Possibility of using the acoustic emission method for monitoring deviations in the operation of the valve mechanism of an internal combustion engine

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Abstract: *Current diagnostic approaches, although widely applied, often fail to identify defects at the earliest stages of their development. This limitation not only reduces operational efficiency but also results in unplanned downtime, costly repairs, and increased risks to both personnel and the environment. Unlike conventional techniques, AE enables real-time detection of microstructural changes associated with defect initiation and provides valuable information about their severity and rate of progression. Obtained results confirm that the AE method allows reliable identification of early-stage defects, enabling the prediction of their further development and the assessment of the technical condition of critical engine components. These findings demonstrate that AE-based monitoring can serve as an effective diagnostic and prognostic tool, enhancing the safety, energy and environmental efficiency. The study involved placing AE sensors on specific areas of the engine. The engine was then operated in various modes, with the AE system recording AE signals. The results were analyzed (express analysis) to identify the sources of the AE signals.*
KEYWORDS: *ACOUSTIC EMISSION METHOD, INTERNAL COMBUSTION ENGINE, VALVES, DEFECT, MICRO CRACK,*

1. Introduction

At present, the traditional non-destructive testing methods used to assess the technical condition of various machines and structures are visual-optical, ultrasonic, eddy current, magnetic-powder methods, as well as methods of penetrating liquids (color and luminescent). However, their capabilities are limited in detecting defects such as fatigue cracks, which in most cases are hidden (internal) defects. Thus, visual-optical methods and methods of penetrating liquids are effective only when cracks emerge on the surface in places open for viewing. Ultrasonic, eddy current and magnetic particle methods make it possible to determine hidden defects, such as subsurface cracks. The ultrasonic method also allows you to find cracks in the depth of the material. But all of these methods also have limitations related to the design of the controlled parts; for example, they are ineffective if it is necessary to detect an engine defect at the very beginning of its occurrence. Thus, traditional methods are effective if disassembly of the structure is possible and limitedly effective in cases where disassembly is limited or impossible[6].

It is therefore advisable to consider the possibility of using other methods of non-destructive testing and diagnosis. One such method could be the method of acoustic emission (AE). Its main advantage is the fact that with its help it is possible to detect only developing defects, thus allowing a more accurate assessment of the degree of their threat to the inspected object. By analyzing acoustic emission signals, it is possible to assess the technical condition of ICE parts such as injectors, intake/exhaust valves, crankshafts, cylinder-piston groups, etc. It is particularly important to detect defects in the intake/exhaust valves, crankshaft, internal combustion engine shaft, as these are the most expensive parts of the power equipment [4,5].

The methods of AE control of metals have been known for a long time. The AE method uses the radiation of mechanical waves from the material due to dynamic changes in the internal structure of the material caused by any kind of loading. AE can be caused by plastic deformation, crack formation and growth, fluid / gas flow in pipelines, corrosion, loss of oil layer between rubbing parts (increased friction), gas / fluid flow in defects and other deformations of solids. It can be assumed that AE signals in materials are caused by a change in pressure, stress or temperature[1].
The main function of the development of a monitoring system is to determine the initial state of internal combustion engine , support decision-making during the operation of the equipment, and determine the moment the equipment is put into repair. The creation and use of a monitoring system must be simultaneously accompanied by the connection and use of CALS technology, SCADA systems, PDM systems, STEP standards, CASE tools [7,8]

2. General provisions and its application methodology of acoustic emission testing (AET)

The stress acts on the material and causes local plastic deformations in it. These deformations in the material create AE: an elastic wave that propagates from the source in all directions and is detected by a sensor installed at some distance. As a result, the sensor generates an electrical signal that is transmitted to the electronic equipment for further processing. The basic principle of the AE method is shown in Fig. 1.

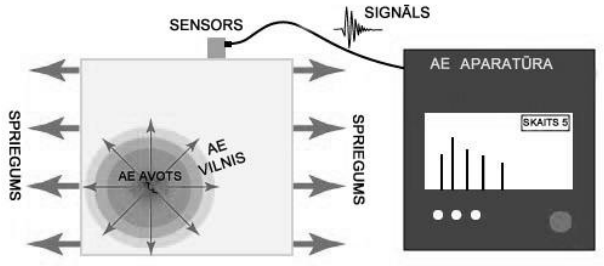

Fig. 1. *Principle of the AE method*

The main defect detection circuit is shown in Fig. 2.

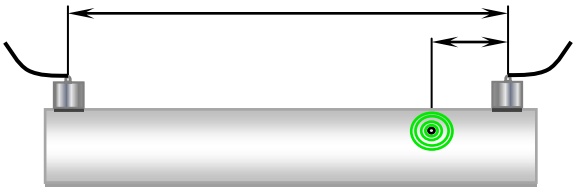

Fig. 2. *Determining the location of a defect by the AE method [2]*

The distance from the sensor to the defect is determined by formula [1].

$$d = \frac{1}{2}(D - \Delta T \cdot V) \qquad (1)$$

where:
d – the distance from the first sensor to the defect;
D – the distance between the sensors;
V – the speed of wave propagation;
$\Delta T = t_1 - t_2$ – the difference in the transit time of the acoustic emission signal from the defect to the second and first sensors.
The AE method does not respond to non-developing (static) defects, which are usually detected by most other non-destructive testing methods and which form a conclusion about the degree of their danger to the object. Naturally, in order to apply the AE

method, issues related to the identification of failure criteria and the prediction of the fatigue life of structural elements should be worked out.

3. AE criteria in testing of the valvesof the internal combustion engine (ICE)

Components the internal combustion engine are subjected to various loads that can cause fatigue cracks in the material, and it is important to determine not only the existence of a defect, but also its location[6].

Let's consider these issues on the examples of the operation of the intake and exhaust valves of the internal combustion engine, shown in Fig. 3.

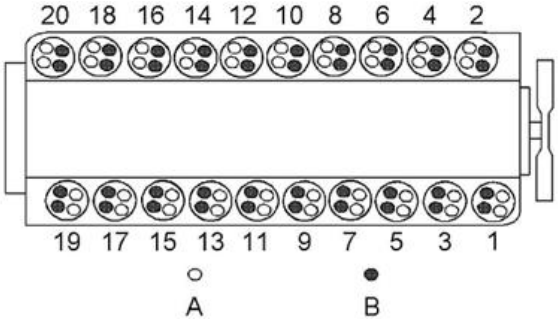

Fig. 3. *The layout of the cylinders and valves of the internal combustion engine; A - exhaust valves, B - exhaust valves*

In this case, the AE signals from sensors installed in the area of the malfunctioning valve create a turbulent gas flow in the channel, which occurs as a result of a defect and causes a leak. Leakage can be caused, for example, by the most common malfunctions in the operation of valves and their nozzles, such as increased abrasion and stratification of the surface, which cause gas to escape from the cylinder even when the valves are closed. The most common defect is an irregularly shaped channel and configurations in the valve disc and / or valve seat.

It is assumed that AE signals occur only during turbulent motion of the gas, when the occurrence of unstable vortices causes pressure pulsations (stress waves) on the channel walls of the controlled object and the AE signals are recorded as turbulence noise in the ultrasonic range.

To simplify the theoretical analysis of the acoustic signals, it is assumed that the duct is straight, has smooth walls, has a constriction r (the size of the gap between the valve and its seat) and a length L (the thickness of the valve), and is perpendicularly connected to the main duct

(which is connected to the cylinder) (Fig. 4). The relative length (length) of the channel characterizes the parameter λ=L/r.

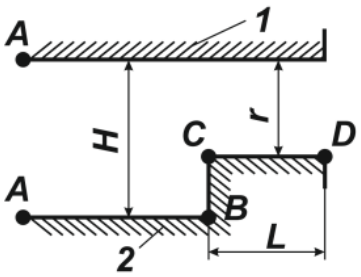

Fig. 4. Defect Model [3]

In addition, the assumptions were made that the parameter r is sufficiently small compared to the cylinder size and the duct height H, the gas flow in the duct and in the constriction is isothermal, and the flow continuity condition is satisfied.

In the presence of a defect in the valve, there is a turbulent mode of gas movement in the channel determined by the AE method. The mathematical model of gas outflow through a defect in the valve consists of the following equations, which express the critical ratio of the pressure upstream of the valve to the atmospheric pressure (2) and the limit value of the valve clearance (3), at which the gas flows out at the speed of sound [5]:

$$\left(\frac{p_A}{p_{at}}\right)_{kr} = \sqrt{1+\xi\lambda}, \quad (2)$$

$$r_{lim} = \frac{\mu \cdot Re_{kr}}{2 \cdot \rho_D \cdot c} = \frac{\mu \cdot Re_{kr}}{2 \cdot \sqrt{\rho_D \cdot p_D}}, \quad (3)$$

where:

$\xi = \xi(Re)$ – the coefficient of hydraulic resistance in the valve;

μ – coefficient of dynamic viscosity of the gas;

Re_{kr} – Reynold's number at the speed of sound;

ρ_D, p_D – density and pressure of the gas upstream of the valve (at point D, Fig.4);

c – speed of sound.

When analyzing the test results of ICE valves using the AE method, the most important factors were filtered out :

- The maximum amplitude of the AE signal;
- Rise speed of the AE signal;

Decay speed of the signal.

Experimental measurements on ICE valves led to the following conclusions:

1. When the valves have reduced thermal clearance, the gas exchange cycle changes, and both the amplitude and duration of the signal are slightly reduced.
2. If there are precipitates on the exhaust valve, the amplitude and duration of the sound are reduced.
3. If the inlet valve has a crack, the amplitude decreases and the duration of the sound increases.
4. If the exhaust valve has increased precipitation and outburning, the amplitude decreases and the duration of the sound increases.

Since valve cracks are the most dangerous defects that can lead to an engine damage, the following intake valve crack locations are examined for a more detailed analysis:

- Six valve closures with no defect.
- Six valve closures with an early-stage crack.
- Six valve closures with a crack in the final stage (before the planned repair).

The following diagrams show only two of the six AE signals, Fig. 5:

1) AE signals when the valve closes without failure;
2) AE signals when a cracked valve closes at the initial stage;
3) AE signals at the end of the crack (before detection).AE signals at the end of the crack (before detection).

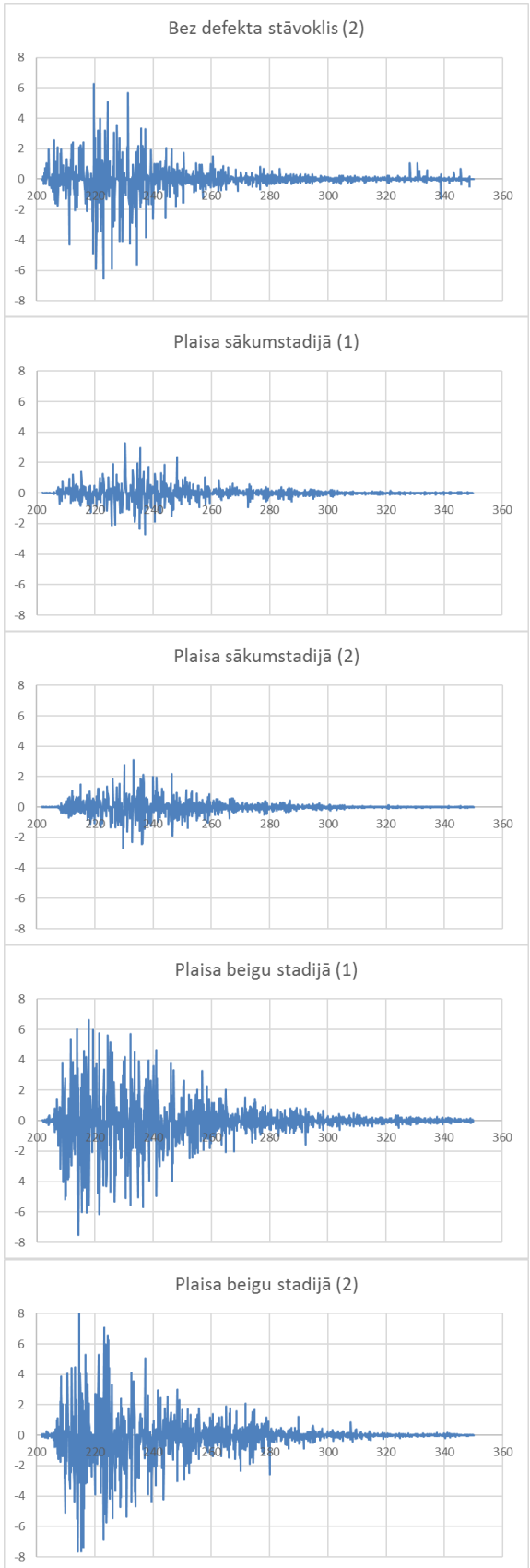

Fig. 5. *Graphical representation of the measurements for a valve without a defect and with a defect*

The results of the study showed that within the permissible pressure range, modes are formed in which the occurrence of side acoustic signals (noise) is likely, and the area where the defect is located creates high acoustic resistance. Each deformation or fracture causes interatomic bonds to break, releasing a certain amount of energy. The accumulation of damage and repeated breaking of interatomic bonds can generate an acoustic pulse, which is sufficient for the transducer to detect. Measuring the repetition rate of acoustic emission events allows us to estimate the rate of fracture processes. There is a clear relationship between the kinetic energy released during crack propagation and the rate of its growth.

Conclusions

The study provides a mathematical justification for the use of the AE method for searching and detecting fatigue microcracks in internal combustion engine components.
The potential of the AE method for:
- identifying defects in internal combustion engine valves;
- assessing the degree of fatigue crack development in critical internal combustion engine components;
- monitoring the closing moment of the intake and exhaust valves during crankshaft rotation.
- monitoring the operating power of the intake and exhaust valves.
- monitoring the clearances in the intake and exhaust valves, identifying system components where deviations from normal operation occur.
Of particular interest is the further evaluation of the operation and adjustment of diesel cylinder valves using the proposed approach (AE method).

Disclosure statement

No potential conflict of interest was reported by the authors

Additional information

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