Diagnosis of mining and oilfield equipment by excited oscillations analysis technique

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Abstract. The paper presents relevance of application of non-destructive testing methods in the assessment of technical condition of the mining and oilfield machine components is justified. The prospects of diagnostics of process equipment by the excited oscillations analysis technique are proved. Design and operation algorithm of the multichannel synchronous analyzer Kamerton by LLC NPP ROS (Perm) are described. Methodological bases of defect finding using the multichannel Kamerton analyzer are described. The basic quality criteria characterizing the diagnostics-based state of technical elements are listed. It is proved that the mining and oilfield equipment technical condition assessment method by excited oscillations analysis allows carrying out operative diagnostics of technical facilities without shutdown. This method has no analogues in terms of efficiency compared to the traditional equipment nondestructive testing methods: magnetic particle, metal magnetic memory, ultrasonic flaw detection, ultrasonic thickness measurement, radiographic, metallographic, etc. In some cases, for example, for structures made of heterogeneous materials such as reinforced plastic or reinforced concrete, it is the only possible diagnosis method.

1. Introduction

Reliability improvement of process machines, reducing the costs of equipment operation, and increasing the efficiency of repair and rehabilitation work remain relevant challenges for mining and oil producing enterprises. Insufficient accuracy of estimation of the service life of parts and units of process machines, complexity and high labor intensity of diagnostics leads to an increase in the number of downtimes due to the occurrence of sudden failures and growth of material costs to maintain the efficiency of equipment. These problems can be solved on the basis of development and wide use of nondestructive testing [1, 2].

The prediction of individual service life of process equipment parts includes a set of challenges: assessment of the current state of the object, forecasting the development of this state for the near future and determination of the residual life [3, 4]. To date, one of the most promising ways to diagnose the components of mining and oilfield machines is the assessment of the technical state by the excited oscillations analysis method [1, 5, 6].
2. Research methodology

The process machine components diagnostics by excited oscillations analysis is based on oscillations propagation analysis inside the structure and is related to the internal structure of the object. Pulse excitation (produced by a hammer or impulse source of oscillation) leads to the development of oscillations in the target object, which differ in harmonic composition and damp out at different rates [7]. Mono-oscillations prevail in a homogeneous environment after impulse exposure, damping out for a long time. Presence of cracks (cavities, other discontinuity flaws), as well as the weakening of the internal structure of the environment due to the material ageing, increases the number of harmonics in the signal spectrum, reduces oscillation time due to energy absorption in the flawed areas [10]. Measurement of the wave movement timing parameters inside the object allows analyzing the environment parameters and to identify the flawed area. The method is used to detect internal defects, cracks, cavities in various equipment and structures, including metal, ceramic, plastic and multi-component parts, welded joints, bedding points, internal joints of equipment components and structures, allows revealing signs of material fatigue, localize probable flaw locations.

Figure 1 show that for the practical implementation of diagnostics by excited oscillations analysis the multichannel diagnostic tool Kamerton by LLC NPP ROS is used. The diagnostic complex includes 2 to 32 piezoelectric accelerometer and (or) acoustic sensors for measuring excited oscillations, synchronous analog-to-digital converter for normalization and primary signal conversion, analyzer on the basis of a laptop or a special controller, and oscillation exciter. The oscillation is excited by a hammer, less often by a special pulse oscillation source. Pulse excitation is the most rational method: lack of impact on the target object of the variable load created by the weight of the pulse vibration source is a significant advantage in lightweight structure testing, as the point-to-point load change can cause the shift of frequencies in different measurement cycles. Besides, lack of necessity to use fixtures for installation of pulse oscillation source provides convenience of carrying out nondestructive testing directly at the place of process equipment operation [7].

Figure 1. Multichannel analyzer Kamerton by LLC NPP ROS
The distance between the sensors varies depending on the size of the elements and the density of the structure material. E.g., in the assemblies made of hard metals and alloys, the sensors can be installed at considerable distances from each other, because in solid media the excitation signal can be transmitted at considerable distances, and the softer the material, the closer the sensors should be to each other.

3. Research procedure and analysis
Let's consider the algorithm of diagnostics of the oilfield equipment by the resonant oscillations excitation, as in the case of SK8 horsehead attachment unit. Figure 2 show that technical condition control method provided for installation of three sensors directly on the target element of the object. No cracks or other defects have been detected during the visual inspection of the horsehead attachment unit.

Following installation of the sensors oscillations were excited on the element by a hammer with a head weight of about 0.1 kg. At least four to five similar measurement cycles in a row were carried out to increase the reliability of diagnosis and eliminate accidental interference. Figure 3 show that normal registrations are smoothly attenuating harmonic signals with no sharp local emissions, breaks, overswings.

Pulsed excitation causes the resonant wave processes in the product, which have characteristic features of space- and time development. In a uniform density environment, the time, speed and frequency parameters of the response signal are identical to those of the excitation signal. In the presence of cracks (cavities, discontinuities), and upon ageing of the material (when there is a rarefaction or weakening of its structure), the conditions for the passage of pulse-induced oscillations in different parts of the object are significantly different from each other, which allows identifying homogeneous and heterogeneous areas in the object. Analysis of the energy components of each recorded signal allows not only a qualitative but also a quantitative assessment of the object condition.

Signals registered by the device was processed in the expert diagnostic system Kamerton, which carries out the analysis of the spectral composition of oscillations of structural elements and the calculation of generalized parameters of the element quality.
Figure 3. Head-initiated oscillation signal (a), and response (b) registered by piezoelectric accelerometer sensor

Figure 4 shows that when analyzing the condition of a machine part or a structural element, each signal determines the damping rate, shock (carrier) frequency, deviations of the shock frequency from the normal range of values for a given material, the spectral pattern of the response signal is analyzed. The spectral pattern of defects in individual elements of technical objects is the same, which allows using this method to determine the state of materials of various hardness and composition.

The analysis of the technical condition of SK8 horsehead attachment unit was carried out by estimation of signal attenuation degree in the connection, and comparison of the spectral parameters of the excitation signal and the response signal. Each measurement was analyzed twice in different signal directions, when the excitation was carried out on both sides of the connection alternately.

After the full cycle of measurements all registration signals were processed by mathematical statistics methods. The expert software uses the following parameters to define the element and connection quality criteria:

– mean resonance carrier frequency for all available signals for the element or connection;
– average damping rate of an element or connection;
– mutual frequency deviation in the connection and the element;
– the probability of wall thinning or density reduction, weakening the structure of the element material;
– the probability of cracks, cavities, discontinuities in the element or connection [7].

According to the results of diagnostics of SK8 horsehead attachment unit it is established that the areas of welded joints between the points of installation of sensors 1–2 and 2–3 (see Fig. 2) have signs of cracks. Conclusion by the expert system: the object condition is unacceptable; no further operation of the horse-head pump is possible. Specialists of the company’s service department decided to shutdown the horse-head pump, and to open the target unit in order to visually detect defects. A 1.5 mm deep cut over the section of the horsehead attachment unit exposed a U-shaped crack with kinkings (see points 1, 2, 3, Fig. 2, b), and an incomplete fusion of the weld joint between the bushing and the horsehead horizontal metal sheet [8, 9].
Figure 4. Examples of response signal spectra obtained during examination by the resonance oscillations excitation method on the SK8 horsehead attachment unit: a – no defect found; b – metal cracking

It should be noted in particular that the earlier performed diagnosis of the same unit by ultrasonic control method did not allow detecting the defects determined using the described method.

4. Conclusion
Diagnostics of mining and oilfield equipment units by means of the excited oscillations analysis allows an estimation of the technical condition of machines without their shutdown. This method has no analogues in terms of efficiency compared to the traditional equipment nondestructive testing methods: magnetic particle, metal magnetic memory, ultrasonic flaw detection, ultrasonic thickness measurement, radiographic, metallographic, etc. In some cases, for example, for structures made of heterogeneous materials such as reinforced plastic or reinforced concrete, it is the only possible diagnosis method.

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