Digital technologies used in technical diagnostics, assessment of technical condition, maintenance and repair of mining machines and equipment

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Abstract. The article deals with the organization of a single technological space for technical diagnostics, maintenance, and repair of mining equipment. The digital technology that unites all services related to production, diagnostics of technical condition, maintenance and repair of mining equipment is based on the SAFE PLANT software package, which provides globality, scalability, versatility, integrability, modularity, distribution, and functionality. The article reflects the results of the implementation of the system at an industrial enterprise.

1. Introduction
At present, industrial enterprises, for several objective reasons, pay close attention to the issues of increasing the reliability, efficiency of operation and repair of technological equipment. These issues are especially acute at hazardous production facilities, which, of course, include the facilities of the coal and mining industries. This is because the approaches to the operation of coal and mining transport equipment are changing, the equipment itself and the technological processes of its operation are becoming more complicated, the requirements of industrial and environmental safety are becoming more stringent. Many various units included in this equipment have a latent nature of the origin and development of malfunctions accumulated over many years of its operation, which is often the cause of emergency situations that can be accompanied by significant economic and social damage, as well as environmental pollution. A few accidents and man-made disasters of various scales in recent years [1] force us to rethink the requirements for the reliability of assessing the current state of equipment and determining its residual resource, considering the latest advances in science in the field of technical diagnostics [2, 3].

On the other hand, most enterprises, in the face of cost savings and budget cuts, are faced with an urgent need to reduce costs, including for the modernization of production, maintenance and repair of main and auxiliary equipment. At the same time, a large share of the equipment in operation has a general deterioration of components and assemblies, some of which, to a large extent, have already exhausted their residual resource [4]. In these conditions, it is especially important that decisions on minimizing costs are made without compromising the reliability of equipment operation. This
becomes possible only if there is reliable information about the current technical condition obtained using various methods of technical diagnostics [5-9]. At any modern industrial enterprise, the closest attention is paid to the issues of increasing the profitability of production through the effective management of production assets using the optimal strategy of maintenance and repair. The experience of domestic and foreign industrial enterprises shows that a justified reduction in maintenance costs without reducing the reliability of equipment operation is achieved only through the comprehensive implementation of modern diagnostic methods.

A new stage in the development of the maintenance and repair system at enterprises may be the introduction of a global plant-wide system for managing fixed assets Oracle. In addition to the modules responsible for finance, warehouse, and personnel, this EAM system includes a maintenance module for planning the timing and scope of repair work. This module provided automation of the processes of organizing maintenance and repair, made it possible to carry out a statistical analysis of repair measures and select the most cost-effective forms of maintenance. The initial information for making decisions using the MRO module is information about the current technical state of the main production assets and the results of diagnostics with the assessment of information about the current state of the equipment, clarification of the causes of failures and unplanned downtime, analysis of the actual terms and volumes of the MRO measures etc. However, the introduction into production of new devices from foreign manufacturers (Pruftechnik, CSI, etc.) does not solve the existing problems. Due to their excellent technical characteristics, these devices made it possible to identify malfunctions of individual mechanisms at the early stages of their development with high reliability, however, due to closed exchange protocols, the measurement results could not be exported to the existing databases included in the Oracle EAM-system maintenance module.

Diagnostic information alone is not enough to solve the whole range of tasks related to increasing the reliability of equipment operation and reducing the cost of its maintenance and repair [10-14]. It is necessary to implement a whole range of measures, united within the framework of a general strategy for the effective operation, maintenance, and repair of equipment. Such activities include (Figure 1):

![Figure 1. Scope of application of diagnostic tools for technical condition at different stages of the life cycle of mining machinery and equipment.](image-url)
reliable assessment of the technical condition of the entire fleet of technological equipment,
- timely identification of malfunctions and forecast of the residual resource using the entire arsenal of methods and means of technical diagnostics within the framework of distributed monitoring,
- control of units at all stages of the life cycle (incoming control during installation, acceptance tests, operation, pre-repair control, repair, post-repair control),
- implementation of “optimal” maintenance approaches.

The organization of effective production activities is impossible without a full-fledged data exchange between diagnostic measuring devices and software control systems. Specialized software should be used to form a single diagnostic space (processing, accumulating, storing, and displaying measurement results) and transferring information about the current state of equipment to global information systems. The requirements for the functionality of such support are extremely high. The program must have a network distributed architecture, support multi-user mode with various access rights, provide unified data exchange with all diagnostic measuring tools, reliable storage of measurement results, convenient tools for multilevel viewing and analysis of data, as well as interact with ACS and external media.

2. Software development
The main requirements for the created software were formulated to solve these problems SAFE PLANT [14-15]:
- globality;
- scalability;
- versatility;
- integrability;
- modularity;
- distribution;
- functionality.

The software product of the same name SAFE PLANT is a unified intelligent platform for collecting, storing, displaying, and analyzing various diagnostic information to increase the reliability of operation and the efficiency of maintenance and repair of the entire fleet of technological equipment based on information about its actual and predicted technical condition (Figure 2).

Figure 2. Distributed SAFE PLANT software network architecture.
SAFE PLANT is the first scalable software product that allows combining information about the state of equipment, modes of operation, maintenance and repairs performed into a single diagnostic database, analyzing them, and transferring the necessary information to plan the timing and scope of repairs (Figure 3).

![Figure 3. Diagram of the interaction of various user groups.](image)

The results of various types of measurements can be used, obtained both with the help of hardware solutions of the company “Diatech” and measuring instruments from other manufacturers as input data (Figure 4).

![Figure 4. Software SAFE PLANT versatility.](image)

Summary data on the current state of the equipment and recommended repairs can be transferred upon request to external information environments. A mixed-type expert module is implemented in the program, adapted to the main types of mining equipment to automate diagnostic procedures. The
practical implementation of this software product will allow coal mining and mining enterprises not only to organize the processing, collection, and centralized storage of information about the results of diagnostics and repairs, to establish more effective interaction of various services, but also to ensure an effective transition to the SAFE PLANT strategy.

3. Results of implementation of SAFE PLANT software at industrial enterprises.

The “Corvet” vibration analyzer and SAFE PLANT software were purchased to develop an enterprise standard for assessing the technical condition of manufactured gearboxes by vibration parameters at “ANZHEROMASH” plant within the framework of creating a management system for improving the quality of products in accordance with the requirements of the GOST R ISO 9001-2015 standard.

All gearboxes manufactured by “ANZHEROMASH” were run-in at the plant test stand 1139R under various operating modes. At the same time, the depth of the amplitude modulation of the vibration of the bearing supports was monitored using the AL-2-3 device (Figure 5), designed to measure the degree of bearing wear and the state of the lubricant in its assembly during the operation of mechanisms, machines, machine tools, rolling stock, drives, etc., oil temperature and gearbox housing temperature at vibration measurement points.

![Figure 5. General view of the AL-2 device-3.](image1)

The measurement results were recorded in the measurement protocol (Figure 6), which reflected information about the zone in which the arrow of the analog device was located, as well as information about the temperature of the oil and the case and was stored in the quality control department of the plant.

![Figure 6. Form of the measurement protocol. Reducer BCG-250.](image2)

As part of the preparation of the enterprise standard, a run-in was carried out at the factory test
bench 1139R (Figure 7) of bevel-cylindrical gearboxes of the BCG type and bevel-planetary gearboxes of the BPG type.

The registration of the parameters of mechanical vibrations was carried out using the vibration analyzer “Corvet” (STD 3300) and the SAFE PLANT software in accordance with the requirements of the developed guidelines for diagnostic measurements of gearboxes manufactured by “ANZHEROMASH”.

All measuring points by the number and type of monitored vibration parameters were assigned to one group with the following characteristics of measurement parameters when carrying out vibration surveys of bearing assemblies and gearing of gearboxes [16]:
- root-mean-square value of vibration velocity ($V_{RMS}$, [mm/s]) in the dynamic range from 10 to 1000 Hz;
- spectrum of vibration velocity (V, [mm/s]) in the dynamic range from 2 to 3000 Hz, 4 linear averaging (3200 lines);
- vibration acceleration spectrum (a, [m/s$^2$]) in the dynamic range from 10 to 10000 Hz, 4 linear averaging (3200 lines);
- peak value of the time signal [m/s$^2$, HPF - 50 Hz, LPF - 12800 Hz, 1000 ms sample length].

The information collected in this way on all types of manufactured gearboxes was statistically generalized for each type of gearboxes in the form of values of the maximum permissible levels of root mean square vibration velocity [$V_{RMS}$] and spectral reference masks for each control point in three mutually perpendicular directions. For example, Figure 8 shows the results of vibration diagnostics obtained during the running-in of the BCG-400 gearbox in the axial direction at the 4th control point.

![Figure 7. General view of the 1139P break-in stand with RPG-120 gearbox installed.](image)

![Figure 8. Form of presentation of measurement results.](image)
Manufacturing or assembly defects revealed during the running-in of gearboxes are corrected at the plant, and the gearbox must undergo repeated running-in to determine its technical condition. If the developed requirements for vibration permissible during acceptance tests are met, the gearbox is considered to have passed the quality control department and fit for operation at the Customer during the warranty period. A vibration Passport is issued for it, indicating the norms of vibration activity.

4. Conclusion

- Summing up the results of the implementation of the SAFE PLANT strategy at “ANGEROMASH”, we can argue that:
  - a reliable assessment of the state of all manufactured products is possible only with the use of modern means of technical diagnostics in the statistical assessment of the spectral components of vibration in the given narrow-band components determined by the geometry of gearing and rolling bearings;
  - introduction of distributed monitoring of the technical condition of manufactured gearboxes (quality control department of the manufacturer, acceptance tests at the Customer, periodic diagnostics of the technical condition during operation, pre-repair and post-repair tests) will allow obtaining reliable information throughout the entire life cycle of manufactured products;
  - transition to the strategy of “optimal” service according to the actual state will save labor and financial resources due to a single multi-level information space, which allows all participants in the technological, production and repair processes to carry out fast and efficient data exchange.

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