ROZWÓJ KONSTRUKCJI KÓŁ CZERPAKOWYCH KOPAREK EKSPLOATOWANYCH W KOPALNIACH ODKRYWKOWYCH WĘGLA BRUNATNEGO

DEVELOPMENT OF BUCKET WHEEL CONSTRUCTIONS OF EXCAVATORS OPERATING IN LIGNITE OPEN PIT MINES

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Przedstawiono specyfikę budowy i użytkowania kół czerpakowych koparek eksploatowanych w kopalniach odkrywkowych węgla brunatnego. Zaprezentowano rozwój konstrukcji kół czerpakowych. Pokazano sposoby mocowania kół czerpakowych na wale. Podano przykłady zastosowanych rozwiązań. Przedstawiono wytyczne do projektowania kół czerpakowych. Określono wymagania jakie powinny spełniać konstrukcje kół czerpakowych koparek eksploatowanych w utworach trudno urabialnych kopalń odkrywkowych węgla brunatnego.

Słowa kluczowe: *górnictwo odkrywkowe, utwory trudno urabialne, koparki, koła czerpakowe, projektowanie, wymagania*

The specifics of the construction and use of bucket wheels of excavators operating at lignite open pit mines are introduced. The development of bucket wheel construction is presented. The methods of fixing the bucket wheels on the shaft are shown. The examples of applied solutions are provided. Guidelines for designing bucket wheels are presented. The requirements that should be met by the construction of bucket wheels of excavators operating in hard mineable soils in lignite open pit mines are determined. .

Keywords: *open cast mining, hard mineable soils, excavators, bucket wheels, design, requirements*

Introduction

The bucket wheel as a unit which keeps buckets and receives excavated material from them, is the most sensitive unit of excavator mining system (Fig. 1). The main parts of the bucket wheel are: rim (1) with bucket-bottom holes where, at regular spacing, the buckets (2) are fastened, disk (3) connecting the rim with the hub (4) and the shaft (5) with bearing (Fig. 12).

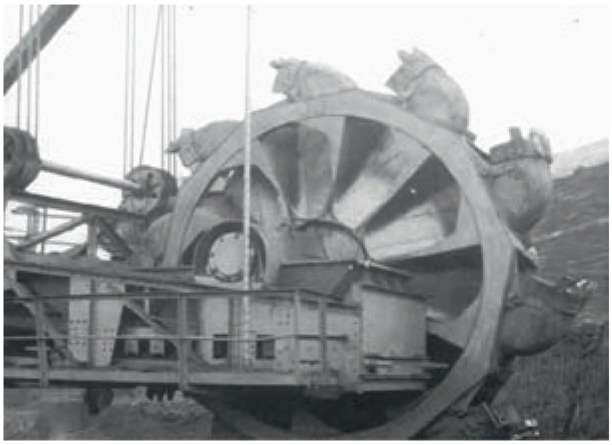
F_{v1} – the tangential cutting force [kN],
F_{v2} – the lateral force [kN]
F_{v3} – the forward thrust force [kN]
v_u – the bucket wheel rotation speed in the vertical plane [m/s],
v_o – the bucket wheel speed in the horizontal plane [m/s],
b, h –the slice dimensions [m],
L – the cutting knife lenght of the side cut [m],
A – slice cross section of the side cut [m^2].

F_{u1} - siła styczna (obwodowa) [kN],
F_{u2} - siła promieniowa (normalna) [kN],
F_{u3} - siła pozioma (binormalna) [kN],
v_u - prędkość obrotowa koła czerpakowego w płaszczyźnie pionowej [m/s],
v_o - prędkość koła czerpakowego w płaszczyźnie poziomej [m/s],
b, h - wymiary wióra [m],
L - długość krawędzi tnącej czerpaka [m],
A - pole przekroju poprzecznego odcinanego wióra [m^2].

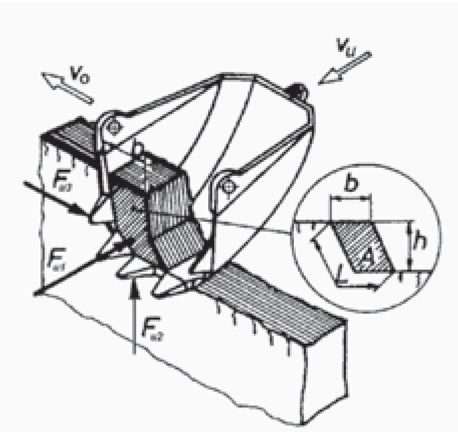
The process of cutting a chip with the bucket is realized as a result of two moves. In case of a wheel bucket excavator operating in a block system, they are: the rotary movement of the bucket wheel (in the vertical or near vertical plane) and the bucket wheel movement in the horizontal plane as a result of the rotation of the machine body. Cutting tools - buckets, spaced at regular intervals on the circumference of the bucket wheel, cut off chips of a characteristic sickle shape from the solid rocks (Fig. 2) [2]. The following loads act at the bucket wheel during its operation:

a) cutting force F_u which is the main force responsible for bucket wheel loads during operation,
b) the force used to raise the excavated material in the buckets F_p,
c) force derived from the weight of the wheel F_w,
d) forces derived from the weight of pollutants, soils, etc. F_z.

Rys. 1. Koło czerpakowe i fragment wysięgnika urabiającego koparki KWK 1500 [1]
Fig. 1. Bucket wheel and bucket wheel boom section of BWE KWK 1500 [1]



Rys. 3. Koło komorowe koparki SchRs 315 [3]
Fig. 3. Cell-type bucket wheel of BWE SchRs 315 [3]



Rys. 2. Schemat obciążeń czerpaka i kształt wióra w procesie urabiania kołem czerpakowym [2]
Fig. 2. Bucket load pattern and slice shape in the bucket wheel mining proces [2]

Rys.4. Koło bezkomorowe koparki SRs 1200
Fig. 4. Cell-less bucket wheel of BWE SRs 1200

The cutting force F_u in the coordinate system associated with the bucket wheel can be divided into three components (Fig. 2):

- the tangential cutting force F_{u1},
- the lateral force F_{u2},
- the forward thrust force F_{u3}.

In practice, only the value of the component F_{u1} is usually determined, and the values of the remaining components are defined as a certain part of the tangential force. Namely:

$$F_{u2} \quad k_2 \quad F_{u1}; \quad F_{u3} \quad k_3 \quad F_{u1} \qquad (1)$$

The coefficients in formula (1) are not constant values. They depend to a great extent on the performance of the excavator and for momentary values the forces can take values from a wide range - from almost zero to values far above 2 e.g. in hard mineable soils [3].

Types of bucket wheels structure

Until the middle of 20th century the cell-type bucket wheels (Fig. 3) [4] were commonly used. Here the excavated material from the bucket is poured into a separate cell and from it directly onto a conveyor. The basic drawback of cell--type bucket wheels was relatively low rotary speed caused by impediment to transport of material and relatively long route of material transport in cells, hence the excavator output was considerably reduced. The advantage of cell-type bucket wheels was their high rigidity of structure. Since the middle of 20th century, the cell-less bucket wheels came into common use (Fig. 4). In these wheels, excavated material is poured directly from buckets to receiving unit (chute) and further onto a conveyor. Thereby, the route of excavated material is shorter, so the wheel can operate at considerably higher speed (about twice higher), so excavator output is much higher too. Furthermore, the cell-less bucket wheel can operate in both directions (working to the rise and to the deep) which is impossible for the cell-type bucket wheel. In turn, the disadvantage of cell-less bucket wheel is its lower rigidity. Hence, a semi- cell-type wheel (Fig. 5) was developed to combine the advantages of both aforementioned wheels.

For the sake of structure rigidity, wheels with diameter up to about 12 m are usually constructed as the cell-less ones, and those with diameter over 12 m – as semi-cell ones. For different types of excavators bucket wheel diameters vary form 2.4 to 21.6 m and weights – from several to 300 Mg.

Bucket wheels are usually joined with the shaft by means of fitted bolts, but keyed joints or permanent joints (welded) or with centring rings are also applied (Fig. 6) [4].

There are two bearing mounting types of the bucket wheel shaft:

- with short shaft, where the bearing on receiving conveyor side is before the conveyor,

Fig. 5. Semi-cell bucket wheel of BWE SchRs 4000
Rys.5. Koło czerpakowe półkomorowe koparki SchRs 4000

- with long shaft, where the bearing is after the conveyor. Rolling self-aligning bearings are exclusively used.

The bucket wheel is not located along the boom axis, hence it is slightly deviated with respect to the working radius coming out from the superstructure rotation point and going through the wheel axle. Apart from the bucket wheel, the boom head includes also its drive, the unit which receives the excavated material and the reverse drum of conveyor. It causes that the head is substantially expanded in horizontal plane and frequently it leads to various angles of contour in horizontal plane.

Aligning the contour angles on both sides of the head, or just reducing the such difference can be achieved by turning the bucket wheel in horizontal plane. In turn, improvement of transferring the excavated material from buckets to conveyor belt can be done by tilting the wheel in vertical plane (Fig. 7) [4].

Bucket wheel operations in hard mineable soils

In domestic open cast brown coal mines, there is a growing need for excavators' operation in hard mineable soils. These are usually soils of the fourth mining class with linear unit mining resistivity K_L of 90-120 kN/m [5]. In addition, they contain large amounts of hard inclusions, stones and highly abrasive quartz fractions. As a result of the above conditions, the wear and damage of the bucket wheels is rapid.

The most unfavorable case occurring during exploitation in hard mineable soils is the impact of the bucket on a stone. A very abrupt stoppage of the bucket wheel rotation takes place and due to a high mass moment of inertia of the drive elements rotating along with the wheel, very high dynamic loads are generated [6]. Buckets and teeth experience quick wear and damage what is extensively described in [5] [7] [8] (Fig. 8, Fig. 9). With regard to construction of the wheels themselves, the shafts and hubs and, to a lesser extent, discs are most often damaged.

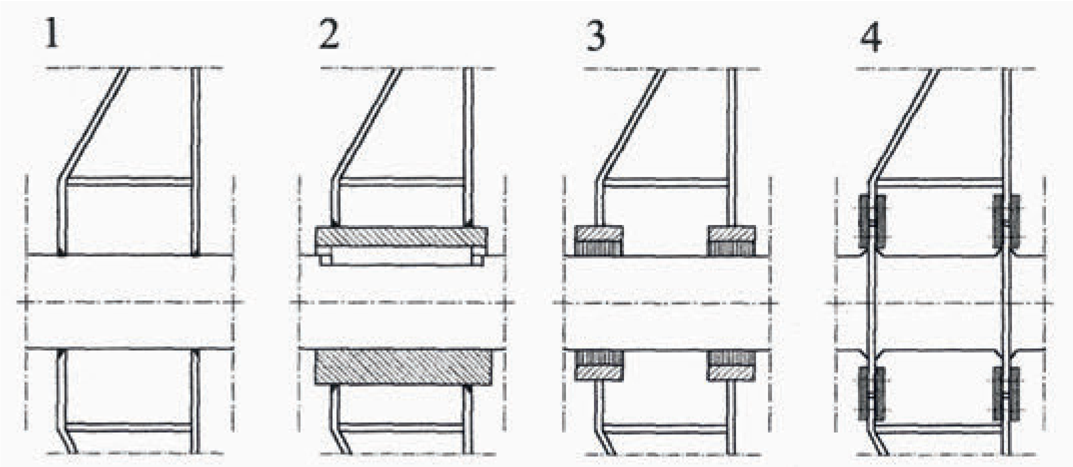
Prevention methods of bucket wheels damages and examples of applications

The disk of bucket wheel can be strengthened by fabricating it from two conical surfaces. This allows also to reduce the bucket wheel mass considerably. On the wheel ring rim, there are radially located bars welded to the wheel to protect the ring against effect of abrasion when the bucket wheel rubs against ground. Successive strengthening refers to the wheel hub. Here, it is possible to use, for instance, the hub composed of two plates shaped as side surface of a truncated cone, which plates have high torsional rigidity (Fig. 10) [9].

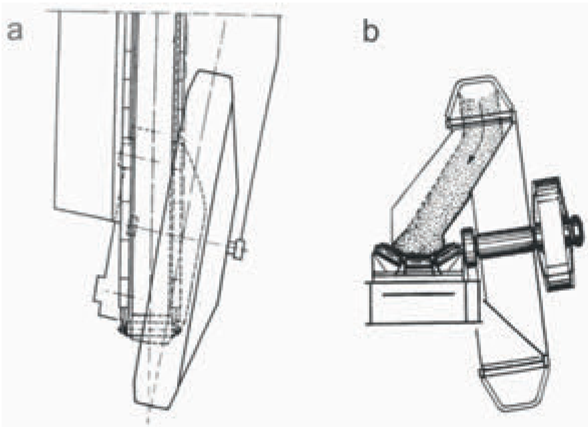
An example of new bucket wheel developed for operation in hardly-workable formations is the wheel of BWE SchRs 4600 at open pit mine Bełchatów (Fig. 11) [10]. This solution is based on a cylindrical hub and conical disc stiffened with radial ribs, which is advantageous for buckling parameters. Radial ribs are more and more wide towards the hub of the bucket wheel which is advantageous in terms of increase of bending moment in the direction of wheel axis resulting from the forward thrust force. The wheel rim is made in the version without box-type chute. Stiffening is made via a radial rib which was extended until the wheel chute. Locally, introduced are stiffening out of metal plates which transfer loads from the baffle box to the rib web. An important stage of this work is also the final determination of mass parameters of the new solution and evaluation of their effect on modal characteristics of the excavator [10].

On the basis of studies and operating experience [4] [6] [7], it was found that the more buckets on the wheel the lower is the dynamics of the excavation process and the higher is the winning break up.

Most often, excavators with outputs less than 5.000 m^3/h are provided with 8-10 buckets, and those with higher outputs – with 12-20 buckets. However, selection of buckets for a given excavator must be preceded by studies including experiments and numerical modal analysis. This research al-



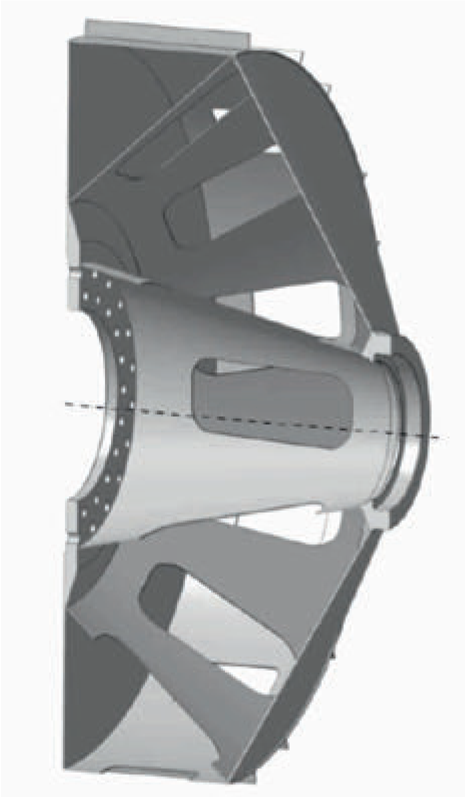
Rys. 6. Różne sposoby zamocowania koła czerpakowego na wale [4]:
1 - zamocowanie nierozłączne, 2 - osadzenie na wpuście lub klinie, 3 - osadzenie na pierścieniach centrujących, 4 - połączenie za pośrednictwem śrub pasowanych
Fig. 6. Various methods of fastening the bucket wheel on the shaft [4]:
1 – permanent joint, 2 – key or wedge mounting, 3 – mounting with centring ring, 4 – mounting with fitted bolts



Rys. 7. Poprawa warunków przekazywania urobku na przenośnik poprzez [4]:
a) obrócenie koła czerpakowego w płaszczyźnie poziomej,
b) pochylenie w płaszczyźnie pionowej
Fig. 7. Improvement of transferring excavated material to conveyor belt by [4]:
a) turing the bucket wheel in horizontal plane, b) tilting it in vertical plane

Rys. 8. Czerpak zużyty – widoczne wyłamania zębów i uszkodzenia noża [7]
Fig. 8. Worn out bucket – visible are broken teeth and knife damages[7]

Rys. 9. Zużyte zęby przez ścieranie i wyłamania [7]
Fig. 9. Worn out teeth due to abrasion and breaks[7]



Rys. 10. Piasta koła czerpakowego o kształcie pobocznicy ściętego stożka [9]
Fig. 10. Bucket wheel hub shaped as side surface of a truncated cone [9]

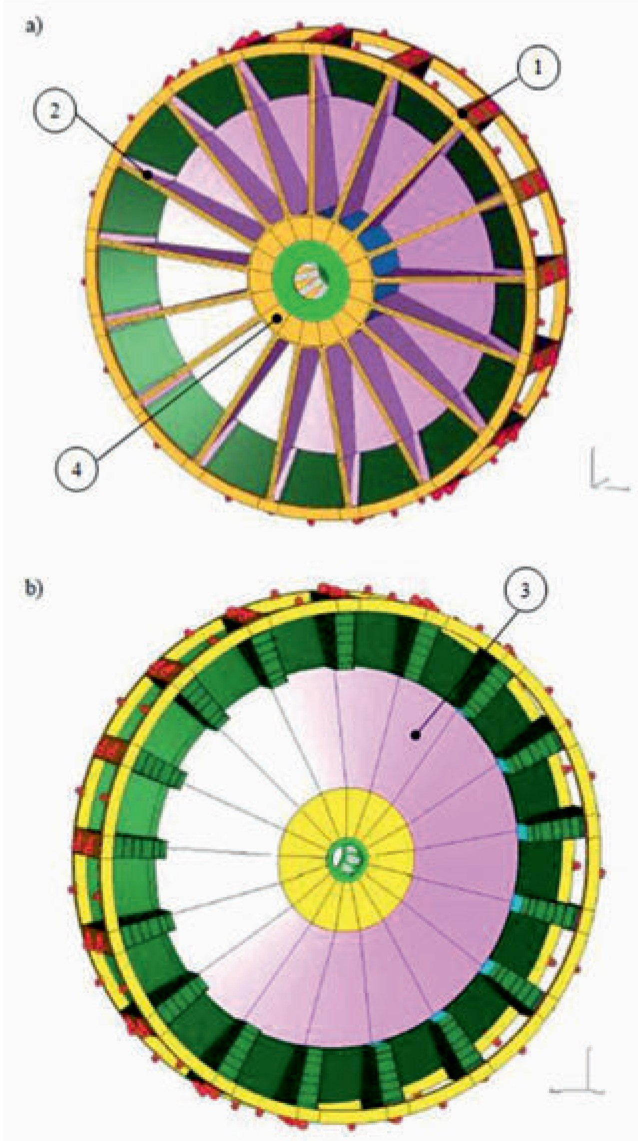


Fig. 11. Concept of new constructional form of bucket wheel of BWE SchRs 4600 at Bełchatów lignite open pit mine [10]
1 – Rim, 2 – Radial ribs, 3 – Conical disc, 4 – Cylindrical hub
Rys. 11. Koncepcja nowej postaci konstrukcyjnej koła czerpakowego do koparki SchRs 4600 w KWB Bełchatów [10]
1 – Pierścień, 2 – Żebra promieniowe, 3 – Stożkowa tarcza, 4 – Walcowa piasta

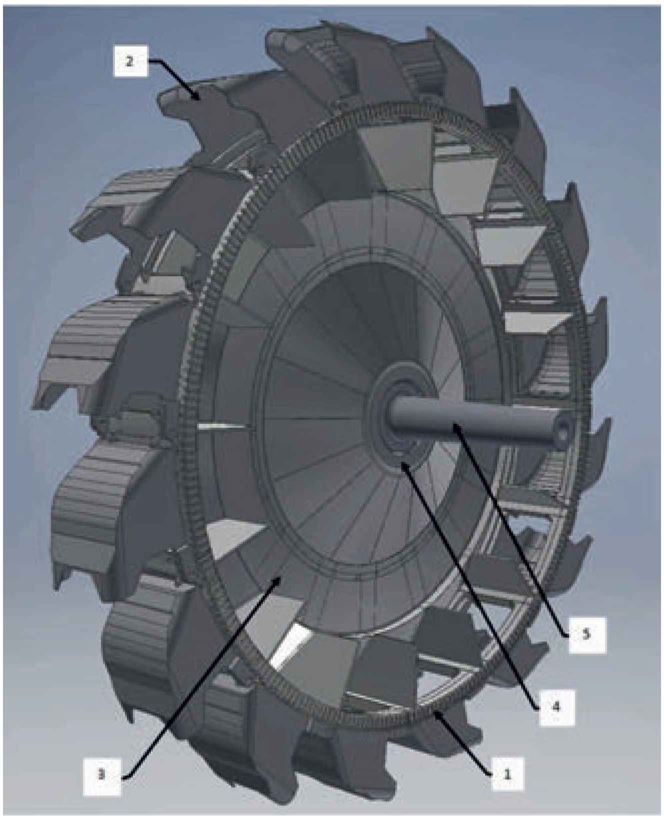


Fig. 12. Model of bucket wheel of BWE SchRs 4000 at Bełchatów lignite open pit mine
1 – Rim, 2 – Buckets, 3 – Disk, 4 – Hub, 5 - Shaft
Rys. 12. Model koła czerpakowego koparki SchRs 4000 w KWB Bełchatów:
1 – pierścień, 2 – czerpaki, 3 – tarcza, 4 – piasta, 5 – wał

lows to determine such number of buckets that activation generated during excavation process would not correspond to any resonance frequency. This way was used to determine, for example, the number of buckets in modernized mining system of BWE SchRs 4600.30 open pit mine at Bełchatów or in new mining system of BWE SRs 1200 at Konin open pit mine [11].

Bucket wheels, like most of modern constructions, are designed with FEM method. In this case, its construction should be designed so as the maximum stresses fall on the buckets which subject to replacement and repairs. In turn, the values of stresses on the wheel structure should be considerably lower because repair of the wheel is much more complicated and costly. This requires the excavator to be put out of operation which makes the repair costs higher.

An example of a bucket wheel designed according to the above requirements is the wheel of BWE SRs 4000 operated in hard mineable soils at Bełchatów lignite open pit mine (Fig. 12).

Conclusions

To sum up the above description, the bucket wheels of BWEs operating in hard mineable soils, should:

- have relatively large rigidity of construction, and especially its hub,
- be designed so as the maximum stresses are located on buckets, while those on the construction of the wheel itself should be considerably lower,
- have secure, durable and quick mounting/dismounting joint with the shaft,
- be stiffened in the middle part,
- be adapted for installation of increased number of buckets,
- have the ability to control the rotary speed.

Moreover the angles of bucket wheel positioning in the boom head should be selected so as to reduce the value of bending moment from digging force (turning the wheel in horizontal plane) and to facilitate excavated material dumping from buckets to conveyor (turning the wheel in vertical plane).

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