The Piston Compressor: 
The Methodology of the Real-Time Condition Monitoring

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Abstract. The methodology of a diagnostic signal processing, a function chart of the monitoring system are considered in the article. The methodology of monitoring and diagnosing is based on measurement of indirect processes’ parameters (vibroacoustic oscillations) therefore no more than five sensors is established on the cylinder, measurement of direct structural and thermodynamic parameters is envisioned as well. The structure and principle of expert system’s functioning of decision-making is given. Algorithm of automatic expert system includes the calculation diagnostic attributes values based on their normative values, formation sets of diagnostic attributes that correspond to individual classes to malfunction, formation of expert system messages. The scheme of a real-time condition monitoring system for piston compressors is considered. The system have consistently-parallel structure of information-measuring equipment, which allows to measure the vibroacoustic signal for condition monitoring of reciprocating compressors and modes of its work. Besides, the system allows to measure parameters of other physical processes, for example, system can measure and use for monitoring and statements of the diagnosis the pressure in decreasing spaces (the indicator diagram), the inlet pressure and flowing pressure of each cylinder, inlet and delivery temperature of gas, valves temperature, position of a rod, leakage through compression packing and others.

1. Introduction
The purpose of the work is to describe the methodology and technology for the health monitoring of reciprocating machines in real time.

A technology of monitoring and diagnostics of reciprocating machines is based on the collection and processing of data, which should provide a definition of defects and malfunctions of the machine with the specified depth of detail and accuracy, their degree of danger [1].

An implementation of monitoring and diagnostics technology, based on vibroacoustic structure models when various defects and malfunctions of units and parts of reciprocating machines [18], [20], [21], [23], combined diagnostic signs of deterioration and options signal malfunctions [4], [6], [9], [10], [11], [22], normative values of diagnostic characteristics and diagnostic parameters of signals when troubleshooting [3], [5], [8], how to convert vibroacoustic signal and vibroacoustic signal system parameter estimates [11], [14], [13], [15], [24].

One practical way to implement technology and the decision of problems of monitoring and diagnostics of piston machines is the introduction of these methodological solutions which underlie the knowledge base, that links parameters of a diagnostic signals and the malfunction,
technical status of units and parts of reciprocating machines, algorithms of diagnosis and monitoring systems COMPACS® [2], [4], [7], [12], [17].

2. Methodology of analysis of diagnostic information

Another section of our paper

On the basis of established knowledge base processing methodology can generate diagnostic parameters of acoustic signals and the allocation of diagnostic signs, which can be summarized as follows (figure 1) [4], [19], [20], [24]:

- integro-differential conversion (for example, velocity, displacement);
- analysis of variance;
- amplitude-phase analysis (for example, the analysis of signal parameters on the angle of the shaft);
- peak-frequency analysis (for example, allocation and analysis of signal parameters in typical area of frequencies);
- analysis of envelope a signal parameters selected in specific frequency ranges, which are determined by the properties of the diagnostic units and parts.

![Diagram](image)

**Figure 1.** Methodology of diagnostic information analysis.

This methodology for monitoring and diagnostics is based on the measurement of parameters of the indirect processes (vibroacoustic oscillations), which is not more than five sensors per cylinder also provides for the direct measurement of structural and thermodynamic parameters.

This methodology allows to realize algorithms of expert system for real-time decision support with automatic identification (diagnosis at a pace measurement of diagnostic signals) of more than 20 shooting sites, for example, reciprocating compressors of hazardous activities, risk and issue target designation regulations for staff to bring the compensatory activities [4], [10] - [12], [16], [17], [24].
3. Real time condition monitoring

The algorithm for vibroacoustic diagnostics and monitoring in real time can be represented as a functional diagram (figure 2), which is offered on the basis of known schemas [25].

![Figure 2. Block diagram of the technical diagnostics and real-time condition monitoring.](image)

Like any algorithm or schema of pattern recognition, the scheme of acoustic diagnosing of technical object consists of actually object of diagnosing with a set of a technical states, a set of diagnostic signs and rules of decision-making.

A diagnostic model of the object is developed on the basis of a comprehensive study of the object, its sources of signal diagnostic and the signal reactions to changing technical condition, defects and malfunctions of units and parts of object diagnosing.

The diagnostic model properties define the requirements for diagnostic signal and its parameters, which determine the availability of malfunctions diagnostic parameters (MDP) in the required amount, quantity and quality, which possess demand selective properties to the specified classes of defects and faults, that subject to recognition, as well as the properties and parameters measuring system.

The adequacy of the diagnostic model of the possible technical condition determines the frame diagnostic parameters of the signals in the case of malfunctions and synthesis of the diagnostic signs. These form a matrix of diagnostic signs (DS). The diagnostic model produces standards of parameters diagnostic signals, when malfunctions occur. The model makes diagnostic signs, as well as generates a set of decision rules. These allow you to define the types of the technical conditions, defects or defects and their dangers.

The selection set of parameters diagnostic signals out of the source diagnostic signal and formation of the diagnostic signs shall be based on a matrix of the diagnostic signs and on the standards of the parameters diagnostic signals.

As a result out of a combination of a diagnostic sign contained in the diagnostic signal are formed with quantifying both each diagnostic parameter signal malfunctions and in general diagnostic signs.

The classification of the technical condition and diagnostics is carried out according to the current measurements of the diagnostic parameters on the basis of the decision rules sets that define the risk and severity of the identified problems.

The depth of the diagnosis is determined by the properties of a diagnostic model and the amount of the measured diagnostic parameters. The latter is a very important factor, because the limit on the amount of measured diagnostic parameters in real operation system diagnostics and monitoring, with adequate diagnostic model can significantly reduce the depth of the diagnosis.
Function object control in accordance with the decision of its actual position provides: emergency shutdown, gentle treatment, incorporation of reserves, etc.

4. The automatic expert system

The algorithm of automatic expert system (figure 3) includes calculation of diagnostic parameters values for signals in case of malfunctions on the basis of data on their normative values, forming sets of diagnostic signs (DS) that correspond to individual classes and the expert system messages (ESM).

One of the problems of development of algorithms to operate is the differentiation of diagnostic parameters of signals when malfunctions are intersecting and overlapping classes.

For example, in vibroacoustic diagnostics is widely used by the root-mean-square value (RMS) such vibration as vibration acceleration (A<sub>rm</sub>), vibration velocity (V<sub>rm</sub>), vibration displacement (S<sub>rm</sub>) [3]. However, the use in the diagnosis of reciprocating machines only feature [A<sub>rm</sub>] gives an indication of the broad class of malfunctions, covering a number of subclasses. Use as a diagnostic sign of amplitude values of vibration parameters of AVS (A<sub>peak</sub>, V<sub>peak</sub>, S<sub>peak</sub>) enables you to select other classes, separate subclasses which may overlap with subclasses RMS AVS. However, the emergence in diagnostic signal, for example, signs of [A<sub>rm</sub>] and [A<sub>peak</sub>] together indicates that it is an non-overlapping subclass of malfunction.

An automatic separation of defects classes and corresponding the reports of the expert system is based on the attribution of significance to the diagnostic signs, both jointly and separately, taking into account that the same fault classes conformed to diagnostic signs received from other sensors.

The expert reports of diagnostic signs with the higher value replace expert reports with the lower value. This allows to exclude the error messages about the intersecting classes of faults when there is the class of diagnostic parameters, which divides them up into disjoint classes of malfunctions.

Figure 3. Algorithm of the expert system functioning.
Based on decades of diagnosing and condition monitoring experience of reciprocating compressors dangerous productions have been formed a set of diagnostic signs for defects, faults, breaches of the technological mode of compression and other causes of vibration activity of piston compressor.

A database of knowledge of cause-effect relationships of diagnostic signs (diagnostic parameters of signal malfunctions) and classes of overlapping and disjoint malfunctions, as well as the corresponding expert reports, taking into account the value of diagnostic signs (diagnostic parameters of signal malfunctions) have been generated.

5. Conclusion
The proposed principles of technology in diagnostics and monitoring of reciprocating machines have been confirmed by years of experience in the practical operation of the system diagnostics and monitoring which shows that only 5 vibroacoustic signal sensors on reciprocating compressors (cylinder in axially, pressure and inlet valves, crosshead, fundamental bearing [8]-[12]), the shaft angle position sensor and sensor for reciprocating compressors from the drive or a drive can form a 15 diagnostic parameters of signals in case of malfunctions according to signal of each sensor. Using these parameters signals system diagnostics and monitoring on unconditional algorithm automatically determines 36 causes vibrational activity reciprocating compressors. It provides control of almost 80% bounce of commonly occurring failures [24].

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