Mechanical and Acoustic Characteristics of the Weld and the Base Metal Machine Part of Career Transport

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Abstract: Currently, many industries use foreign-made machinery. There is no opportunity to purchase quality original spare parts for which machinery. Therefore, enterprises operating this equipment are looking for producers of analogues of various parts and assemblies. Quite often, the metal of such analog components turns out to be substandard, which leads to their breakdown at a much earlier date and the enterprises incur material losses.

Due to the fact that the complex of performance characteristics and the resource of products are laid at the stage of their production, it is extremely important to control the quality of the raw materials. The structure, mechanical, acoustic and magnetic characteristics of metal samples of such destroyed details of quarry transport as hydraulic cylinders and detail "axis" of an excavator are investigated. A significant spread of data on the chemical composition of metal, hardness and characteristics of non-destructive testing is established, which gives grounds to recommend to manufacturers and suppliers of parts is more responsible to approach the incoming quality control. The results of the investigation of metal samples by destructive and non-destructive methods of control are compared, which showed that the spectral-acoustic method of non-destructive testing can be used to control the quality of the responsible machine parts under conditions of import substitution.

Introduction

Ensuring the durability of machine parts is an important task of modern machine building, which is determined to a significant extent by the quality of the surface layer [1]. At the same time, it is necessary to solve the problems of improving the reliability of instruments, installations, improving their quality and efficiency, and, consequently, the issues of saving metals, fighting corrosion and wear of machine parts [1]. This is especially important now in conditions of import substitution. In many industries, foreign-made machinery is used, original spare parts for which there is no way to purchase. Therefore, enterprises that operate this equipment are looking for manufacturers of analog parts and components. Quite often, the metal of such analog components turns out to be substandard, which leads to their failure at a much earlier time [2].

In general, in the mining industry in the Kemerovo region, the share of equipping the mines with the main mining equipment of the imported production is: 76.6% of the face faces, 46% of the bottom holes, 63% of the equipment for the transportation of goods and personnel (diesel transport, electric locomotives, lifting installations), equipment ventilation - 30%, systems of air-gas control, communication, warning and automation of about 50% [3, 4].

High performance of mining equipment operating under extreme conditions is provided by a complex of mechanical properties such as resistance to shock loads at low temperatures, wear resistance of the friction surface, etc. [5, 6].

Thus, the purpose of this work is to investigate the microstructure, mechanical, acoustic and magnetic characteristics of the metal of the "axis" part, as well as to derive the dependencies between the measured
mechanical characteristics and the characteristics of non-destructive testing for the timely and accurate determination of the part boundary at the pre-destruction stage.

**Methods and materials of experimental research**

The "axis" part (Fig. 1) after 1 year of operation and having wear, and samples of the analogue metal of the piston rod of the hydraulic cylinder of a mining excavator were selected as objects of study.

The investigated "axle" part of the P & H 2800 XPC excavator is the most loaded element in the hub-axis system, which receives unevenly distributed loads during operation, which leads to their accelerated wear (Fig. 1). After the indicated service life (1 year), the wear value was 17 %, and the diameter decreased to 163 mm. The wear of the shaft axis is due to the fact that on the surface there are defects - scuffing. In the future, there are gaps, which leads to an accelerated destruction of the shaft-bushing pair. The technology of manufacturing the "axis" part is much more complicated and more expensive than the details of the bush, so it is more economical to restore the "axis" part.

![Fig. 1. Bucket of excavator P & H 4100 XPC (a) and the nature of the damage details "axis" (b) and details "bushing" (c)](image)

The fragment in the form of a disc in the cross section of the part was cut out for research. Samples of metal of analogs of the details of the hydraulic excavator unit of the mining excavator have also been investigated in the present work (Fig. 2). The destruction of one of the hydraulic cylinders occurred along the eyelet, the destruction of the other hydraulic cylinder – according to the rod.

![Fig. 2. External view of the hydraulic cylinder of the excavator](image)
The chemical composition of the metal of the samples was determined by the spectral analysis method using the Q4 TASMAN optic emission spectrometer. The hardness of the metal was measured using a universal hardness tester DuraVision-30. Toughness tests were carried out at room temperature on a Izod Pendel pendulum coil, the type of samples with a U-shaped concentrator.

Spectral acoustic analysis, with the automated acoustic system ASTRON, was used to identify the zones with a changed structure, as well as the degree of its change, measurements were made on a transverse sample at 11 points 9 mm apart between the points. Using the surface acoustic wave sensor (Rayleigh waves), the following characteristics were determined:

- Surface acoustic wave delay time, ns;
- attenuation factor, $1 / \mu s$;
- amplitude of the received signal, $mm \cdot 10^{-1}$.[7–11]

For the "axis" part, the acoustic characteristics were measured in two stages: first, measurements were made on the surface of rotation (Fig. 3, a), then, after selecting the sections with the greatest deviations, along the cross-section of the part in the direction from the surface of rotation to the center of the part (Fig. 3, b).

![Fig. 3. Scheme of measuring acoustic characteristics by the spectral-acoustic method of the "axis" component: a – the surface of revolution; b – cross-section](image)

The microstructure analysis [12] was performed with an optical microscope Axio Observer. To study the structure, one sample was cut from each fragment of the hydraulic cylinder, which were pressed into the resin. The samples pressed into the resin were polished, polished and etched in a 4 % solution of nitric acid and 2 % solution of nitric acid in ethyl alcohol. Microstructure studies were performed with an increase of $\times 130$, $\times 500$, $\times 800$ for the sample metal of the "axis" part and with an increase of $\times 200$ for samples of the hydraulic cylinder fragments.

The microhardness was measured on a PMT-3M device [13] with an increase of 100 times by indenting the tip (quadrilateral pyramid with a square base), under a load of 1.96 N applied for 20 s, the analysis of the data was carried out according to [14].

Results and its discussion

The results of the determination of the chemical composition of the metal of the "axis" part are presented in Table 1.
Table 1 – Chemical composition of weld metal and base metal "axis" details

|                  | C  | Si  | Mn  | Cr  | Mo  | Ni  | V   | W   |
|------------------|----|-----|-----|-----|-----|-----|-----|-----|
| Weld metal       | 0.34 | 0.37 | 1.20 | 5.00 | 0.90 | 1.00 | 0.15 | 0.90 |

|                  | C  | Si  | Mn  | Cr  | Mo  | Ni  | V   | W   |
|------------------|----|-----|-----|-----|-----|-----|-----|-----|
| Base metal       | 0.43 | 0.22 | 0.50 | 1.20 | 0.30 | 4.10 | <0.01 | <0.01 |

Fig. 4 and 5 show the results of investigations of the surface layer of a component by the spectral-acoustic control method.

At the first stage of measurements, the maximum deviations of the acoustic characteristics along the surface of rotation were established (Fig. 4). The areas with the maximum deviations from the average values were identified: 12, 15, 19, 28 and 30. However, for sections 12, 15 and 19, where the attenuation coefficient and the amplitude values were decreasing, further cross-sectional measurements were not performed, since defects or structural changes are not implied.

![Amplitude vs. Measurement Sites](image-url)

Fig. 4. Results of measuring acoustic characteristics by the spectral-acoustic method.

Surface of rotation

For sections 28 and 30 (Fig. 4), acoustic characteristics along the cross section of the part were measured (Fig. 3, b). Analysis of the measurement results of the values of the damping factor and the amplitude of the received signal showed the presence of a transition between surfacing and the base metal, as well as significant differences in the values of the characteristics for the overlaying layer and the base metal of the part.
According to the results of measuring acoustic characteristics, zones were detected with a change in the amplitude of the received signal (Fig. 7) on the sample of the "axis" part. Samples were cut from these zones to study the microstructure and measure the microhardness.

In the metallographic study, the interfaces between the layers were identified, and the microstructure of the deposited and base metals was investigated. In the cross section, the initial sample of the "axis" part consists of several layers: a layer subjected to impact loads; a layer of welded metal and a section of HAZ – a transition to the base metal, which differ in their degree of etching, microstructure and grain sizes. The structure at the boundary of the HAZ and the base metal is a ferritic cement mixture with dendrites that pass into the deposited metal, the microhardness in this layer is from 305 to 501 HV. The boundary of the HAZ and the welded layer is characterized by a high heterogeneity of the microstructure, which is martensite, and the range of microhardness values, which is from 438 to 590 HV. High values of microhardness, relative to other areas of surfacing, are probably due to an increased cooling rate of the lower part of the liquid phase of the bath.

Microcracks are found in the HAZ – transition layer to the base metal, the layer differs by a sharp jump in the microhardness values from 305 to 501 HV (HAZ). Microcracks have the same orientation in the direction of tensile stress, but at different angles. In the deposited metal layer, microcracks were also detected, but in a smaller amount compared to the HAZ layer, a transition to the base metal. The microhardness values were from 438 to 540 HV.

In the layer subjected to impact loads, a deformed metal structure was detected, the microhardness values were from 416 to 499 HV.

Based on the results of experimental studies, a plot was plotted of the amplitude of the received signal of the surface acoustic wave from the microhardness for the metal of the "axis" part (Fig. 6).

It follows from the graph (Fig. 6) that as the microhardness values increase, the values of the amplitude of the received signal of the surface acoustic wave decrease.

Thus, according to the results of metallographic studies, microcracks were detected in areas with a change in the amplitudes of the received signal of surface acoustic waves, and also the boundaries of the section to be selected were determined.

For the destroyed parts of the hydraulic cylinders (rod and eye), differences in the chemical composition of the metal between the original and analogues are established. According to the passport, the original is made of steel SM45C (steel 45). Of the analogues, the closest was the version made from the material most appropriate to steel 50. Thus, the deviation in content of C between the original counterparts was more than 5 %.
The hardness of significant differences was not revealed. The results of the toughness tests showed the following: the metal of the originals corresponds to KCU values of 70–80 J/cm², then the value of KCU 18 J/cm² was obtained for the sample metal of the fragment of the cylinder destroyed by the rod, and for the sample metal of the fragment of the cylinder destroyed by the eye – 16 J/cm².

When analyzing the microstructure, it was revealed that the metal structure of the samples of the fragments of hydraulic cylinders consists of a ferrite-pearlite mixture, the structure is fine-grained, the grains have an elongated character. In all the samples studied, defects in the form of nonmetallic inclusions and microcracks in the metal of a specimen of a fragment of a cylinder destroyed by a rod were observed (Fig. 7). The size of nonmetallic inclusions is not the same.

The evaluation of metal by the spectral-acoustic method was performed with respect to the delay time of the surface acoustic waves. The values of this characteristic varied from 4691 ns in the original metal to 4752 ns in the analog metal. Based on the results of a comparison of the study of metal samples with destructive and non-destructive testing methods, a plot of the shock viscosity versus the time delay of surface acoustic waves was constructed (Fig. 8).

![Fig. 6. Dependence of the amplitude of the received signal of surface acoustic wave from the microhardness for metal parts "axis"

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![Fig. 7. Structure of the metal samples of the fragments of the cylinder: a – destroyed by eye, ×200; b – destroyed by the rod, ×200
The graph shows (Fig. 8) that with a decrease in toughness occurs growth of the surface acoustic wave delay time values of values. This relationship can be used to assess the state of equipment on the characteristics of non-destructive testing.

Conclusions
1. Analysis of the equipment of coal enterprises with equipment of domestic and imported production showed that at present the share of domestic equipment is about 20%, while that of imported equipment is 80%.
2. Samples of originals and analogues of such details as the piston of the hydraulic cylinder and the "axis" of conjugation "axis-bush" were destroyed by destructive and non-destructive methods of control. It is established that for these details a considerable scatter of data on the toughness, microhardness and characteristics of non-destructive testing is observed. This gives grounds for recommending manufacturers and suppliers of parts to take a more responsible approach to incoming quality control.
3. Comparison of the results of the study of metal samples with destructive and non-destructive methods of control was conducted, which showed that the spectral-acoustic method of nondestructive testing can be used to control the quality of the responsible machine parts under import substitution conditions.

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[4] Dubov, G.M. Sravnitel'nyy analiz osnashchennosti ugol'nykh predpriyatiy gornoshakhtnym oborudovaniyem otechestvenogo i importnogo proizvodstva // sbornik trudov Mezhdunarodnyh nauchno-prakticheskyh konferentsii "Innovatsii v toplivno-energeticheskym komplekse i mashinostroyenii (TEK-2017)". – 2017. p. 45–50.

[5] Sleptsov O.I. Perspektivy razvitiya metallurgii v Yakutii v svyazi s sozdaniyem novyh pokoleniy staley severnogo ispolneniya/ B.S. Yermakov, O.I. Sleptsov, P.P. Petrov// NAUKA I OBRAZOVANIYe. – 2015. №3. p. 59-63.

[6] Kobernik, N. V. Sovremennye predstavleniya o modifikatsii naplavlennoego me-talla i metalla shva nanorazmernymy chastitsami / N. V. Kobernik, R. S. Mikheyev, A. S. Pankratov i dr. // Svarka i diagnostika. –2015. № 5 p. 13–18.

[7] Criteria for the evaluation of the technical state of the long-lived metal of HPP equipment based on acoustic structuroscopy / Smirnov A. N., Ababkov N. V., Muravev V. V., Folmer S. V. // Russian Journal of Nondestructive Testing. 2015. T. 51. № 2. p. 94-100.

[8] Conceptual model of resource assessment of fuel and energy complex long working equipment on the basis of structural criteria / Smirnov A. N., Ababkov N. V. // IOP Conference Series: Materials Science and Engineering 6. Cep. "6th International Scientific Practical Conference on Innovative Technologies and Economics in Engineering" 2015. p. 012005.

[9] Analysis of acoustic and physical-mechanical parameters Of Cr-Mo-Va steel in the vicinity of the crack / Smirnov A., Logov A., Ababkov N. // AIP Conference Proceedings 2. "Advanced Materials in Technology and Construction, AMTC 2015: Proceedings of the II All-Russian Scientific Conference of Young Scientists "Advanced Materials in Technology and Construction"" 2016. Ch. 020009.

[10] Substructure, grain boundaries, and microcracks in long-operating metal / Smirnov A. N., Kozlov E. V., Koneva N. A., Popova N. A. // Metal Science and Heat Treatment. 2005. T. 47. 3-4. p. 155-161.

[11] Mitenkov, F.M. O novom metode kontrolja povrezhdaemosti materiala oborudovania JAJEU i apparatno-programmnih sredstvah dlja ee realizacii / Mitenkov F.M., Uglov A.L., Pichkov S.N., Popcov V.M. // Problemy mashinovedenija i nadezhnosti mashin, 1998. – №3. p3–9.

[12] GOST R ISO 6507-1-2007. Metally i splavy. Izmereniye tverdosti po Vikkersu. Chast' 1. Metod izmereniya. Moskva: Izd-vo Cstandartinform, 2008. 16 p.

[13] GOST R ISO 6507-4-2009. Metally i splavy. Izmereniye tverdosti po Vikkersu. Chast' 4. Tablitsy opredeleniya tverdosti. Moskva: Izd-vo Cstandartinform, 2010. 25 p.

[14] GOST 5639-82 Stali i splavy. Metody vyyavleniya i opredeleniya velichiny zerna. Moskva: Izd-vo IPK Izdatel'ствo Standartov, 2003. 21 p.