Method for determining the technical condition of piston machines by measuring the angular velocity of the shaft

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Abstract. A method for determining the technical condition of piston machines was proposed. The method is based on measuring the deviations of the angular velocity of the piston shaft machine depending on the angle of rotation. In order to verify the operability of the proposed method, a mock device for measuring the angular velocity of the shaft was developed. Trial measurements of the angular velocity of a rotating shaft were also carried out.

1. Introduction
In connection with the development of technological processes at various industrial enterprises, the issue of an effective way to keep industrial equipment in good technical condition is of particular relevance. The main ways of servicing equipment at present are:
- hardware failure service;
- preventive maintenance;
- scheduled diagnostic service (SDS);

The most effective type of service is SDS because it relies on diagnostics and prediction of the technical condition of equipment. To control the state parameters, special means of technical diagnostics are used. Continuous monitoring is characterized by determining the time during which the operating condition of the equipment is maintained. Periodic monitoring is used to determine the time point of the next monitoring.

The obtained results of diagnosis and control help to decide on the maintenance, including the time and scope of activities. The basis for the use of this type of maintenance is the use of non-destructive testing means.

2. Features of non-destructive testing of reciprocating machines
Currently, a large number of piston-type pumps and compressors are operated at the enterprises of the petrochemical complex, in particular, the Angarsk Petrochemical JSC. To determine the technical condition of machines of this type various non-destructive testing methods can be used [1]. However, the effectiveness of most non-destructive testing methods in determining the technical condition of piston machines is much lower compared with the effectiveness of the same methods for rotary-type machines.

To identify defects of various types requires the use of suitable methods. For example, the acoustic or vibro-acoustic method is used to identify various cracks and pores in the housing units of piston machines, cylinders, cylinder and spool bushings, cylinder covers and valves. But to search for defects in the crankshaft and bearings, penetration control and the magnetic method are used, the acoustic method is used in places where it is not possible to use other diagnostic methods. The possibility of
applying various non-destructive testing methods for various equipment of oil refineries is presented in table 1.

**Table 1.** The possibility of applying non-destructive testing methods for different types of industrial equipment.

| Method            | Rotary machines | Piston machines |
|-------------------|-----------------|-----------------|
| Ultrasonic        | -               | -               |
| Acoustic          | +               | +               |
| Eddy current      | -               | -               |
| Radiation         | -               | -               |
| Magnetic          | +               | +               |
| Optical           | +               | +               |
| Vibro-acoustic    | +               | -               |
| Radio wave        | -               | -               |
| Thermal           | +               | +               |
| Electrical        | -               | -               |
| Liquid penetrant testing | +               | +               |

Acoustic and vibro-acoustic non-destructive testing methods have been widely used in the inspection of rotary-type machines. Figure 1 shows the results of vibro-acoustic control of a rotary compressor.

![Figure 1. Vibration signal obtained from a rotary compressor.](image)

The graph shows that the amplitude of the vibration of the compressor practically does not change over time, in contrast to the amplitude of the vibration of the piston type compressor, the graph of which is shown in Figure 2.
Figure 2. Vibration signal obtained from piston compressor.

To conduct diagnostics according to vibration data, the Fourier transform is used, with the help of which spectral analysis of the vibration signal is obtained [2]. So, the spectrum of the vibration signal of a rotary compressor has the form shown in Figure 3.

Figure 3. Rotary Compressor Vibration Spectrum.

Analysis of the spectrum of the vibration signal is the basis of vibro-acoustic diagnostics. The spectrum of the vibration signal carries all the useful information about the state of the monitored device. In particular, based on the location and amplitude of individual harmonics or their groups, conclusions can be drawn about the technical condition of individual parts of the compressor.

Figure 3 shows a graph of vibro-acoustic diagnostics of a rotary compressor. Speed measurements are carried out along the vertical axis.

However, upon receipt of the spectrum of the vibration signal obtained by measuring the vibration of the reciprocating compressor, the problem of scatter of measurement results when performing the Fourier transform. As a result, the shape of the spectrum of the vibration signal of the piston machine varies significantly, depending on which section of the vibration signal was used as the source data. Figure 4 shows the change in the shape of the spectrum of the vibration signal of a reciprocating compressor versus time.
3. The proposed method
One possible way to solve this problem is to identify defects by monitoring the uneven rotation of the shaft of the piston machine. So in a piston compressor at the moment of reaching the top dead center (Figure 5), when the piston body is pushed out, the angular velocity of the shaft at the moment of sampling the gaps in the joints of the crank mechanism increases, and at the time of the occurrence of an impact load, the speed sharply decreases. At the bottom dead center, at the time of the return of the piston one can also observe an abrupt change in the angular velocity of the shaft. If a defect occurs in articulated moving parts, for example, a crankshaft with a connecting rod or a connecting rod with a piston, the change in angular velocity will be greater [3].
Figure 5. The process of sampling the gaps at the time of passage of TDC and BDC, respectively.

Taking this into account for non-destructive testing of piston-type machines, it is proposed to use a method based on measuring changes in the angular velocity of the machine shaft depending on the angle of rotation. The implementation of this method requires the development of new measuring tools, software and methodological support.

Currently, the authors have completed the development of a device layout for measuring the angular velocity of a piston machine shaft. The measuring part of the device is based on an absolute magnetic encoder located opposite the end of the crankshaft of the piston machine. The rotation angle is measured by changing the magnetic field around the transducer.

Using the model of the device the experimental data were obtained. The device was tested in two modes. In the first mode, the shaft was rotated at a constant speed without the influence of artificially created defects. In the second mode, the rotation of the shaft was artificially slowed when it was rotated through a predetermined angle using the cam mechanism. The result of measurement is shown in Figures 6 and 7.

Figure 6. Change in the angular velocity of the shaft from the angle of rotation with uniform rotation

Figure 7. Change in the angular velocity of the shaft from the angle of rotation when the shaft is decelerated by the cam mechanism

The graph in Figure 7 shows a decrease in angular velocity during rotation in the range from 175 to 185 degrees, this change is due to the fact that when the shaft rotates, the cam mechanism reduces angular velocity, this method introduces uneven rotation of the shaft.

4. Conclusion
By measuring the non-uniformity of the rotation of the shaft of piston machines it is possible to collect a volume of information about the dependence of the change in the angular velocity of the machine shaft at various angles of rotation from emerging defects. Which in turn will make it possible to develop a hardware-software complex for non-destructive testing of piston-type machines.

References
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