagnostics systems [6-9]. Specialized and universal vibration acoustic diagnostic complexes based on PC or PDA on the ideology of virtual measuring instruments are created and serially produced [8-13]. However, all of them, in fact, allow only primary processing of vibration acoustic signals.

The purpose of this research paper is to develop methods for obtaining the natural frequencies of vibrations of the valve mechanism of an internal combustion engine.

Statement of basic materials

Knowing the frequency of natural vibrations of the ICE valve mechanism allows outlining the possible resonance excitations of the construction or determine its nature. Evidence on the frequencies of natural vibrations becomes particularly important if the spectrum of the excitatory force is known.

If the frequencies of natural vibrations coincide with the maximums of force spectrum, one should always expect an increased vibration and emission of sound energy at these frequencies, all other conditions being equal.

If the part is loaded by a force, the spectrum of which falls in the high-frequency region, it is sufficient to find one natural frequency, at which the response of the system is maximum. In this case, 80% of the energy of the vibration process excited by the impact falls on the vibrations with this frequency.

As a result of the impact of the valves to the sockets, vibrations with natural frequencies of the parts of the construction adjacent to the place of excitation are excited. While spreading, these vibrations enter the outer surfaces of the engine and are radiated.

Considerable forces are developed in the operative gas distribution mechanism, which cause the parts of the mechanism to make vibration movements.

The sizes of the parts are insignificant, so the part that vibrates (spring, rocker arm, rod) cannot be a good radiator and thus a source of the noise.

However, the shock fit of the valves in the socket, the shocks resulting from push bar clearance sampling and other combinations of mechanism give rise to vibration pulses in the block and head, which are radiated by the outer surfaces of the engine. This results in noise occurrence from the gas distribution mechanism, rather significant in level and with an unfavorable spectrum.

Due to the fact that the vibration, due to which defects can be diagnosed, has an acoustic nature, it is proposed to use the directional microphone of industrial design as a sensitive element of the diagnostic system, which has an appropriate degree of protection for work in harsh atmospheric conditions. Such a microphone can be installed at some distance from the mount being diagnosed, and directed to it.

Due to the high cost of the industrial directional microphone, an experiment on obtaining the vibration spectrum with the help of an ordinary directional microphone EM-8800 and noise recorder of the 1º class Robotron 00023 c was carried out (Fig. 1).

FIGURE 1. Noise recorder of the 1º class Robotron 00023 with Robotron MK 211 measuring microphone
Source: author's photo

The directional microphone EM-8800 is designed to measure the level of acoustic noise, sound pressure level and obtain the amplitude-frequency response over the entire audible sound range from 100 Hz to 20 kHz, measuring microphone Robotron MK 211 with a sound range from 1 Hz to 20 kHz. Frequencies of the majority of defects in the vehicle ICE are in the frequency range up to 4 kHz.

The directional microphone EM-8800 has a wide dynamic range of the measured signal of 70 dB and a high sound pressure limit of 150 dB. The measured signal is encoded inside the microphone and transmitted digitally via a sound card to a personal computer or tablet.

To perform measurements, using the handheld vibration analyzer (Fig. 2), it is necessary to point the microphone to the place on the engine where the valves of the valve mechanism are placed.

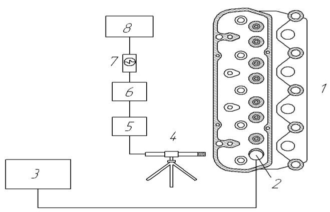

FIGURE 2. Generalized block diagram of the handheld vibration analyzer
Source: developed by the authors

The signal measured by the narrowband microphone 4 is fed to the input of the preamplifier 5. After amplification, the signal is filtered by means of the low frequencies filter 6. This filter is needed to exclude entry of the vibration signal components with frequencies higher than half of the sampling rate into the instrument analysis path, which leads to the occurrence of false components in the low-frequency part of the vibration signal spectrum.

After the adjustable amplifier, the signal is converted from analog to digital form by means of analog-to-digital converter 7. As mentioned above, to diagnose the motor transport ICE and their mounts generating vibration signals with the broadband spectrum and having a significant spectral density in the low-frequency region, the sampling rate values of 32 kHz and more are required. High values of sampling rate provide more precise transmission of the signal form, but at the same time, the volume of the required memory of the device increases significantly and the requirements to the fast operation of the processor 8 increase as well.

The microphone 4, which is connected by means of a microphone cable to the computer or laptop running the application software Sonic Visualiser ver.3.3. to read data from the microphone EM-8800 and to carry out further calculations, such as signal detection by its spectrum (Fig. 3). The program Sonic Visualiser ver.3.3. automatically calculates the direct spectrum of the time signal of acoustic vibration, measured by the microphone in the whole frequency range from 1 Hz to 20 kHz. On the screenshot (Fig. 3 and 4) the range from 10 Hz to 7 kHz is set for spectrum display.

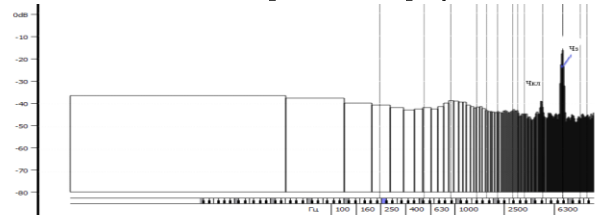

FIGURE 3. The result of measurements on the bench of amplitude-frequency characteristics of the *exhaust* valve of cylinder 4 (Fr class)
in the logarithmic scale
Source: obtained by the authors.

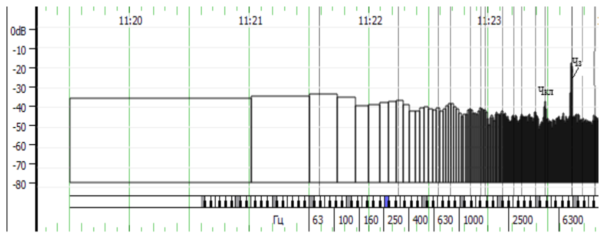

FIGURE 4. The result of measurements on the bench of amplitude-frequency characteristics of the *intake* valve of cylinder 4 (Fr class)
in the logarithmic scale
Source: obtained by the authors

The research part of the experiment is performed on a full-scale Ford V 1.3 8-valve engine and SpectraLAB software, created on the basis of a PC using a handheld vibration analyzer. SpectraLAB is a powerful two-channel spectrum analyzer that is software compatible with any Windows supported sound card. It provides real-time spectrum analysis, signal recording and playback, spectral analysis of pre-recorded signals, simulation of signals of different complexity. With the help of a full-scale experiment, the vibration processes were recorded and placed in the PC memory (Fig. 5, Fig. 6).

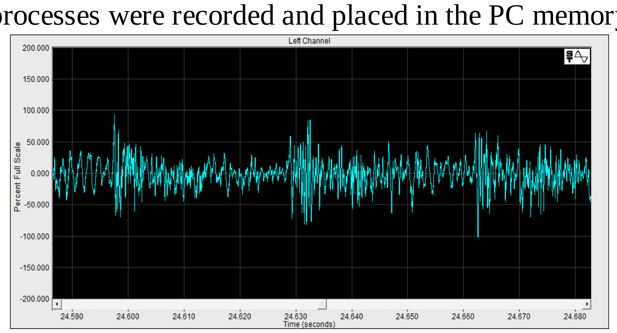

FIGURE 5. Oscillogram of the vibration pulse occurring at intake and exhaust valves seating
Source: obtained by the authors [13, P. 50]

FIGURE 6. The spectrum of single-component valve vibration in the range from 4.2 kHz to 20 kHz.
Source: obtained by the authors [13, P. 50]

Conclusions

The article presents methods based on a handheld acoustic vibration analyzer, which is reasonable to use to obtain and process the natural frequencies of the internal combustion engine valve mechanism vibrations.

The solution to obtain diagnostic information with the help of a directional microphone is fundamentally new, and will let to determine the technical condition of the ICE valve mechanism in real time, that is to monitor the technical condition. With the help of the carried out study the frequency of natural vibrations of the exhaust valve was obtained, namely 4,630.12 Hz.

The existing methods of vibration diagnostics of ICE valve mechanism allow performing only primary processing of vibration acoustic signals.

Application of the developed methods, the basis of which is the receipt and processing of diagnostic information by means of a handheld acoustic vibration analyzer, will allow determining the technical condition of the valves in advance based on the results of physical diagnostics, characteristics of which are close to the critical. This will lead to a significant improvement of the reliability indicators of the ICE valve mechanism and allow avoiding its sudden faults and many of the negative consequences related to them. Determining the resource of ICE valve mechanism based on the values of diagnostic parameters will allow predicting the technical condition of motor and tractor equipment with a certain probability, which is one of the functions of technical diagnostics.

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