Prospects for using the Bayes algorithm for assessing the technical condition of internal combustion engines

Farit Kh. Khaliullin¹, Alexander V. Matyashin², Rishat R. Akhmetzyanov², Vladimir M. Medvedev² and Maxim A. Lushnov³

¹Department of Automobile Engines and Services of the Institute of Aviation, Land Transport and Energy Production, Kazan National Research Technical University named after A.N. Tupolev – KAI, 10 K. Markska St., 420111, Kazan, Russia
²Department of Machines Operation and Repair of the Mechanization and Technical Service Institute, Kazan State Agrarian University, 65 K. Markska St., 420015, Kazan, Russia
³Department of Machinery and Equipment in Agribusiness of the Mechanization and Technical Service Institute, Kazan State Agrarian University, 65 K. Markska St., 420015, Kazan, Russia

khaliullin_kai_adis@mail.ru

Abstract. Appropriate assessment of the technical condition of internal combustion engines allows determining optimal values for standards of their technical operation, adjusting the parameters of maintenance and repair process operations, and, as a result, reducing the cost of their effective operation. The article is devoted to the use of the Bayes algorithm for assessing the technical condition of internal combustion engines. This algorithm allows using statistical data on repair and maintenance of internal combustion engines, wherein the missing information is determined by the dynamic systems modeling method. The choice of transitional functions of constituent elements of internal combustion engines as diagnostic parameters increases the reliability of obtained results.

1. Introduction
The choice of efficient methods and technologies for diagnosing internal combustion engines reduces the likelihood of making erroneous decisions on maintenance repair and overhaul. Currently, there are quite a lot of methods and technologies for in-place diagnostics of internal combustion engines [1-3], which in varying degrees meet the objectives of assessing their technical condition.

First of all, it is necessary to note the vibroacoustic diagnostic methods, which allows for the registration, processing, and interpretation of vibration or noise indicators of the operation of internal combustion engines. The current state of development of vibroacoustic diagnostic technologies makes it possible to single out the following advantages [4-6]:
- flaw detection and the possibility of diagnosing failures at an early stage;
- forecasting the possibility of further operation of machine components or the machine as a whole, as well as adjustment and planning of the maintenance and repair volume and technology;
• the ability to quickly collect information on the technical condition of equipment and the mobility of diagnostic equipment.

At the same time, it is necessary to note the complexity of extracting the vibration signal caused by the presence of a malfunction [7-9], difficulties of applying Fourier transforms for non-stationary processes, as well as the dependence of vibration on the transient time, and increased requirements for processing the vibroacoustic signal.

Another common method is to analyze the composition and amount of engine exhaust gases. It allows determining the nature and conditions of the combustion process and assessing the maximum allowable wear of parts included in the cylinder-piston group (CPG). The main disadvantages of this method include the impossibility of in-process monitoring of the engine condition and the low capabilities for forecasting the residual engine life. The measurement of the flow rate of crankcase gases is a special case which, in fact, can be carried out in process. It has been established that in this method of analyzing the technical condition, the most significant factors influencing the flow rate of crankcase gases, in addition to the condition of the CPG itself, are the engine load and temperature, which allows for rather accurate assessment of the engine CPG condition in most steady modes of operation. At the same time, it is difficult to estimate the engine operation under unsteady load by this method due to large fluctuations in the flow rate of crankcase gases in such modes. In addition, an obvious disadvantage of this method is the ability to assess only the condition of the CPG, but not the general engine condition.

Also, there is an interesting method for assessing the technical condition of an internal combustion engine (ICE) based on monitoring the current values of wear product concentrations. During the ICE operation, wear products that come from various parts are accumulated in the engine oil, which makes it a carrier of information about the technical condition of the engine. However, the method also cannot be performed in the process and does not allow assessing the overall technical condition of the engine.

To assess the technical condition of the CPG, such an indicator as burning oil consumption is also used, which makes it possible to establish the type of necessary repairs in the case of proper accounting. The oil feed mode, level, and temperature significantly influence the life of the engine and the oil itself. However, during the period from the start of engine operation to overhaul, oil consumption increases by 3-5 times and depends on the engine operation conditions; therefore, the assessment of the CPG technical condition according to burning oil consumption requires operating the equipment under the same conditions.

The CPG technical condition is also determined according to the compression pressure. The disadvantage is that the extreme wear may cause a slight change in compression due to significant oil consumption for sealing the CPG connection [10]. It should be noted that the amount of compression is also influenced by not only the wear of the CPG but also by the faulty sealing of the gas distribution mechanism (GRM) valves. When assessing the technical condition, the compression value is not reliable, since the compression pressure depends not only on the CPG condition but also on the crankshaft speed, the constancy of which cannot be achieved when using a starter.

2. Procedures
The diagnostics of internal combustion engines uses dynamic methods, which involve analyzing the response of operation process parameters to standard signals. Due to the convenience of implementation, the Fourier method for analyzing the harmonic series is used, the essence of which is to identify the main harmonics and subsequently identify the amplitude and frequency spectra, which allow obtaining the spectrum of the signal under study and then identifying the malfunction [11]. However, the well-known analysis by the Fourier method has several disadvantages, among which the main ones are as follows:

• Lack of information and the almost complete lack of the ability to analyze based on the time of occurrence and the shape of amplitudes, low denoising capabilities.
• Fourier harmonic series cannot reliably reflect the shape of signals with a large steepness of harmonics, since this requires cumbersome construction of digital series.
Due to the fact that the above method has a sufficient number of limitations, the wavelet analysis of ICE characteristics, which is an alternative method, eliminates the disadvantages of the Fourier series analysis method and provides a more flexible signal processing technique, is used more and more frequently. This transform method is a detailed and time-weighted space argument through the representation of signals. A distinctive feature of the Fourier transform is that the wavelet transform of one-dimensional signals provides their two-dimensional representation, and at the same time, the frequency and coordinate are considered as independent variables, which allows simultaneous analysis of signals in two dimensions [12].

However, the wavelet analysis method is not widely used to date due to software and hardware limitations.

Due to simplicity and efficiency, the method based on the generalized Bayes formula is the most commonly used. This method has its disadvantages: a large amount of preliminary information and rare diagnoses. But if the volume of statistical information allows application of this method, it is reasonable to use it as one of the most reliable and efficient. This method is used when diagnosing the technical condition of tractors, automobiles, railway transport, or aviation equipment [13, 14].

It is also worth noting the perspectivity and usability of the Bayes algorithm for forecasting malfunctions of ICE due to the fact that this formula allows more accurate recalculation of the probability using either previously known statistical information or new test data.

3. Results
The authors have developed an in-place engine diagnostic method based on the Bayes algorithm. Considering the internal combustion engine as a dynamic system with stationary parameters, the authors used methods for identifying dynamic systems through dynamic characteristics. As diagnostic parameters, the intensity of change in parameters was chosen, namely, the transition functions of the fuel and air supply systems (Figure 1 and Figure 2), as well as the response of the system to a single pedal perturbation in terms of engine crankshaft speed (Figure 3) [15].

![Figure 1. Cyclic feed transition functions $g_c$ depending on the D-243 engine nozzle condition.](image)

Note: 1, 4 – at a fuel injection pressure of 18.5 MPa, 2, 5 – at a fuel injection pressure of 16.5 MPa, 3, 6 – at a fuel injection pressure of 15.5 MPa.
Figure 2. Transient functions of air flow $G_a$ depending on compression $k$ of the D-243 engine.

Note: 1, 4 – at compression of 2.7 MPa, 2, 5 – at compression of 2.4 MPa, 3, 6 – at compression of 2.1 MPa.

Figure 3. Transient functions of rotation speed $n$ depending on compression $k$ of the D-243 engine.

Experimental and approximating data: 1, 4 – at compression of 2.7 MPa, 2, 5 – at compression of 2.4 MPa, 3, 6 – at compression of 2.1 MPa.

The obtained values of diagnostic parameters depend on the technical condition of the engine and therefore, it is necessary to conduct preliminary calibration studies of the engine under test in its various conditions [16, 17] in order to deliver a relevant diagnosis. As a result, one can obtain three ranges for each diagnostic parameter: good (G), satisfactory (S) and bad (B) (Table 1).
Table 1. Gradation of diagnostic parameters

| Parameter | Good (G) | Satisfactory (S) | Bad (B) |
|-----------|----------|-----------------|---------|
| $T_{gc}$, sec (cyclic fuel feed) | 0.5–1 | 1–1.5 | >1.5 |
| $T_n$, sec (rotation speed) | G 0.8–1.3 | S 1.3–1.7 | B >1.7 |
| $T_{Ga}$, sec (air flow) | G 1–1.5 | S 1.5–2 | B >2 |

4. Conclusion

The economic effect of implementing the developed method of engine diagnostics is achieved by reducing the process complexity. Compared with existing methods, the proposed method improves productivity by 30–40% and reduces complexity by 25–35%. Based on the developed method, the authors plan to continue research on determining and refining the diagnostic parameters for modern engines with various types of malfunctions, as well as to expand the field of application of the developed method for assessing the residual life of modern engines.

5. References

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