STUDY ON THE THEORETICAL BACKGROUND OF IN SITU AND TEST RIG MEASUREMENTS OF LOAD IN BOOM OF BWE WORKING IN HARD TO EXCAVATE ROCKS

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ABSTRACT

The machinery predominantly used for overburden removal as well as for lignite and inter-bedded waste layers extraction in surface mining operations in Europe, is the bucket wheel excavator. The existence of hard rock structures—layer or boulder types— with higher cutting resistance as the normal rock—produces downtimes, increased equipment wear, or even severe damage of the bucket wheel excavator’s structures or operation parts, resulting in increased energy consumption, lower production rate and finally increased mining costs.

The present paper, based on some aims and results obtained in BEWEXMIN RFCS project is devoted to the development of solutions to reduce failure rates of bucket wheel excavators working in these conditions. This outcome can be achieved by developing methods for adaptation of already working excavators to those conditions and prescription of standard requirements for newly built ones, and on the other hand, a system of continuous surveillance of machinery superstructure’s stresses and in due time signaling the emerging threats.

GENERAL OVERVIEW

In recent years, on excavators’ working faces it is clearly visible the increased amount of unmineable structures and interlayers with excessive mining resistance. This situation occurs in many countries in Europe, among others, in Poland, Czech Republic, Romania, Serbia and Greece.

Excavators operating in these countries are not fully adapted to such conditions. The main bases for their construction are guidelines developed in the mid-90s of the XX century in West and in East Germany. The bases for these standards and norms development were experiences from excavators operating in
these countries on that time. It must be also considered that the BWE has been historically developed as a loading equipment for bulk coal from stockpiles.

They were operating then only in easily mineable soils. Exploitation of bucket wheel excavators in other countries, mainly in Poland, Czech Republic, Serbia and Romania was based on German examples. This resulted in the use of the same technical solutions as for easily mineable soils during operation in structures with increased mining resistance.

It turned out that these norms and guidelines did not consider increased dynamic loads resulting from more difficult mining conditions. Based on several studies mainly conducted by Poltegor on SRS 2400 excavator in Machów Sulphur Mine in the framework of cooperation with Lauhammer Company, TGL13472/2 standard [7] was updated and the values of substitute dynamic coefficients were increased. However this change was not sufficient.

As showed later tests and operating experience [7] this coefficient was only useful for calculations of head and first transverse wall of bucket wheel boom [9]. DIN 22261 [12] norm- the basic safety norm for bucket wheel excavators which is currently in force in Europe still includes unchanged values of dynamic coefficients. It includes the commentary that when experimental values of these coefficients are higher than these proposed in the norm, experimental values should be taken.

The state of the art presented above, shows that there are relatively many methods and that many tests and experiments are conducted on bucket wheel excavators in Europe.

As stated above, these tests are mainly focused on elimination of consequences of different failures and damages of excavators. But there are no tests and research enabling adaptation of superstructures, mining systems and all other mechanism of an excavator to operate in difficult conditions with excessive dynamic loads typical for hard mineable soils.

There are no complex tests focused on influence of variable loads on the size of dynamic loads and their relation with dynamic properties of an excavator. Moreover, existing calculation standards do not include in a proper manner dynamic loads, which makes impossible the designing of excavators fully adapted to operate in hard mineable soils.

It is to be noted that there is still no sufficient experience in order to construct bucket wheel excavators intended to operate in different mining conditions, also in hard mineable soils. The project results will help to fill in this gap.

METHOD OF DETERMINATION OF STRENGTHS VALUES DURING RESISTANCE CALCULATIONS OF LOAD CARRYING STRUCTURE OF BUCKET WHEEL EXCAVATORS

Preparatory activities are currently carried out. The aim of this research activity is to estimate the values of maximum force and a factor of impulse forces’ increase and decrease on the basis of experimental research. A review of gathered measurements, associated with the estimation of mining resistance, has been done
and distributions of bucket wheel loads in time, when it was registered that hard fractions caused shutdown due to overload of the mining drive, were detected. Based on the analysis of the gathered material and the proposed model guidelines for necessary research of the mining unit loads at the planned research object were prepared.

The available measurements indicate that it was impossible to register a direct collision of the bucket with unmineable obstacle (inclusion). The main reason is the randomness of this phenomenon, which means that one cannot predict and plan measurements allowing for the registration of this phenomenon. The gathered research material made it possible to analyze interactions of the bucket wheel with the mined rocks when activating the overload clutch.

Based on the mining resistance research results it may be preliminarily assumed that the value of the load increase factor depends largely on the size of the mining unit. As a measure of this size, one can assume the ratio of force increase to the power of the bucket wheel drive. The value of the agreed rate of increase is initially assumed to be equal to $K_N = 68 \text{kN/kW}$. Verification of this value requires experimental testing.

In order to better evaluate the impulse load value it is important to know the real interaction of the excavator and unmineable obstacle. To register such event it is proposed to use a continuous monitoring system. Therefore, it is planned to expand the existing system with an element, which at the time of exceeding specifically defined mining resistance caused by the contact with unmineable obstacle, will automatically start to record the measured values for a specified period of time before and after an event of excessive mining resistance.

It is proposed to develop a program to simulate the operation of mining drives and study the influence of the parameters of its elements when transferring impact load:

- automatic registration of construction effort and the drive unit load in case of collision of the bucket wheel with unmineable inclusion
- measurement of vibration and construction effort with simultaneous registration of the mining drive load during operation.

It is very difficult to perform short-term measurements, during which the collision of the bucket wheel and the unmineable inclusion occurs. It is therefore proposed to develop a module to monitor the status of the drive load and construction effort, which will record data in the buffer in the loop. In case of an incident involving the impact load of the drive, the module will automatically save the stored measurement data.

DEVELOPMENT OF A METHOD OF LOAD CARRYING STRUCTURE
EFFORT ASSESSMENT BASED ON REGISTERED SIGNALS

Elaboration of a vector of monitored measurement data as well as rules of their analysis and interpretation, enabling assessment of efforts of the bucket wheel excavator load carrying structure

As part of the carried out tasks, a theoretical analysis of loads occurring during operation of the machine and their influence on the value of effort of the excavator
load carrying structure was performed. A review of available measurement data of the bucket wheel excavator construction efforts was done. The measurements, where the influence of the mining unit directly affects the construction, were analyzed. Based on the analysis, field research and gained experience, values required to be monitored, having a significant impact on the load-carrying structure effort, were selected. These include, in particular, the electric power of mining drive load and rotating mechanism. A scope of theoretical research which gives a basis for the analysis and identification of construction loads derived from loads of mining drives was developed.

The load-carrying structure of basic machines being the object of the research is complicated in its construction. Depending on the type of structure and applied construction solutions, one can choose sites particularly vulnerable to damage. Monitoring will be carried out at basic units of machine load-carrying structure in places where the units are connected:
- a mining boom unit with a tower,
- a tower with a rotating platform,
- a counterweight boom with a tower.

![General overview of a bucket wheel excavator.](image)

The conventional division of the whole bucket wheel excavator load-carrying structure, regarding geometric features of unit connections and their nature of operation and external loads is as follows:
1. Mining boom unit with a movable mast,
2. Counterweight boom unit with a tower,
3. Chassis unit,
4. Bridge unit. Based on the gained experience and analysis of measurement data on the load-carrying structure reaction to loads associated with machine operation, a method of estimating the boom load, based on the measurement of stress at a diagnostic cross section of the bucket wheel boom, was selected. A cross-section in the middle of the bucket wheel boom has been recognized as the diagnostic cross section (Figure 5).

![Figure 2. A diagnostic cross section of the bucket wheel boom.](image)

The expansion of the existing measurement system is designed to additionally measure temporary component forces causing the boom load. The idea behind the measurement system is to correlate readings from tensometric sensors in such a way that it is possible to determine loads varying in time, such as:
- Torque of bending boom construction in vertical plane at any cross-section, i.e. torque caused mainly by the circumferential component of the digging force;
- Torque of bending boom construction in horizontal plane at any cross-section, i.e. torque caused mainly by the lateral component of the digging force;
- Compressive force of boom construction, i.e. the force caused mainly by normal component of the digging force;
- Similar characteristics occurring in the construction of masts, and towers, etc.;
- Tensile forces in boom hoist ropes;
- Shear forces in selected sections of steel structure.

EXPERIMENTAL DETERMINATION OF THE VALUE OF CORRECTION COEFFICIENTS ENABLING MONITORING OF EFFORT OF AREAS IN WHICH THERE IS NO TECHNICAL POSSIBILITY TO INSTALL MEASUREMENT SENSORS

Definition of changes value of efficiency in the areas of stresses sensors installation in relations to fatigue strengths of neighboring construction nodes. Experimental determination of fatigue strength variation at positions where stress sensors are located with regard to fatigue strength phenomena in neighboring nodes or sites of the construction will be performed. Fatigue strength is determined experimentally for standard strength samples. The actual element has different
properties and the fatigue strength of the construction part may be different from the strength of a sample of the same material.

Furthermore, it is not possible to place the sensors in the construction nodes. The fatigue strength of a given element is dependent on the size, shape and condition of the surface. At the design stage, depending on the accuracy of calculations, the influence of factors changing the calculated stresses is taken into account by assuming the factors that increase their values.

Stress value approximation from the measurement point to the monitored sites is based on node modeling with use of FEM calculation methods with load carrying structure caused by an external force taken into account. In order to identify the load based on measurements of stress, it is necessary to perform stress analysis of load-carrying structure with use of FEM enables separating pulsation stress from impulse load of the mining unit (which comes from its own mass vibration as well as from technological moves) out of general overview of load-carrying structure stresses that occur during mining.

The results of model calculations will be used to verify the data obtained from the analysis of the stress signals measured at the monitored machine. Based on the planned experimental studies, the actual distributions of stresses in the excavator load carrying structure for different operating conditions will be determined. The obtained results will be correlated with the values of parameters dependent on physical and mechanical properties of the mined material and loads of the mining unit. On this basis, a correction factor value for the adopted hypothesis of fatigue strength assessment will be estimated. This will allow for more accurate determination of residual strength of the monitored structure.

Guidelines to perform measurements that aim at correlating the value of dynamic stresses in the machine body with the impulse load of mining mechanism drive were also developed. To reach the objective, it is necessary to make strength calculations for the load carrying structure of the excavator’s body, which will be researched. The calculations mainly include stresses originating from the weight of the body and individual forces applied to the bucket wheel. The calculations will be performed by a research team from Wroclaw University of Technology specialized in this field.

Due to large size and dynamic loads associated with the machine operation, theoretical determination of actual effort of the individual construction elements is subject to errors which result from generalization adopted in the process of modeling and subsequent calculations.

A limited number of points have been predicted for evaluation and effort monitoring the required theoretical analysis of calculations which aimed at the selection of sites within the construction, which are the most strenuous under variable loads.

To indicate sites particularly exposed to fatigue failure, it is required to accurately reflect geometry of the selected element or area of occurrence of the construction notch. Calculations are then carried out with the use of FEM. Indicated areas are sites of significant change in geometric dimensions, connections, those in particular which have not been subject to mechanical processing after welding and places that have been subject to repairs. This information can be provided by the
practical assessment of the load carrying structure, or retrieved from a record of repairs, if available.

The analytical assessment of the influence of variable load on the degree of variation from the average stress level in the concerned elements (nodes) that are subject to fatigue damage is performed on the basis of measurements and analysis in measurement points.

The occurrence of local stress concentration and determination of its magnitude dependent on load is the goal of this stage. The most difficult issue is to estimate the variability of the stress concentration magnitude, which depends on the load. In a technical manner, the measurement corresponds to the stresses at the point of measurement. Based on the results of stage II, the stress value should be interpolated to the monitored point.

CONSTRUCTION OF THE MONITORING MEASUREMENT SYSTEM ON THE BUCKET WHEEL EXCAVATOR AIMING AT DETERMINING THE FATIGUE STRENGTHS

Completing the research equipment for the construction of the monitoring system has started. An analysis of the required components was made and basic devices and equipment for construction of measuring systems were purchased.

The existing monitoring system is planned to be expanded with additional measuring modules and data retrieval functions. It is to enable research of the influence of external loads caused by operating mining drives on load transferring to the excavator’s load carrying structure.

For this purpose, it is anticipated to increase a number of tensometric points for measuring the effort of construction, add signals to measure the operating status of the main mechanisms and implement functions to record time series data from the measuring points for the automatically selected events such as the occurrence of the bucket wheel impact load or manually initiated tests of the external load influence on the load carrying structure effort.

In addition to the measurement data collection, the current system regularly generates fatigue spectrum and performs fatigue analysis. These processes require for data analysis to be performed on a continual basis. This results in high demand for a computing power system. Due to the high use of computing resources, measurement data are made available in 10-20 second periods. To expand the capabilities of the system with new measurement signals, allow more frequent recording of signals and implement functions of automatic data capture at the collision of the bucket wheel with unmineable inclusion, it is necessary to purchase the new controller of greater efficiency.

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