Vibroacoustic Control of Technical Conditions of GTE

A.V. Kochergin, N.V. Pavlova, K.A. Valeeva*

Kazan national research technical university of A. N. Tupolev - KAI, 10, K. Marx Str., Kazan, 420111, Russia

Abstract

This research is aimed at determining the technical conditions of compressor blades and turbines of GTE, which are analyzed both as individual components and in the composition of the working wheels. The paper also dwells upon analysis of combustion chamber welds by the method of free oscillations. Tests were carried out on experimental installations. Informative parameters characterizing the oscillatory process were defined. The developed defect detection methods allow: (1) to determine hidden and open mechanical defects of composite parts (lack of fusion, shrinkage cavities, non-metallic inclusions, gas porosity, casting defects, hot and cold crack, small dent); (2) to determine the hidden and open defects of welds in the structure of any composite part; (3) to determine the structural defects of composite parts (zonal or chemical heterogeneity, the emergence of macrograin borderlines on the surface, and alloy heterogeneity); (4) to determine deviations in the shape and geometrical dimensions of composite parts.

© 2016 The Authors. Published by Elsevier Ltd.

Keywords: acoustic diagnostics; method of free fluctuations; acoustic characteristics; information processing.

1. Introduction

The noise arising during the operation of heat engines along with negative impact on the person can bear also useful information about their technical condition. Characteristics of the acoustic fields generated by engines can be diagnostic signs at technical control, both all engine, and his components or elements.

At the same time feature of diagnostics is use as signs not of the static, but dynamic parameters which are result of interaction of details of the mechanism in the course of his functioning.

* Corresponding author. Tel.: +7-905-310-5468; fax: +7-843-571-9696.
E-mail address: akustika2014k@mail.ru
Wide frequency and dynamic ranges of oscillatory processes, small lag effect, high speed of distribution of acoustic waves on a design cause fast reaction of an acoustic signal to changes of technical condition of a product. The listed qualities are defining, especially in emergencies.

Violation of balance, the symmetry, emergence of pushes, knocks, beats, emergence of new voice-frequency sounds called by increase in friction of the rotating parts of cabs – all this leads to change of acoustic characteristics. Practice shows that parameters of the acoustic field are most suitable as diagnostic signs for identification of damages and defects. As a physical data carrier about a condition of elements of the engine (mechanism) serve acoustic waves and vibrations of a product. The methods of acoustic diagnostics based on the analysis of changes in controlled object of fluctuations in the frequency range of 50 Hz – 50 MHz, allow to rationally organize the production technology, to provide procedure of effective control of an actual state of difficult technical systems and to predict their changes over time of an operating time, to considerably lower material and labor inputs on maintenance and repair.

Efficiency of methods of acoustic defectoscopy is caused:
- organic communication of the used measuring information which is contained in acoustic signals with dynamic processes of excitement and distribution of fluctuations in designs;
- a possibility of automation of processes of a sjem and processing of multidimensional measuring information by means of modern microprocessor equipment.

Acoustic diagnostics allows to reveal both external, and internal defects, not only to define already available malfunction, but also to find the developing defect at very early stage that gives the chance to predict an emergency and to reasonably plan terms and volume of repair of the equipment.

The rational choice of diagnostic signs of the acoustic field generated by various sources of the heat engines sensitive to change of technical condition of a detail (knot, the mechanism) considerably defines success of diagnosing [1].

2. Problem definition

Results of the researches making a practical basis of creation of system of vibroacoustic diagnostics are given in this article.

Among methods of acoustic defectoscopy of elements of heat engines the simply, accepted and attractive is represented the method of free fluctuations which essence consists in mechanical excitement of controlled object and registration of fluctuations after removal of exciting force. Existence in object of defects (cracks, sinks, nesploshnost, etc.) leads to change of distribution of oscillatory energy on frequency fashions of own fluctuations of object and to change of speed of attenuation of fluctuations because of effect of dissipation of energy on defects.

3. Results of research

In the acoustic research laboratory (RL) of name Ampere-second A.C Figurova at Kazan scientifically - research technical university with use of the specified method big statistical material on diagnostics of such elements and details of gas-turbine engines (GTE) as shovels and disks of compressor and turbine wheels, longitudinal seams of cases of combustion chambers, preparations of shovels of the compressor and the turbine is saved up [1, 2]. Acoustic diagnosing was carried out according to the scheme represented in fig. 1.

The main components of the block scheme are: object of diagnosing with a set of the technical states which are subject to recognition, the block of measurements, the block of formation of diagnostic signs, the block of formation of standards, the decision-making block on the basis of certain decisive rules consisting of the block of formation of threshold values, the block of long-term memory and the block of recognition of current state.

The block of measurements delivers information on a condition of object which is contained in an acoustic signal. The block of formation of diagnostic signs carries out functions of the converter of initial information according to algorithms of diagnosing for the purpose of search informative a component of an acoustic signal.

In blocks of formation of standards and threshold values values of diagnostic signs are averaged definitely and their threshold values corresponding to extreme values of the diagnosed parameters of technical condition of objects are formed.
On the basis of comparison of the current and reference values of diagnostic signs taking into account the threshold values which are stored in the block of long-term memory the diagnosis on the basis of which operations of management of object of diagnosing are carried out is made.

![Diagram of System of Acoustic Diagnosing](image)

**Fig. 1** Block scheme of system of acoustic diagnosing

Functions of blocks of formation of diagnostic signs, standards, threshold values, long-term memory and recognition of current state of objects are carried out by PEVM with a package of the working ACOUSTIK programs [3].

Experimental installation for diagnostics of shovels of the compressor and the turbine GTE in a free state is presented in fig. 2

![Experimental Installation](image)

**Fig. 2** Installation for control of technical condition of shovels: 1– elevators, 2– microphone, 3– holder of the microphone, 4 – guide, 5 – brake, 6 – rubber substrate, 7– shovel, 8 – drummer, 9–mobile carriage, 10 – resonator, 11– basis

Experimental installation for diagnostics of shovels of the compressor and the turbine GTE fixed on the driving wheel is presented to fig. 3. Installation consists of a welded rack-1, the compressor wheel fixed on a shaft with shovels-2, the electric motor with system of rotation-3, system of tracking-4, the microphone-5, the drummer-6 and an oscillograph-7. Base for search of the informative parameters characterizing technical condition of elements are
amplitude-time signals of acoustic fields and amplitude ranges of these signals corresponding to the chosen time intervals [4].

For the analysis of pilot studies the following informative parameters characterizing oscillatory process have been used:

- area of a range

\[ S_i = \int_0^f A_i^2(f) df \]  

(1)

where \( A_i \) – amplitude of fluctuations on \( i \) \( \rightarrow \) frequency;
\( f \) – frequency of fluctuations;

- coefficients of correlations:

1. standard assessment

\[ r_x = \frac{M(x_i, x_j) - M_{x_i}M_{x_j}}{\sigma_{x_i}\sigma_{x_j}} , \]  

(2)

where \( M_{x_i} \) – a population mean of size of a reference range;
\( M_{x_j} \) – a population mean of size of the current range;
\( \sigma_{x_i}, \sigma_{x_j} \) – mean square deviations of reference and current ranges;

2. nonparametric assessment

\[ r_{HH} = 1 - \frac{6\sum_{i=1}^{N}(\text{rank } x_i - \text{rank } x_{i})^2}{N(N^2 - 1)} , \]  

(3)

where \( \text{rank } x_i \) – a number \( j \) rank in a variation number of a reference range;
\( \text{rank } x_{i} \) – a number \( j \) rank in a variation number of the current range;
\( N \) – selection volume;

- deviation of frequencies of the main fashions of own fluctuations;

Fig. 3. Installation for the control of a technical condition of blades, enshrined on the drive of the compressor wheel
• statistics of amplitudes

\[ A = \sum_{i=1}^{n} \lg \frac{A_i}{A_j}, \quad (4) \]

where \( A_i \) – amplitude on \( i \)-th to the frequency of the current range;
\( A_j \) – amplitude on \( i \)-th to the frequency of a reference range;

• Uilkokson's criterion

\[ W = \sum_{i=1}^{n} \left| \text{rank} x_j \left( x_j \right) - \text{rank} x_j \left( x_j \right) \right|, \quad (5) \]

where \( \text{rank} x_j \left( x_j \right) : x_1 \leq x_2 \leq \ldots \leq x_n \) – the rank of amplitude variation range of the current spectrum;
\( \text{rank} x_j \left( x_j \right) : x_1 \leq x_2 \leq \ldots \leq x_n \) – the rank of the amplitude variation in the combined number of current and reference spectra;

• coefficient of attenuation of fluctuations

\[ \beta_n = \alpha_n c, \quad (6) \]

where \( \alpha_n \) – coefficient of attenuation of a wave at a frequency, own frequency equal to \( n \)-y
\( c \) – sound speed.

By means of acoustic characteristics, using the specified diagnostic signs, it is possible to reveal such defects on elements and details of GTE as:
• cracks on an entrance and output edge of a feather of a shovel (from 1 mm long and more);
• violation of the geometrical sizes of shovels (reduction of thickness, thinning of entrance edges, defect like "cone", perforation, "burnout" and other defects);
• low-quality landing of a shovel in a groove of a disk of a wheel of the compressor and turbine;
• change of structure of material of preparation of a shovel (macrograin border exit to a shovel feather edge);
• lack of fusion of the weld seam of the combustion chamber (to 3 mm and more);
• sinks (depth of 0,8 mm and with a diameter of 1,2 mm).

With use of a method of free fluctuations on installation (fig.2) control of technical condition of 13 preparations of shovels of the turbine I of a step 86.441 of ZhS6UVI alloy in a condition of molding is carried out. Four of them had cracks on an output edge a feather of shovels with sizes from 4 of 10 mm [5,6].

For an exception of influence of casual factors experiments with each shovel repeated on 10 times, the received amplitude ranges of signals were normalized, the essence consisted in normalization of amplitudes at all frequencies so-so integrated amplitude. On 10 normalized ranges the average range with use of a robust method was formed. The average range of the checked shovel was compared to a range reference, the manager- dokmo serviceable, shovels.

The analysis of the received results has shown that statistical characteristics of preparations with defects go beyond confidential intervals, and characteristics of faultless shovels are in their limits. Schedules of change of statistical characteristics are given in fig. 4 and 5 where at numbers 1-9 correct preparations of shovels, and at numbers 10-13 with cracks respectively 4 are designated. 6. 8 and 10 mm, the dashed line has designated border of a confidential interval, by the continuous line – a population mean of characteristics.
4. Conclusion

The developed techniques can be used at diagnostics of elements both GTE, and other heat engines and power cars at a stage of production and in use during scheduled works. When carrying out scheduled works control of technical condition of elements of the engine is carried out without dismantling of the engine (nondestructive control).

For such diagnostics it is necessary to use:
- the special probes intended for visual control of a condition of the GTE elements
- system of tracking rotation of a wheel and movement of shovels,
- the device of mechanical initiation of own fluctuations in elements,
- system of registration of oscillatory process.
Will be applied to tracking rotation of a wheel electronic system of tracking. Rotation of a wheel (wheels) is carried out by uniform rotation of a shaft of GTE by means of the special electric drive.

It is possible to find the developing defect at very early stage only during scheduled works. Using the characteristics of the acoustic passport of an element of the engine received during the real technical control and comparing the acoustic characteristics of the passport received earlier (at the beginning of operation), it is possible to reveal a stage of the developing defect. It gives the chance to predict destruction and to reasonably plan terms and volume of repair of the equipment.

Control of technical condition of GTE during operation ("hot rotation") is exercised by means of control of vibration of racks of the engine and temperature condition. Such control is exercised by means of thermo - and the vibration sensors established on engine racks or by means of the laser measuring system watching the frequency and amplitude of fluctuations of racks of GTE [7]. Vibration control allows to reveal "rough" defects

- break of a shovel of a wheel of the compressor or turbine,
- critical lengthening of a shovel of the turbine,
- violation of operation of the bearing (rupture of a separator, change of a form of elements of swing, change of a form of a path
- crack of a disk of a wheel of the compressor or turbine,
- hit to the highway of the engine of a foreign matter,
- rupture of a longitudinal welded seam of the case of the combustion chamber.

At "critical" change of amplitude-frequency parameters of oscillatory process of a rack of GTE by system of tracking emergency sound and light signals with the subsequent stop of GTE are given. Further search of malfunctions (defects) is carried out by a technique of search of defects during scheduled works.

References

[1] V.A. Kochergin, Development of vibro-acoustic methods of defining the technical condition of the products of complex shapes using the results of numerical simulation, Herald of the Kazan University. 2 (2009).