# RESISTANCES OCCURRING DURING THE EXPLOITATION OF SOILS WITH BUCKET WHEEL EXCAVATORS

## OPORY WYSTĘPUJĄCE PODCZAS EKSPLOATACJI GRUNTÓW WIELONACZYNIOWYMI KOPARKAMI KOŁOWYMI

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*One of the aims of the project BEWEXMIN Bucket wheel excavators operating under difficult mining conditions including unmineable inclusions and geological structures with excessive mining resistance'is the development of a load and fatigue monitoring system for bucket wheel excavator's superstructures. The article describes resistances associated with exploitation of soils with bucket wheel excavators, which were the basis for the development of a system for assessing the risks of damage to the excavator's superstructures in real time based on recorded signals.*

***Keywords: opencast mining, exploitation resistances, bucket wheel excavator***

*Jednym z zadań międzynarodowego projektu badawczego BEWEXMIN: „Praca koparek kołowych w warunkach występowania w urabianym ośrodku utworów o nadmiernych oporach urabiania jak i wtrąceń nieurabialnych" jest opracowanie systemu monitorowania wytężenia ustroju nośnego wielonaczyniowej koparki kołowej. W artykule zestawiono i opisano opory związane z urabianiem gruntów wielonaczyniowymi koparkami kołowymi, które były podstawą budowy systemu oraz opracowano metody oceny zagrożeń uszkodzenia ustroju nośnego w czasie rzeczywistym w oparciu o rejestrowane sygnały.*

***Słowa kluczowe: eksploatacja odkrywkowa, opory urabiania, wielonaczyniowa koparka kołowa***

## INTRODUCTION

BEWEXMIN international research Project „Bucket wheel excavators operating under difficult mining conditions including unmineable inclusions and geological structures with excessive mining resistance" is being carried out by an international consortium since 2015 as part of the Research Fund for Coal and Steel. Poltegor-Institute is the leader of the Project. PGE Górnictwo i Energetyka Konwencjonalna S.A., Oltenia Energy Complex from Romania and Public Power Corporation from Greece are the industrial partners included in the consortium, which are the largest producers of electricity from lignite in their respective countries. The consortium's scientific partners include, apart from the previously mentioned Poltegor-Institute, VUHU Výzkumný ústav pro hnědé uhli from the Czech Republic, Technical University of Crete, National Technical University of Athens, Petrosani University and Instytut Techniki Górniczej KOMAG. This Project is an interdisciplinary project that combines issues in the fields of mechanics, automation, mining technology as well as geology and geophysics. [1].

One of the tasks of the Project is to develop a system for monitoring the effort of the bucket wheel excavator load-carrying structure. Along with the developed System, there is a need to develop a method for assessing the effort of the load-carrying structure basing on signals recorded on a real-time basis. The starting point in the interpretation of the read values is the precise definition of the resistances associated with the exploitation carried out at a given moment. On this basis, a vector of parameters of monitored measurement data has been developed and constructed, as well as principles of its analysis and evaluation, sufficient for a uniform assessment of the effort of structural components, depending upon external loads related to the operation of the machine mining systems. Due to the importance of this issue, project contractors have often been asked to standardise and describe the basic resistances associated with soil exploitation using bucket wheel excavators, and this is the purpose of this article.

## OPERATING TECHNOLOGY OF A BUCKET WHEEL EXCAVATOR

Modern wheel excavators are only adapted to work in a shortwall system. Usually, the mining is carried out with a vertical chip. The horizontal operation is only carried out under specific conditions, e.g. when working near an unmineable obstacle, due to the disadvantageous load growth [6], which is disadvantageous for the machine load-carrying system and its drive mechanism. The basic task carried out by bucket wheeled excavators is the process of generating a stream of excavated material. Simultaneous occurrence of the main working movement (Fig.1a), performed by the rotating bucket wheel and the lateral movement of the bucket wheel (Fig.1b), which is obtained by the rotation of the machine body are the conditions of the productive state. Additional movements, which ensure

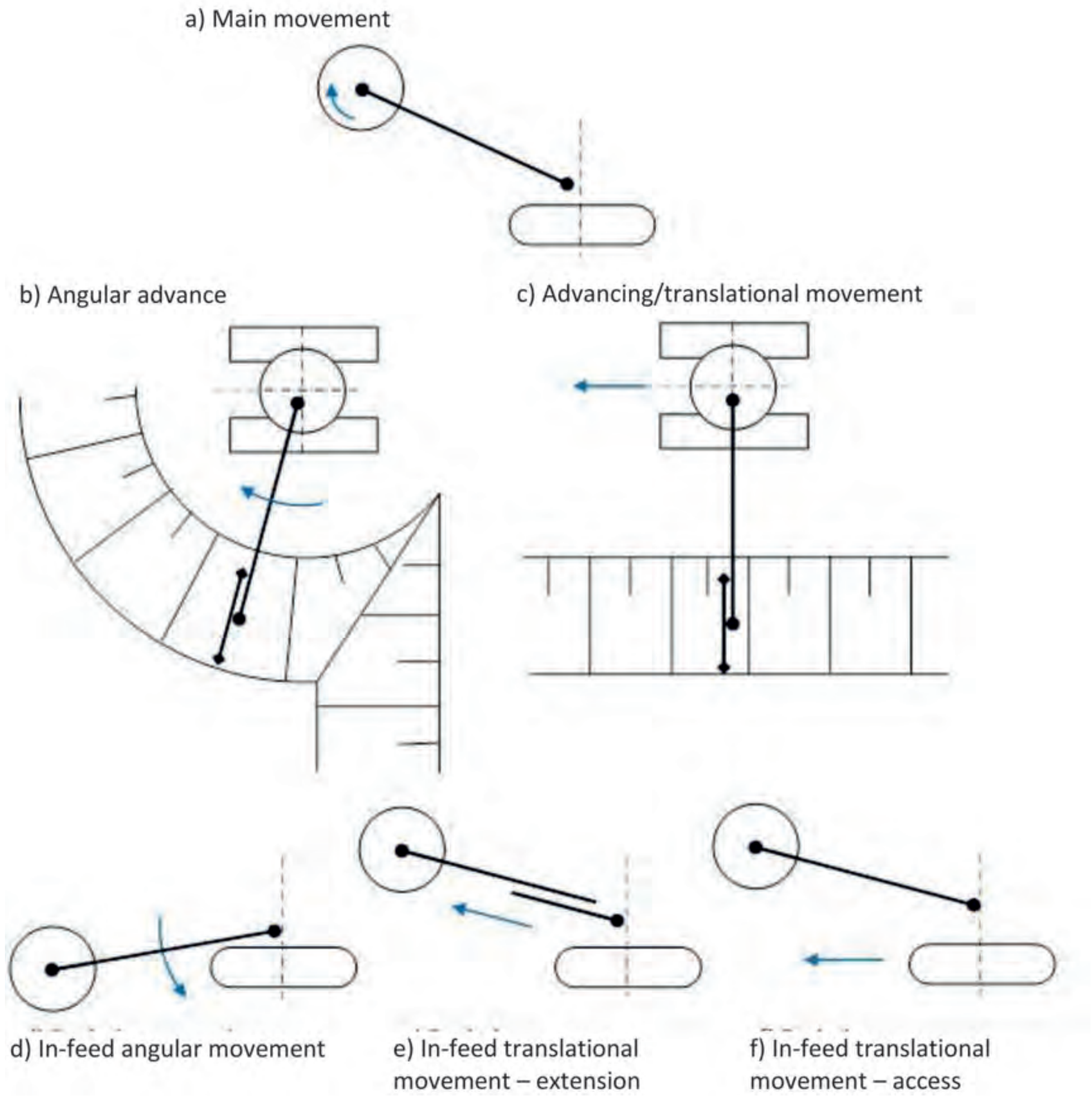


Fig. 1. Bucket wheel excavator working movements [2]
Rys. 1. Ruchy robocze koparki kołowej [2]

contact between the mining unit and the unmined coal after completion of mining at a given working range of the mining wheel, at a given location in relation to the excavator body and at a given excavator site in the excavated shortwall, are as follows: horizontal in-feed movement of the bucket wheel (fig. 1e) – performed by the travel mechanism through the excavator access – and in-feed of the bucket wheel in the vertical direction (fig. 1d) – obtained by changing the angle of inclination of the bucket wheel boom and performed by the vertical movement mechanism [3], [4].

## RESISTANCES ASSOCIATED WITH WORKING MOVEMENTS

### *Resistance to loosening*

As a result of working movements performed by an excavator, its bucket wheel penetrates into the ground. The buckets directly interact with the soil and cut down pieces of ground in the slope. The loosened soil resists (resistance to loosening), which is overcome by the buckets by cutting force exerted on the ground.

Resistance to loosening (fig. 2) is associated with resistance to the destruction of the loosened structure of the piece of ground, $P_O$, resistance of the cutting edges to indentation into the ground, $R_O$ and frictional resistance of the ground on the internal, $P_{t1}$, and external, $P_{t2}$, surfaces of the cutting edge.

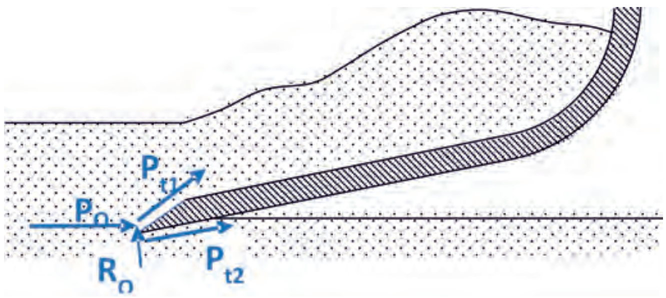


Fig. 2. The components of the resistance to loosening acting on the bucket [2]
Rys. 2. Składowe oporu odspajania działające na ostrze czerpaka [2]

Cutting force, $P_U$, (fig. 3) is a resultant of the following forces: circumferential, $P_K$, horizontal, $P_B$, and radial, $P_P$ forces. These forces are the result of the operation of individual drives performing the working movements. The circumferential component is of the largest value, which is associated with the main movement and results from the operation of the bucket wheel drive. The other two components are of lower values. The horizontal component is associated with the advance. For wheel excavators operating in the shortwall system, this force is the

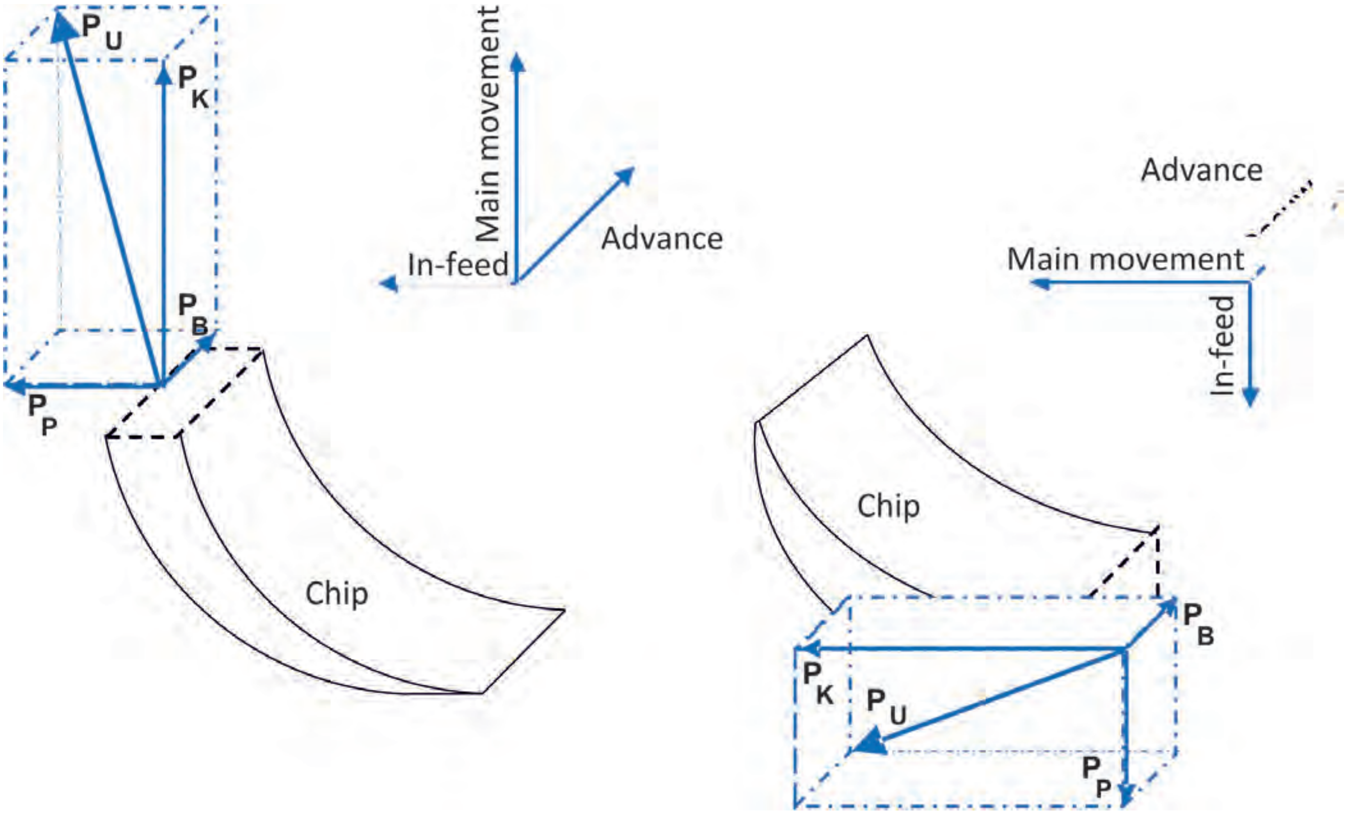


Fig. 3. The components of cutting force a) vertical chip, b) horizontal chip
Rys.3. Składowe siły skrawania: a) praca wiórem pionowym, b) praca wiórem poziomym [2]

result of the operation of the body rotation drive. For excavators operating in the longwall system, the horizontal component comes from the travel driver, while the radial component is associated with the in-feed movement. If this motion is implemented by the drive of the bucket wheel boom winches, then the radial force is due to the weight of the bucket wheel rest. If the in-feed movement is implemented by extension, then this force comes from the extension mechanism, and if it is caused by access, then this force comes from the travel drive [2], [8].

In the bucket wheel excavators, the tool edge tools acts in parallel (tangential) to the surface of the medium being mined. As a result of the movement of the tool tip, the so-called cutting of rock (ground) occurs. Cutting is carried out on the side and face parts of the blade (fig. 4). Cutting is carried out by the parallel movement of the tool in relation to the medium. This movement is the main working movement. Since the working movement is associated with the circumferential movement of the bucket wheel, the resistance to loosening is mainly overcome by circumferential force (i.e. associated with the main movement).

The tool also advances apart from the main movement. For this reason, part of the resistance to loosening is overcome by a horizontal component proportional to the ratio of the cross-advancement velocity to the circumferential speed of the bucket wheel (fig. 5). In addition, resistance to the lateral blade penetration into the ground acts on the side external bucket edge, which is also overcome by the horizontal component of cutting force.

The excavator access movement is carried out for a short time and periodically, therefore resistance due to the in-feed movement is not always present. It occurs when the tool pene-

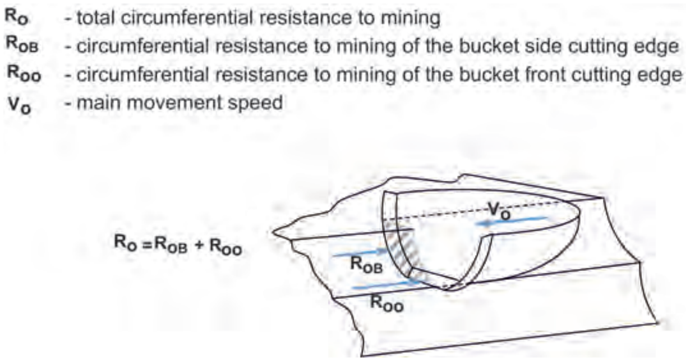


Fig. 4. Cutting of plastic soils diagram [2]
Rys. 4. Schemat urabiania (skrawania) gruntów plastycznych [2]

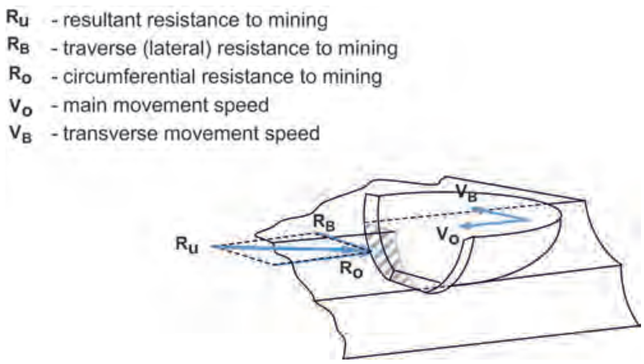


Fig. 5. Transverse component of resistance to loosening [2]
Rys. 5. Składowa poprzeczna oporu odspajania [2]

trates into the ground during in-feed. That is not always the case and this movement is also performed without any interaction between the buckets and the ground.

As for advance, part of the resistance to loosening is now overcome by the radial component, proportional to the ratio of the radial advance speed to the bucket wheel circumferential speed [2], [8]. Resistance to the radial penetration of the blade into the ground occurs also at the radial penetration of the bucket cutting edge (in this case). This radial resistance to the tool penetration is also overcome by the radial component of the cutting force.

Resistance to loosening depends upon the parameters defining the shape and behaviour of the average force on buckets during contact with unmined coal of coal and change of heterogeneity of the cut soil (specific resistance to digging) [7], [9].

Cyclic change of the resistance to loosening is caused by changes in simultaneously operating buckets and is a result of the subsequent entry and exit of buckets into/out of the ground, the number of which changes by one along with the duty cycle. In addition, the cutting force changes on each working bucket. While excavating with the vertical chip, cutting force on the bucket increases slightly, obtaining its maximum value at the end of the loosening of rock and decreases rapidly when the bucket exists the unmined coal (fig. 6a). The total resistance of buckets to loosening is the resultant of the resistance of all the buckets involved in cutting (fig. 6b) [4].

The bucket wheel of a bucket-wheel excavator is provided with a certain number of buckets on its circumference. Depending upon the arrangement and number of buckets and the ground excavating angle, the soil loosening process may be implemented by several buckets at a time. The total resistance to loosening is the result of resistance to loosening of all the buckets cutting the ground simultaneously.

***Resistance to bucket filling***

When the bucket penetrates into the unmined coal, loosen soil fragments move into the bucket. The taken excavated material exerts pressure onto the bucket walls with its weight (fig. 7), therefore, the frictional resistance of the excavated material onto the bucket walls ($P_{t3}$) occurs when filling the bucket. The excavated material rests on its rear wall during filling. This causes the build-up of excavated material inside the bucket, which results in additional excavated resistance to material built-up ($P_n$). Both the frictional resistance of the excavated material onto the bucket walls and excavated resistance to material built-up are overcome by the bucket wheel drive [10].

Resistance to bucket filling varies with both the bucket angle during its operation and the level of its filling. The most unfavourable conditions (i.e. the greatest resistance) occur when the bucket is in the horizontal position and is nearly completely filled. The total resistance to bucket filling is the resultant of the resistance of all the buckets involved in cutting.

***Resistance to the excavated material lift in the bucket wheel***

Excavated material collected in a bucket is lifted from the place of its loosening up to the height of its dumping on top of the bucket wheel. The force, which the bucket wheel drive exerts in order to raise the excavated material, overcomes the resistance to lift ($G_{ui}$) (fig. 8). This resistance comes from the work of the bucket wheel force that is necessary to give excavated material the kinetic energy to obtain the speed of the bucket wheel and potential energy to raise the excavated material to the dump site.

Resistance to the excavated material lift changes with the degree of the bucket filling – it increases gradually from the bucket entry into the unmined coal until its exit from the unmined coal. Once the bucket leaves the unmined coal, the resistance value is constant up to the point of dumping the excavated material, where the bucket is emptied [10].

***Resistance when operating on a slope***

When the excavator stands on a sloping ground, it may advance in the direction of the slope. We can distinguish two cases

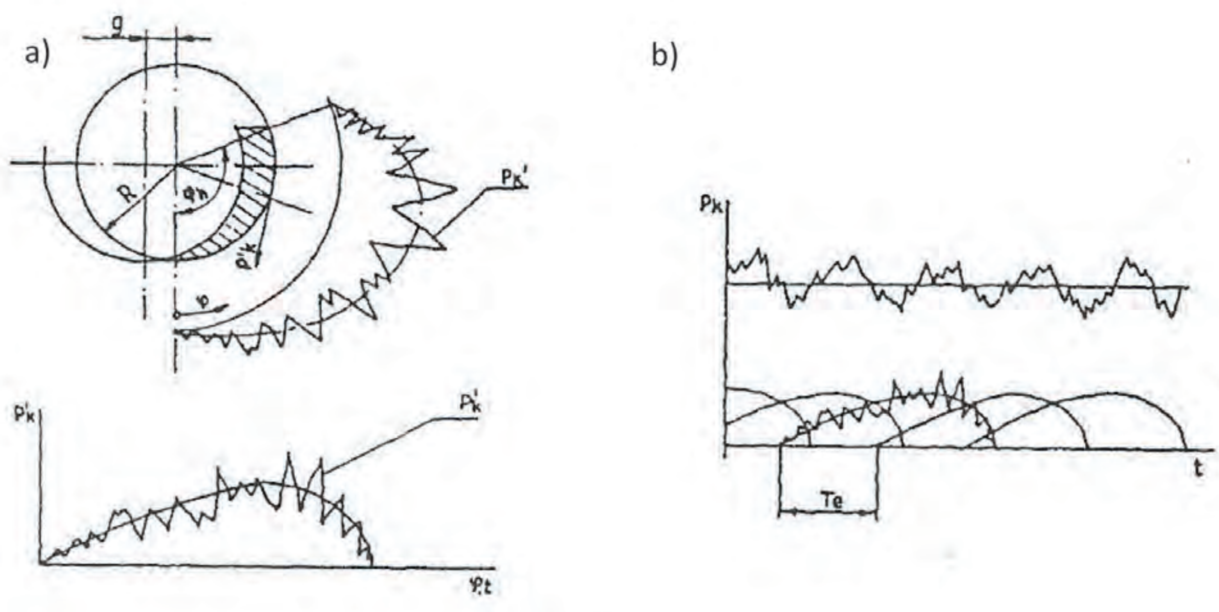


Fig. 6. Cutting force curve for cutting with a bucket-wheel excavator, a) excavation force curve for one bucket, b) total cutting force of all the buckets involved in the cutting of soil [4]

Rys. 6. Przebieg siły skrawania wieloczerpakową koparką kołową, a) przebieg siły ($P_K$) urabiania na jednym czerpaku, b) sumaryczna siła skrawania wszystkich czerpaków biorących udział w skrawaniu gruntu. [4]

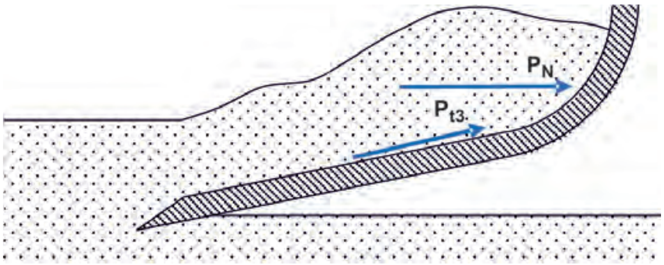


Fig. 7. Components of resistance to bucket filling [2]
Rys.7. Składowe oporu napełniania czerpaka [2]

here. First, when the advancing movement is performed upwards – then, the mechanism performing the advance is overcoming resistance to operate on a slope. This resistance is associated with the work performed, which provides the potential energy for the structural components being raised and the excavated material. The second case is when the advancing movement is performed downward the slope – then, the potential energy of components and excavated material moving in the direction of advance supports the advancing mechanism.

Advance movement can be implemented in two ways in wheel excavators. When the advance movement is angular, then the resistance to operate on a slope loads (or relieves) the body rotation mechanism. When the advance movement is translational, this load overcomes the drive mechanism then [2].

***Resistance to the bucket wheel boom lift***

One of the movements performed by the excavator is changing the elevation of the bucket wheel boom. This movement is performed by the lifting drive (rope system), usually, winch drives. The potential energy of the gravity force of the boom and excavated material in buckets and in the boom transport system changes directly with the change of the boom elevation. This is associated with the resistance to motion when the boom is raised or motion assistance when the boom is lowered.

***The resistance of drive losses***

Electric drives prevail in the currently operated large-size wheel excavators. The following loss occurs mainly in electric motors: in the stator iron, the rotor windings, mechanical and ventilation losses, and other arising from the motor design. The drive electrical efficiency is the measure of losses in electric motors [7], [9].

In order to reduce the high speed of the electric motor, drives are provided with transmission assemblies. There are the following major losses in the mechanical transmissions: in bearings and meshing of all gear stages. The drive mechanical efficiency is the measure of the losses [7], [9].

Multi-drive and multi-motor systems are used in the mechanisms that require high power. The individual drives do not have precisely the same torque characteristics. Therefore, the individual drives in the multi-drive or multi-motor systems should be selected correctly by matching their torque characteristics. However, it is impossible to achieve full compatibility between the characteristics within the entire operating range. Therefore, they are normally selected so that the level of the load was the same at a nominal drive load. Mismatching operating characteristics of the component drives are associated with the characteristic mismatch losses, which are caused by secondary power flows between the individual drives and mutual braking of drives.

The third group of losses is associated with movements

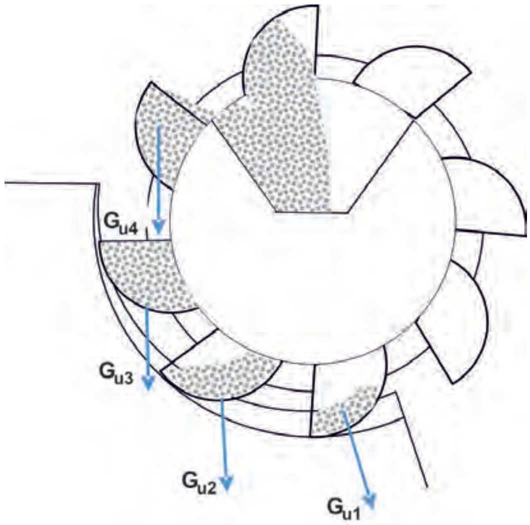


Fig. 8. Resistance to the excavated material lift [2]
Rys.8. Opory podnoszenia urobku [2]

between assemblies. In the case of the main drive (of the bucket wheel), there are the losses in the main bearing. The bearing is treated the transmission component and the losses in the main bearing are considered together as total losses in the transmission. In the case of the body rotation drive, rolling resistance occurs at the point of the body support on the chassis in the toothed wheel rim. Resistance on the toothed wheel rim varies depending upon the turntable position angle and the body rotation speed.

Caterpillar travel mechanisms prevail in currently operated excavators. Caterpillar resistance to motion is mainly due to the substrate deformation and the cutting of the ground edges by the caterpillar. In addition to these external resistances, there is also internal frictional resistance in individual mobile joints of the caterpillar system. These are as follows: frictional resistance in the bolts connecting the track plates during their bending, resistance in bearings of all wheels (i.e. drive, reverse, jockey and support wheels) and the rolling resistance of jockey and support wheels on the track connector.

## SUMMARY

The system developed in the BEWEXMIN Project designed to monitor the effort of the load-carrying structure of a bucket-wheel excavator enables the current assessment of the effort of the structure on the basis of signals recorded in real-time. The article discusses the resistance to mining occurring during soil exploitation being the subject of research and analysis aimed at developing tools enabling the excavator structure to be protected against the effects of strokes resulting from the contact of the bucket wheel with an unmineable obstacle.

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Architectural details of Wrocław