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Digital technologies in modeling and design of mining excavators

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Abstract. Development and application of digital technologies at the stage of new model design is highly relevant. Manufacture of a testbed vehicle and its full-scale pilot testing is impossible for Russian manufacturers of mining excavators due to a high cost of a prototype and a lack of special testing grounds. In order to reduce the risks of machine builders as vehicle manufacturer and those of MPPs as users of the prototype excavator, it is necessary to introduce and develop the digital twin technology at the stage of designing new models. A general reference point in development of the digital twin of a mining excavator is minimizing human input. Due to integration of works by stages of creation of the digital twin in a form of an information diagnostic system, there is a possibility to manage the life cycle of the product and optimize MRO with accounts of actual conditions and operating modes.

1. Introduction

In modern engineering, design of mining excavators is carried out with the use of advanced CAD/CAM/CAE systems of computer 3D modeling.

At the engineering design stage, strength calculations are performed using the developed 3D models, the operating parameters of the main mechanisms of the excavator are calculated [1] and non-linear problems are being solved, including contact non-linearities, non-linear properties of materials, geometric non-linearities of large deformations.

Manufacture of a testbed vehicle and its full-scale pilot testing is impossible for Russian manufacturers of mining excavators due to a high cost of a prototype and a lack of special testing grounds. The most in-demand excavators at mining processing plants are those with the bucket capacity of 20 m³ or more; they weigh over 700 t [2, 3], resulting in correspondingly high cost of the products. Thus, a newly developed model of a mining excavator with the serial number 1 is partially financed by a customer and is supplied on conditions of pilot testing operation.

In order to reduce the risks of machine builders as vehicle manufacturer and those of MPPs as users of the prototype excavator, it is necessary to introduce and develop the digital twin technology (DTT) at the stage of designing new models.

2. Digital twins and creating them

The modern concept of DTT [4, 5] goes beyond a regular 3D model. A digital twin is an aggregate, consisting on the model of the object itself, simulation of its operation complete with a dynamic model of load distribution between the units and components of the excavator, as well as data on the vehicle's operation obtained by means of strain measurements. At that, the digital twin is not limited



to collecting data obtained at the stage of product development and manufacture. It continues aggregating data throughout the life cycle of the object.

The technology provides an ability to model a wide range of situations occurring in actual operation of the excavator. DTT allows for preventive optimization of the structure for selected criteria.

If there is a prototype of the design object, e.g., an operating mining excavator, creation of its digital twin requires field trials to reveal deformations and stresses acting in its structural elements. It allows obtaining a more accurate simulation model that better reflects the reality. Then, it is necessary to ensure operability and dynamics of such a digital twin.

For that matter, excavation is simulated with a possibility to dynamically record loads on the operating equipment under conditions comparable to actual operation; a process of rock mass disruption is simulated; stress-strain behavior is simulated from the obtained loads in both static and dynamic loading modes. As a result, a possibility appears to simulate the excavator's behavior throughout its life.

A general reference point in development of the digital twin of a mining excavator is minimizing human input in defining and analyzing the loads, equipment operating modes and its life cycle, which is the main difference between DTT and 3D modeling.

In order to reach the goal stated in the title of this paper, the following objectives shall be attained:

- to develop a parametric model of units of the operating equipment;
- to model energy streams from the main drives to the operating equipment;
- to model the distribution of power flow through the operating equipment when the excavator is involved in excavation;
- to model a breast with adjustable characteristics;
- to model the kinematics of the excavation process;
- to simulate the excavation process with recording the loads onto the operating equipment elements;
- to perform static and dynamic calculations of the operating equipment structure from the obtained time and motion diagram with considerations for the obtained stress-strain behavior;
- to simulate changes in the operating mode through the life of the product.

3. Simulating the operation of a mining excavator

Simulation of the operation of a mining excavator have been partially implemented [6] in the excavator simulation complex EKG-18R (the training simulation complex belongs to IZ-KARTEKS named after P.G. Korobkov LLC), in particular, excavation kinematics and energy transfer from the main drives have been modeled, there is also a partial modeling of breast. The operation principle of the training complex is based upon the computational model of the excavator that is maximally close to the real equipment, taking into account possible variations in the type of electric drive and installed operating equipment. The software and algorithms of the training complex allows recording the indications of the standard information and diagnostics system (IDS) of the excavator: the volume of rock mass transferred, the arrays of actual vales of energy parameters for main drives during the excavation cycles, etc. The experiments have shown that the values of parameters recorded from the training complex IDS are largely compliant with the values measured at an actual excavator during the excavation cycle.

By now, the modeling of power flow distribution through the operating equipment is complete (Figure 1). Within the framework of the simulation, the cutting angle was changed (the angle between the axial lines of digging prongs and the dipper, changes in the angle were performed by adjusting the attachment links between the bucket and the dipper).

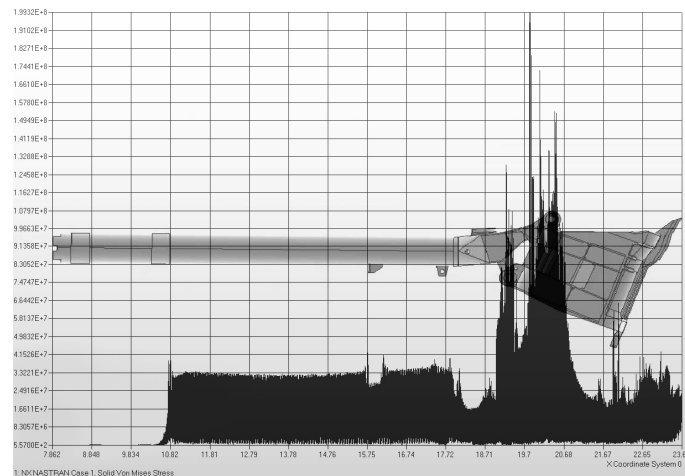


Figure 1. Modeling the distribution of power flow through the operating equipment when the excavator is involved in excavation

The results of the works from different stages of creation of the mining excavator digital twin shall be integrated into the equipment's information-diagnostic system [7]. In this way, a statistic base will be formed for the work, and a possibility will occur to control the product life cycle and optimize MRO to the actual conditions and operating modes; it will provide maintenance units with a wide array of possibilities to analyze the current state of product.

The fact that all the modern mining excavators are provided with stock IDS defines the requirement of integrating the DTT with the programs and algorithms in the IDS in order to control the equipment life cycle and timely correct repair interventions during the manufacturer's condition monitored maintenance. Figure 2 shows a diagram describing perspectives for intellectualization development of a mining excavator through the development of IDS.

4. Intellectualization of mining excavators

The first stage of intellectualization is already implemented in new mining excavators. It assumes collection and reflection of information on the excavator's operating modes, electrical equipment and its possible failures, temperature and pressure in reduction gear of the mechanisms, pneumatic and hydraulic systems, time of useful function, energy consumption.

The second stage is IDS's involvement in correction of the excavator's operating modes in specific operating conditions. Currently, these IDS functionality is partially implemented: a system is developed for automatic protection of mechanical equipment and load control on the excavator's working bodies [8, 9].

The next stage in IDS development involves, first, automation of the rock mass excavation where the operator is only monitoring the excavator's operation and second, an automated adaptation of maintenance and repair schedule to specific operational conditions. It includes development of ways to determine the actual technical state of excavators, which shall be used as a foundation of a completely IDS-calculated MRO system. At this stage of development, the IDS shall determine the periodicity and scope of works, primarily those related to resource distribution (on the basis of actual diagnostic information), as well as calculate the stock of spares, predict repair downtime, assist in troubleshooting, provide lubrication of units and systems (Figure 3) [11,12].

For each group of units and unit assemblies of the excavator, a set of criteria shall be developed to evaluate actual accumulated running time, form algorithms for control of equipment life cycles. The data on actual state of individual units from each of such subsystem are transmitted to the IDS, where they are accumulated, processed and interpreted to be used in management of the excavator's life cycle by means of changes in its MRO schedule. Repair specialists of both the user and manufacturer execute control over the operation of the system. Thus, functioning of the technical service is ensured

within the framework of the condition-controlled maintenance strategy. The algorithm of such work is given in Figure 3.

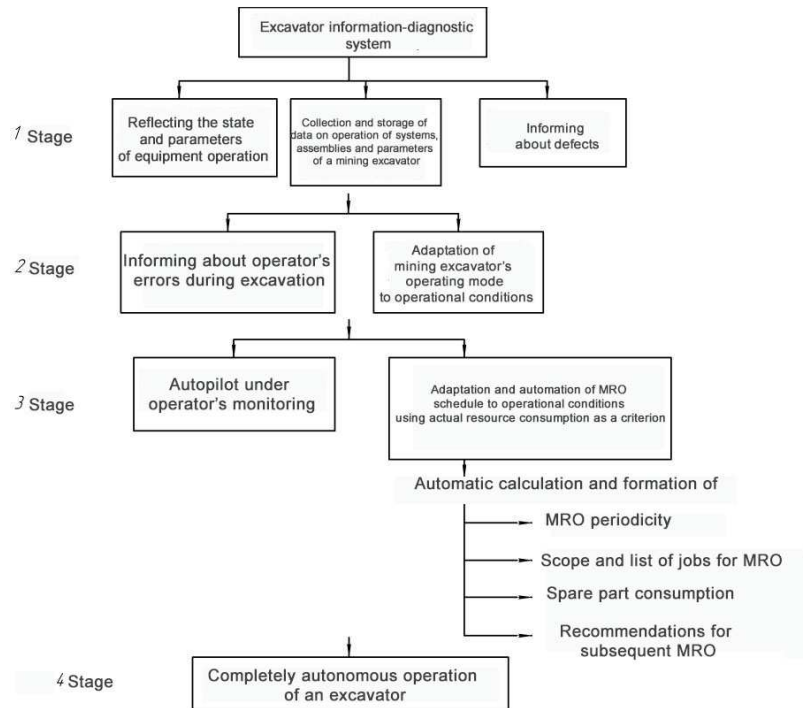


Figure 2. Stages in development of intellectualization of mining excavators

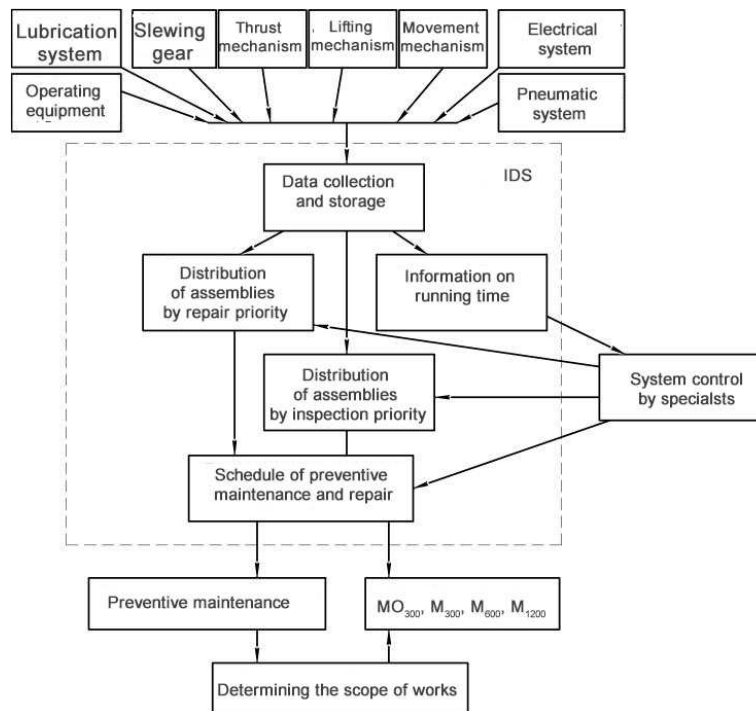


Figure 3. Operation of an MRO system for condition-monitored maintenance

5. Conclusions

Application and further development of digital technologies in design of mining excavators to improve their intellectualization level and managing the technical state through the equipment life cycle results in the fourth stage, namely, design of an excavator, which operates completely independently and requires human involvement only for definition of production objectives and performance of repair, maintenance and adjustments.

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