WYMAGANIA STAWIANE MECHANIZMOM NAPĘDÓW KÓŁ CZERPAKOWYCH KOPAREK WIELONACZYNIOWYCH KOŁOWYCH EKSPLOATOWANYCH W UTWORACH TRUDNO URABIALNYCH

REQUIREMENTS FOR BUCKET WHEEL DRIVE MECHANISM OF BWES (BUCKET WHEEL EXCAVATORS) OPERATING IN HARD MINEABLE SOILS

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Przedstawiono stan dotychczasowy oraz przyczyny podejmowania działań modernizacyjnych mechanizmów napędów kół czerpakowych koparek wielonaczyniowych kołowych eksploatowanych w krajowych kopalniach odkrywkowych węgla brunatnego. Podano rozkład obciążeń i masowych momentów bezwładności oddziaływujących na układ urabiania koparki kołowej. Zaprezentowano stosowane zabezpieczenia przeciążeniowe w mechanizmach napędów kół czerpakowych w postaci różnego rodzaju sprzęgieł. Opisano stosowane przekładnie i silniki mechanizmów napędów kół czerpakowych. Podano przykłady zmodernizowanych mechanizmów napędów kół czerpakowych. Zaprezentowano wykaz wymagań jakie powinny spełniać mechanizmy napędów kół czerpakowych koparek wielonaczyniowych kołowych eksploatowanych w utworach trudno urabialnych.

Słowa kluczowe: *koparki wielonaczyniowe kołowe, mechanizm napędu koła czerpakowego, obciążenia, sprzęgła przeciążeniowe, przekładnie, wymagania*

State of the art and reasons for undertaking modernization activities of bucket wheel drive mechanisms of BWEs operating of domestic lignite open cast mines have been discussed in the paper.

The distribution of loads and mass moments of inertia acting on the BWE mining system has been given. The applied overload protections in bucket wheel drive mechanisms in the form of various types of clutches have been presented. The gears and motors of bucket wheel drives have been described. Examples of modernized bucket wheel drive mechanisms have been given. List of requirements for bucket wheel drive mechanisms which should be met by BWEs operating in hard mineable soils has been presented.

Keywords: *bucked wheel excavators, bucked wheel drive mechanism, loads, overload clutches, gears, requirements*

Introduction

Experience gained so far with excavation so called hard mineable soils in domestic lignite open pit mines (mainly at lignite open pit mine Turów and Bełchatów(Poland) including open pit Szczerców) shows that such soils are usually classified in the class No. IV-V of workability [1] and are distinguished with high hardness (with specific cutting resistance kL ≥ 120kN/m) and also high content of non-workable rock inclusions.

So the bucket wheel drive of BWEs operating in aforementioned soils subjects to very high dynamic loads. It was experimentally found that the working torque on the bucket wheel can be in such case about 5 times higher than the nominal torque [2]. Such high value of the torque causes considerable increase of dynamic stresses, hence reduction of fatigue and immediate strength of particular elements of the drives, other subassemblies of mining system and also the whole load bearing structure of BWE [3]. Hence, in operating practice, several modernizing actions are undertaken to reduce the effects of excessive dynamic loads on excavator [4]. Examples of failures caused by the influence of excessive dynamic loads on particular assembles of BWEs are shown in Fig. 1 [5], 2 [6], 3 [7].

Typical mechanism of bucket wheel drive in BWE prior to starting with modernizing actions is shown in Fig. 4 [4]. It consisted of: gear (1), bevel-cylindrical one with four or five stages, with built-in overload clutch (6), with self-aligned suspension on the bucket wheel shaft and supported with shock absorber (5) (motor base and gear base create a common structure), brake (2), flexible coupling (3) located between the motor and gear, and electric motor (4), usually a slip-ring

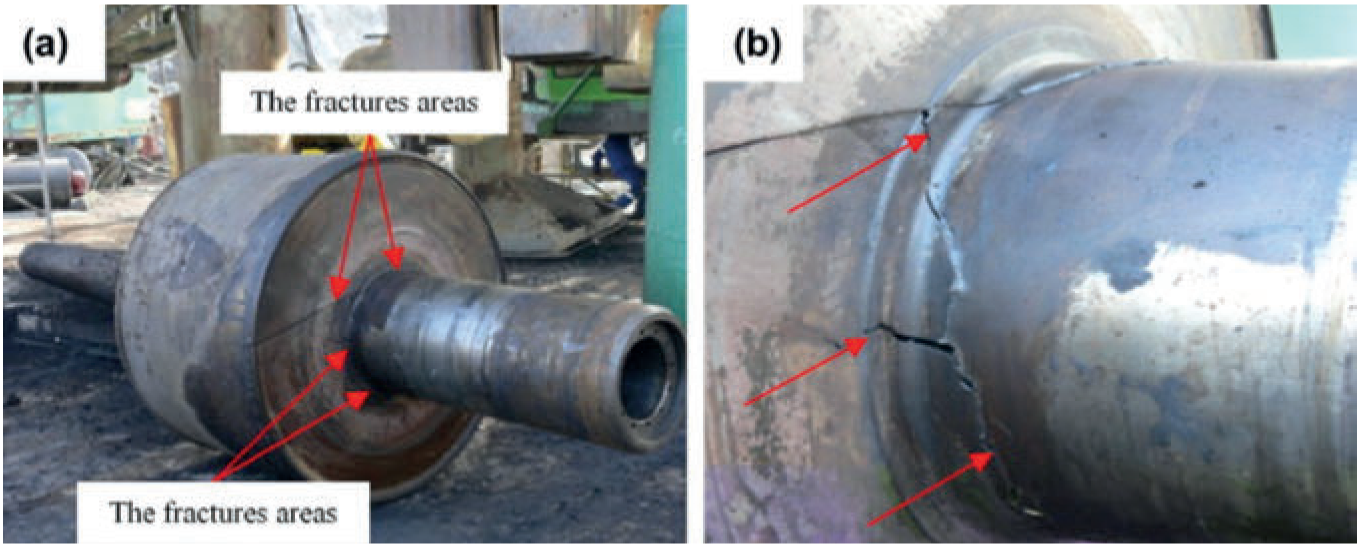

Fig. 1. Damaged bucket wheel shaft of BWE KWK 1200 at lignite open pit mine Turów (Poland) : a) overview, b) fracture locations [5]
Rys.1. Uszkodzony wał koła czerpakowego koparki kołowej KWK 1200 w KWB Turów a) widok ogólny, b) rozmieszczenie uszkodzeń [5]

Fig. 2. Disaster of BWE SRs 1200 at lignite open pit mine Konin [6]
Rys. 2. Katastrofa koparki kołowej SRs 1200 w KWB Konin [6]

Fig. 3. Disaster of BWE KWK 1400 at lignite open pit mine Turów [7]
Rys. 3. Katastrofa koparki kołowej KWK 1400 w KWB Turów [7]

asynchronous unit.

As a result of modernization activities: jointed shafts (located between the motor and the gear), bearing supports, various types of overload clutches and planetary gears (instead of bevel-cylindrical gears) were used successively in bucket wheel drive mechanisms. The above activities are discussed in the following chapters of the paper.

Loads acting on the BWE mining system

As it results from above description, forces acting on the bucket wheel during excavation rocky medium are the basic dynamic load both for the wheel drive itself and other elements of mining system and also the load bearing structure of the BWE [8]. The diagram of bucket loads in the mining process is shown in Fig. 5 [9]. Hence, introducing in the bucket wheel drive effective overload protection, we can considerably limit the value of dynamic loads of the BWE. This function plays various kinds of overload clutches. As concerns their operating principle, they can be divided into two groups [10]:

a) slip clutches – which transmit the torque up to a specific value,

b) disengaging clutches – which cause physical disengaging the drive at the moment of overload.

The maximum load occurs at the moment of impact stoppage of the bucket wheel when the bucket meets non-workable obstacle. The value of pulse load generated at such moment depends on kinetic energy concentrated in rotating elements of the drive which stops together with the wheel. Hence, the purpose of the overload clutch is to disengage a part of wheel with large kinetic energy at the moment of pulse load. The duration of pulse is very short (in the reference scale, it is theoretically infinitely short), so the most important parameter of any overload clutch is its operating time. Fig. 6 [11] shows distribution of mass moments of inertia of the mining system with hydrodynamic coupling and planetary gear in BWE KWK 1200M. It shows that the most of the moments of inertia, hence the kinetic energy of the system is concentrated in high-speed components of electric motor (39.4%) and pumping section of hydrodynamic coupling (30.2%) – amounting totally 69.6%, while the remaining 30.4% refers to the turbine part of coupling (15.8%), brake drum with cardan shaft and bearing support (4%), planetary gear (4%) and the bucket wheel (6.6%).

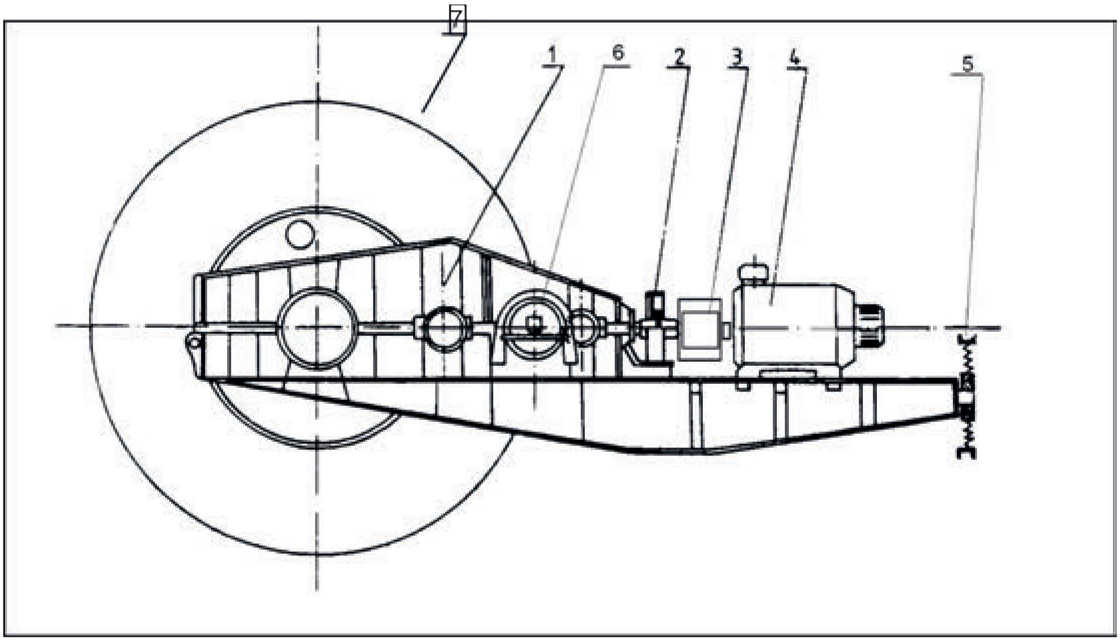

Fig. 4. The bucket wheel drive mechanism of BWE prior modernization [4]. 1 - Bevel-cylindrical gear with build-in overload clutch 6, 2 - brake, 3 - flexible clutch between motor and gear, 4 - electric motor, 5 - shock absorber, 7 - bucket wheel

Rys. 4. Mechanizm napędu koła czerpakowego koparki wielonaczyniowej kołowej przed modernizacją [4]. 1- przekładnia cylindryczno-walcowa z wbudowanym sprzęgłem przeciążeniowym 6, 2 - hamulec, 3 - sprzęgło elastyczne pomiędzy silnikiem a przekładnią, 4 - silnik elektryczny, 5 - amortyzator, 7 - koło czerpakowe

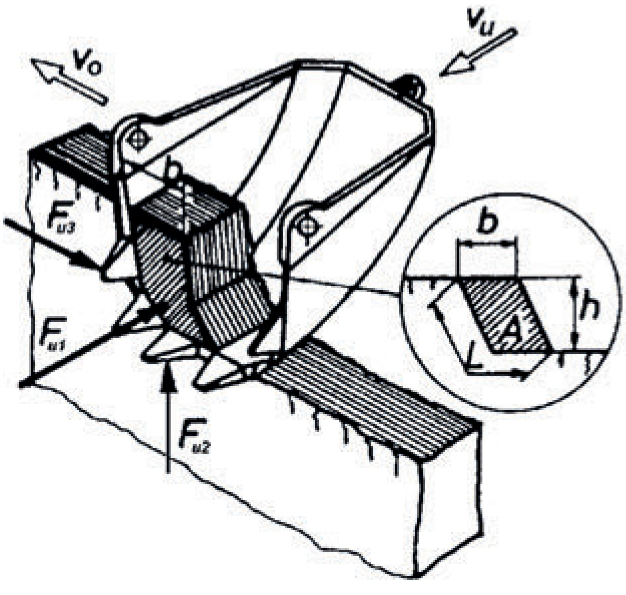

Fig. 5. Bucket load pattern and slice shape in the bucket wheel mining process [9]
F_{u1} – the tangential cutting force [kN]
F_{u2} – the lateral force [kN]
F_{u3} – the forward thrust force [kN]
v_u – the bucket wheel rotation speed in the vertical plane [m/s]
v_o – the bucket wheel speed in the horizontal 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]

Rys. 5. Schemat obciążenia czerpaka i kształt wióra w procesie urabiania
F_{u1} – siła styczna do obwodu koła czerpakowego (kN)
F_{u2} – siła promieniowa (kN)
F_{u3} – siła pozioma (kN)
v_u – prędkość obrotowa koła czerpakowego w płaszczyźnie pionowej (rad/s)
v_o – prędkość koła czerpakowego w płaszczyźnie poziomej (m/s)
b, h – wymiary wióra (m)
L – czynna długość krawędzi tnącej czerpaka (m)
A – powierzchnia przekroju odcinanego wióra (m^2)

Types of clutches used in bucket wheel drive mechanisms

In most of old-type BWEs , such as for instance SchRs 350, SchRs 800, SchRs 1200, SRs 1200, friction slip multi--plate clutches installed in intermediate shafts of wheel drive cylindrical gear were used. Fig. 7 [10] illustrates a typical multi-plate overload clutch with spring clamp (2). When the admissible torque is exceeded, there occurs a slip on clutch plates (1). Usually, there are two limit switches providing drive supply cut off at haft turn slippage. Frequent short-time overloads (occurring especially during operation in hardly--workable formations) can cause small summing up slips of the clutch. As a result, there is a different duration time for cutting off drive supply. For such type clutches the drive is not disconnected totally. Wear of friction linings (1) due to slips cause a change of clutch characteristics and the need to adjust the spring pressure (3).

To sum up, fundamental disadvantage of such clutch is that it does not disconnect the drive completely while hitting an obstacle and that clutch characteristic changes during operation, so frequent adjustment is necessary. Experience and operating studies proved that such clutch does not perform its function, especially in hardly-workable formations [11][12].

Much better results were reached when using a planetary gear as an overload clutch [13].

In this solution, the torque from the motor is transferred to the solar wheel of planetary gear while the gear housing is locked with the brake .The brake is based on a lever rotary mounted on the solar wheel shaft and kept by dynamometer. Increase of the torque due to deformability of dynamometer causes the lever to turn until the position where the switch is actuated and cuts off the motor supply.

Such clutch was used, for instance, in BWE SchRs 4500 at Inden Mine (Germany) [13] and in BWE SchRs 4600 at lignite open pit mine „Bełchatów”.

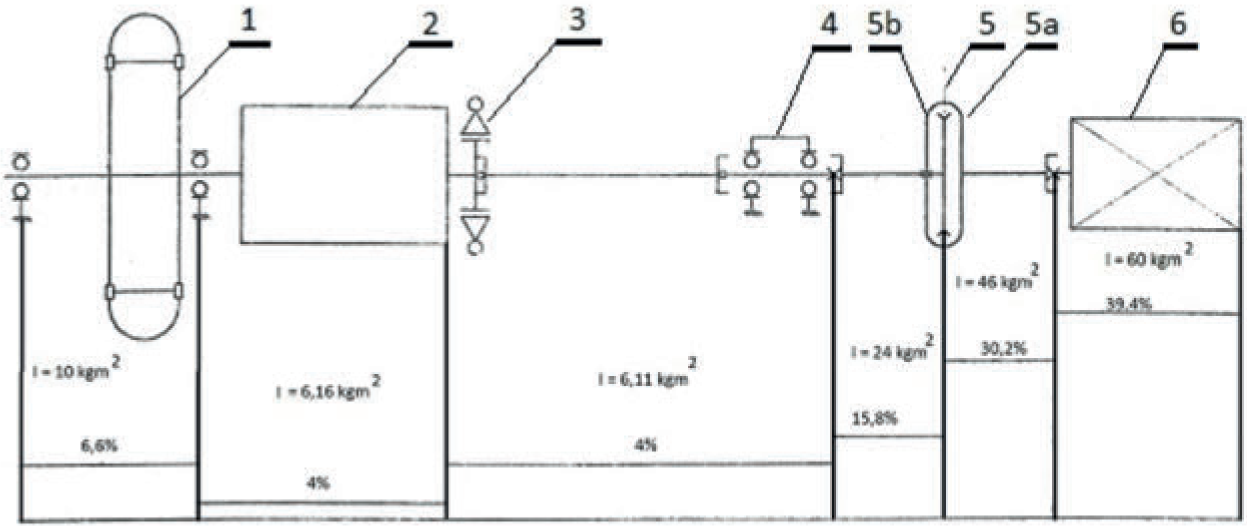

Fig. 6. Mining system of BWE KWK 1200M at lignite open pit mine Turów - distribution of mass moments of inertia [11]

1. Bucket wheel
2. Planetary gear
3. Brake drum with Cardan shaft
4. Support bearing
5. Hydrodynamic coupling, 5a. Pumping section of hydrodynamic coupling, 5b. Turbine part of hydrodynamic coupling
6. Motor

Rys. 6. Napęd urabiania koparki KWK 1200M - rozkład masowych momentów bezwładności [11]

1 - koło czerpakowe
2 - przekładnia planetarna
3 - bęben hamulcowy z wałem Kardana
4 - podpora łożyskowa
5 - sprzęgło hydrokinetyczne, 5a - część pompowa sprzęgła, 5b - część turbinowa sprzęgła
6 - silnik

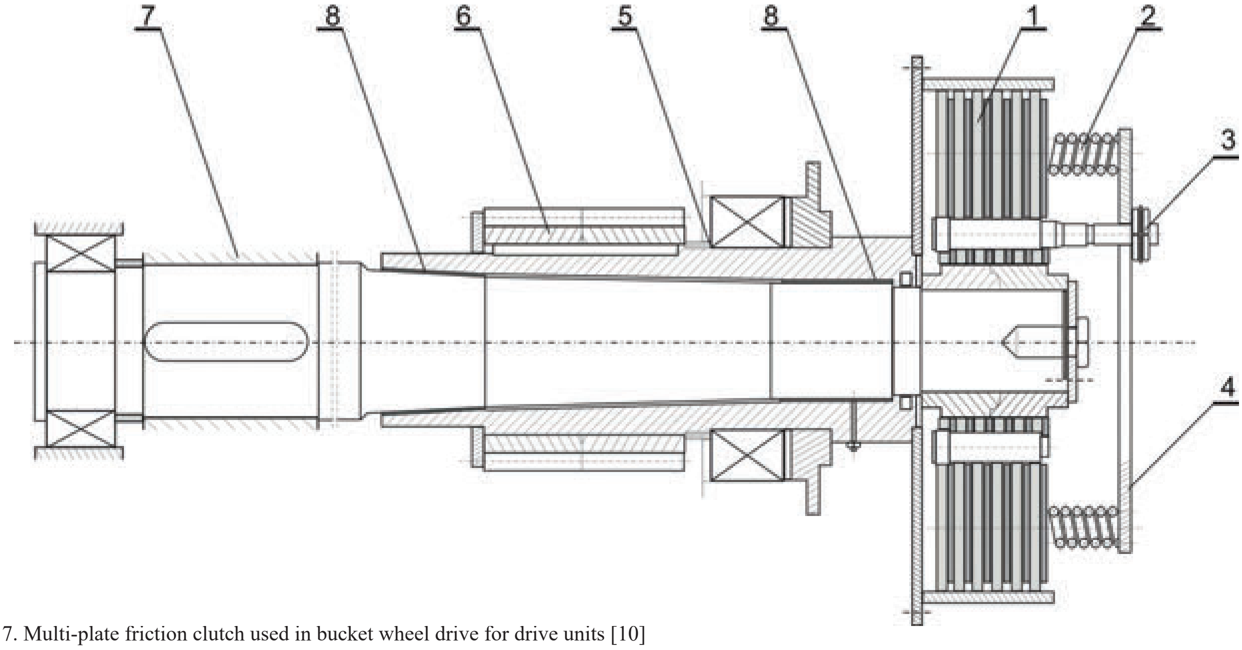

Fig. 7. Multi-plate friction clutch used in bucket wheel drive for drive units [10]

1- friction plates
2 - pressure spring
3 - pressure adjustment bolt
4 - compression disc
5 - clutch shaft
6 - driven wheel
7 - torque transmitting wheel
8 - slide bearing

Rys. 7. Sprzęgło przeciążeniowe cierne napędu kół czerpakowych koparek wielonaczyniowych kołowych [10]

1 - płytki cierne
2 - sprężyna dociskowa
3 - śruba regulująca docisk
4 - tarcza ściskająca
5 - wał sprzęgła
6 - koło napędzane
7 - koło przekazujące moment
8 - łożyska ślizgowe

Another solution using planetary gear and overload clutch is the construction of primary gear in modernized drive of bucket wheel in BWE SchRs 4000 [14]. Here, the brake immobilizes the solar wheel of planetary gear as opposed to its housing as in the previous solution. In order to disconnect the drive kinematic train by means of planetary gear, it is necessary not only to release the immobilized element of the gear, but also to accelerate it. Thus, the solution with immobilized solar wheel is more advantageous than that with immobilized housing due to much less inertia of the former element. In multi-motor drives, usually each motor has a separate overload clutch. A single overload coupling in two-motor drive is used in BWE KWK 910, which constitutes some new solution. Here, there is a shoe brake which immobilize solar wheel of the first stage in two-stage main transmission (Fig. 8) [15].

The drives of bucket wheel more and more often use a hydrodynamic coupling in recent years (Fig. 9) [16]. Usually, it is a coupling with constant filling and located with its pump section towards the motor because the torque it transmits increases in proportion to the square of velocity.

Fig. 8. Shoe brake immobilizing solar wheel of the main transmission of the bucket wheel drive in BWE KWK 910 at lignite open pit mine Turów [15]
Rys. 8. Sprzęgło przeciążeniowe szybko odcinające nadwyżki dynamiczne procesu urabiania napędu koła czerpakowego koparki kołowej KWK 910 w KWB Turów [15]

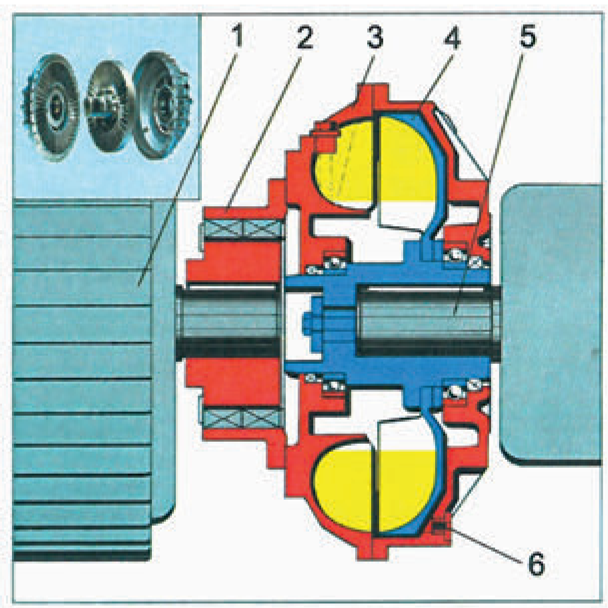

Fig. 9. Start-up hydrodynamic coupling with constant filling manufactured by VOITH (Germany) [16]
1 - motor, 2 - flexible clutch, 3 - pump side of the coupling, 4 - turbine side of the coupling, 5 - input shaft of transmission, 6 - fusible cut-out
Rys. 9. Rozruchowe sprzęgło hydrokinetyczne o stałym napełnieniu firmy VOITH (Niemcy) [16]
1 - silnik, 2 - sprzęgło elastyczne, 3 - strona pompowa sprzęgła, 4 - strona turbinowa sprzęgła, 5 - wał wejściowy przekładni, 6 - bezpiecznik topikowy

This coupling is mainly suitable as the starting coupling as it limits the value of the starting torque, so it protects the motor, gear and the bucket wheel against effects of overloads generated during the initial phase of digging which is especially useful for hardly-workable formations, where the number of turning off and on for the bucket wheel drive is relatively high [17]. In turn, applicability of the hydrodynamic coupling as the overload coupling in drives of bucket wheels is not too high for the sake of considerable value of the moment of inertia of the coupling itself. Therefore, these couplings are most often used with additional clutch which turns off the drive in case of overload. Such solution is used in many modernized and also new drives of BWEs , like in the following machines: KWK 910, SchRs 4000, SRs 1200, KWK 1500, SchRs 4600, KWK 1200, SchRs 900 [12].

The clutches outlined above, especially the fast-acting disengaging clutches increasingly better meet their function of protecting the mining systems and load bearing structures of excavators against impact loads, but due to very fast transmission of impact pulses these clutches are not an optimum solution [12][17][18] . The best solution would be a clutch starting operation prior to the peak value of the pulse, in advance responding to the first or the second derivative of load curve. Numerous control systems operate in this way. It is not a problem to measure quickly the load moment course of the bucket wheel. Such way of measurement was used in BWE KWK 910 [15]. However it is difficult to construct a clutch`s decelerating mechanism operating quickly enough.

For the sake of considerable variation of local properties of the excavated ground, so their uniqueness, especially for hardly-workable formations, the best way for selecting the overload clutches in bucket wheel drives is to use computer simulation [16]. It should be however remembered that this variability causes considerable difficulties in creating a model for bucket wheel loads. In this case the load vectors are random in all aspects – variable is their number, the directions, values and application points. There are also no certainty as concerns assumption of linearity of the system composed by excavator structure, especially for impact loads [19].

Gears used in bucket wheel drive mechanisms

So far, generally the cylindrical gears, most often with 4 or 5 stages, were used in drives of bucket wheels in BWEs . They were seated on the shaft of the bucket wheel and created, together with motor base, a single structure supported with shock absorber (Fig. 4). In second half of XX century, more and more often the planetary gears were used instead of multi-stage cylindrical gears (Fig. 10). These gears are also seated on the bucket wheel shaft but they do not create a common structure with the motor base (Figs. 11, 12). They are supported with a moment lever on a so called hard articulated joint.

Fig. 10. Planetary gear of modernized drive of bucket wheel in BWE KWK 1500s at lignite open pit mine Konin
Rys. 10. Przekładnia planetarna zmodernizowanego układu urabiania koparki KWK 1500 w KWB Konin

A basic advantage of planetary gears as compared with traditional cylindrical gears is their considerable lower mass (by about 40%) and overall dimensions, and also possibility of application of an additional overload protection (disengaging clutch) by means of moment lever [20]. Furthermore, as the gear is separated from the remaining components of the drive seated on a separated base secured to the boom structure, it considerable relieves the bearings of the bucket wheel, which leads to prolongation of their life. Such separation was possible by, among other things, application of articulated joint (cardan shaft) (Fig. 11) between the motor and the gear; such joint also facilitates and accelerates installation of the gear and the motor of the bucket wheel drive.

Motors used in bucket wheel drive mechanism

More often asynchronous slip-ring motors are used in drive mechanism of the BWEs [10]. In small excavators and in various types of loaders and re-loaders, often the hydraulic engines are applied. The advantage of a drive with high-moment low-speed hydraulic engine, but also its disadvantage in specific geological conditions, is the low moment of inertia of the drive mechanism of the bucket wheel. For impact stoppage of the bucket wheel, there occurs a lower pulse dynamic load, but at large variability of load at the bucket wheel and low inertia, there is a need of rapid increase of pressure to overcome the cutting resistance. According to examinations while excavating hardly-workable formations, there occur stalls at the bucket wheel.

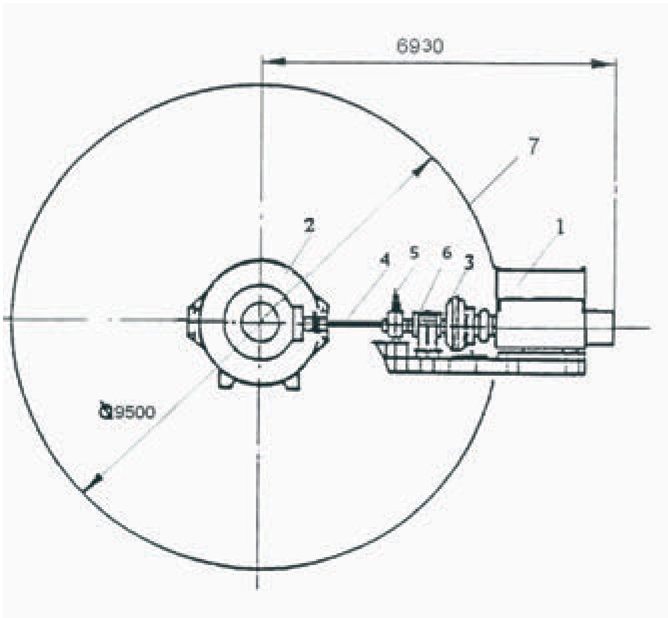

Fig. 11. Diagram of modernized mechanism of bucket wheel drive in BWE KWK 1500 at lignite open pit mine Turów
1 - motor with rated power N=630 kW, 2 –three stage planetary gear, 3 - hydrodynamic coupling with elastic clutch, 4 - jointed shaft with brake drum, 5- shoe brake, 6 - bearing support, 7 - bucket wheel
Rys. 11. Schemat zmodernizowanego mechanizmu napędu koła czerpakowego koparki KWK 1500 w KWB Turów
1 - silnik napędowy o mocy 630 kW, 2 - trzystopniowa przekładnia stożkowo-planetarna, 3 - sprzęgło hydrokinetyczne ze sprzęgłem elastycznym, 4 - wał przegubowy z bębnem hamulcowym, 5 - hamulec szczękowy, 6 - podpora łożyska, 7 - koło czerpakowe

Summary

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

- be of sufficient tangential cutting force enabling the nominal output at specific cutting resistance $k_L \geq 120$ kN/m,
- have effective and stable-during-operation protections against transmission of excessive dynamic loads to remaining components of mining system and load bearing structure. This function has been performed so far by fast - acting disengagin clutches but due to very fast transmission of impact pulses these clutches are not an optimum solution. The best solution would be a clutch starting operation prior to the peak value of the pulse, in advance – responding to the first or the second derivative of load curve. It is not a problem to measure quickly the load moment course of the bucket wheel. However it is difficult to construct a clutch`s decelerating mechanism operating quickly enough,

Fig. 12. Modernized drive mechanism of bucket wheel in BWE KWK 1500s at lignite open pit mine Konin
Rys. 12. Zmodernizowany mechanizm napędu koła czerpakowego koparki wielonaczyniowej kołowej KWK 1500s w KWB Konin

- have the planetary gear instead of multi-stage cylindrical gear,
- have secure, durable joint between motor and gear enabling a fast assembly and disassembly,
- be able to control the rotary speed of the bucket wheel to adept it to the properties of the excavated ground.

Moreover high rotary speed components of the drive, like motor and clutch, should feature as low torque as possible.

Construction of gears, clutches and motors should take into account occurrence of rapid disconnections and braking actions resulting from impacts of the bucket wheel against hard non-workable inclusions (stones).

The gear of bucket wheel drive mechanisms should be separated from the remaining components of mechanism mounted on a separated base fastened to the boom structure.

The motor of bucket wheel drive should be of electric type; hydraulic drive is here of low usefulness.

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