WYMAGANIA STAWIANE CZERPAKOM KOPAREK WIELONACZYNIOWYCH KOŁOWYCH EKSPLOATOWANYCH W UTWORACH TRUDNO URABIALNYCH

REQUIREMENTS FOR BUCKETS OF BWEs OPERATING IN HARD MINEABLE SOILS

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Przedstawiono specyfikę budowy i użytkowania czerpaków koparek wielonaczyniowych kołowych eksploatowanych w utworach trudno urabialnych. Wskazano na przyczyny powstawania uszkodzeń i zużycia czerpaków. Zaprezentowano mechanizm pracy czerpaka w utworach trudno urabialnych. Podano wytyczne do projektowania i produkcji czerpaków. Przedstawiono przykłady czerpaków przystosowanych do pracy w tych utworach. Zaprezentowano wykaz wymagań jakie powinny spełniać czerpaki koparek wielonaczyniowych kołowych eksploatowanych w utworach trudno urabialnych.

Słowa kluczowe: *koparki kołowe wielonaczyniowe, czerpaki, urabianie, wytrzymałość, zużycie, wymagania*

Specificity of construction and use of buckets of BWEs operating in the hard mineable soils has been presented in the paper. Reasons of failure and wear in these buckets have been indicated. The operational mechanism of buckets for hard mineable soils has been presented. Guidelines for design and production of buckets have been given. Examples of buckets adapted to operate in these soils have been placed. List of requirements for buckets which should be met by BWEs operating in hard mineable soils has been presented.

Keywords: *buckets wheel excavators, buckets excavation, strength, wear, requirements*

Introduction

Buckets are those components of excavator mining system which contact directly with the ground. Hence, they are exposed to intense wear much more than other subassemblies and components of mining systems.

Bucket structure is shown in Figure 1 below. The main components of the bucket are: bucket body (1), knife support (2), knife (3), rim (4), attachments (5), teeth with pockets (6).

The knifes of buckets are usually provided with teeth or corners; they also can be used without additional cutting elements (depending on the mining conditions). All aforementioned elements are interconnected by means of welding except the teeth which, as in this case, are replaceable (it is also possible that teeth are permanently welded to the knife).

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 including open pit Szczerców) shows that such soils are usually classified in the class No. IV-V of workability and are distinguished with high hardness (with specific cutting resistance $k_L \geq 120$ kN/m), high content of sharp-edge quartz grains of strong abrasive power, and also high content of non-workable rock inclusions.

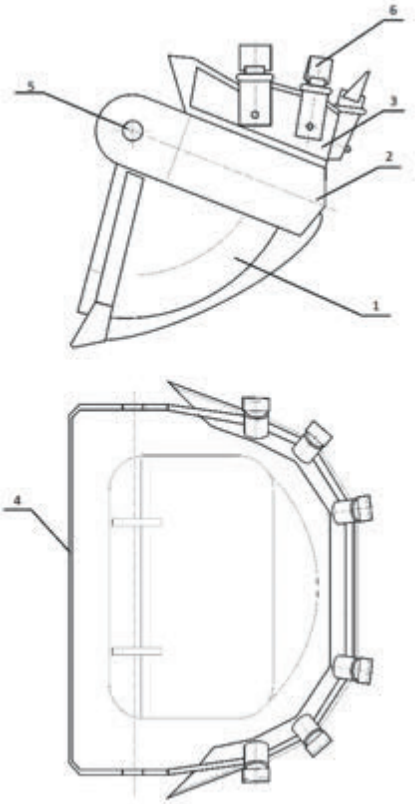

Fig. 1. Scheme of bucket in BWE KWK 1500
Rys. 1. Schemat czerpaka do koparki wielonaczyniowej kołowej KWK 1500

The character of buckets wear

In practice, this results in very fast wear of buckets, especially the teeth and knifes, and – to a lesser extent – the bucket

body, knife support and bucket attachments.

This wear is mainly of abrasive nature and, less frequently, of impact type. It consists in abrasion of teeth and, partially, the knifes of buckets; furthermore, it happens that teeth get broken, the knife surface get cracked and crumbled, and also the sleeves of attachments get abraded and broken. Due to increased dynamic loads, also the knife supports get broken, bent or bucket body get cracked (Figs. 2, 3 and 4). Also the chain mats (if used) are subject to abrasion and coming off.

Fig. 2. Worn out bucket – visible are broken teeth and knife damages
Rys. 2. Czerpak zużyty - widoczne wyłamania zębów i uszkodzenia noża

Fig. 3. Worn out teeth due to abrasion and breaks
Rys. 3. Zużyte zęby przez ścieranie i wyłamania

Fig. 4. Total damaged bucket
Rys. 4. Całkowite zniszczenie czerpaka

Such condition has influence on reduced durability of not only the mining system of excavator (buckets, bucket wheel, wheel drive), but also – due to increase in dynamic loads – on reduced durability of load bearing structure, especially the bucket wheel boom [1].

The operational mechanism of bucket in hard mineable soils

During the initial phase of the movement of excavator bucket, which contacts with the ground being excavated, plastic strains occur in the ground near the cutting edge [2]. As the tool moves further in the ground, the area covered by plastic strains increases, the stresses in the medium rise and there is a need of higher force to move the tool. This process is continued until at some surface within the medium the stresses exceed the critical values. Then, a sector of the medium along the slip surface would be pushed out (Fig.5) and the force required to move the tool decreases rapidly. Then, the process repeats from the beginning. The area of plastic strain depends on the properties of the medium.

The area of plastic strains decreases along with increasing the medium susceptibility to brittle fracture. In such media, including most of hardly-workable rocks, and especially low--cohesive ones, while they are excavated with bucket provided

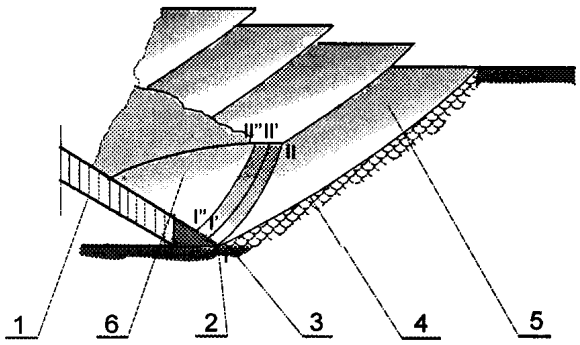

Fig. 5. Mechanism of medium destruction during excavating operation [2]:
1 – knife, 2 – wedge created out of excavated material, 3 – initial slip line, 4 – main slip line, 5 – slice sector pushed out, 6 – area of total destruction of medium structure
Rys. 5. Mechanizm niszczenia ośrodka podczas urabiania [2]:
1 - nóż, 2 - klin utworzony z urobionego materiału, 3 - wstępna linia poślizgu, 4 - główna linia poślizgu, 5 - wypchnięty wycinek wióra, 6 - obszar całkowitego zniszczenia struktury ośrodka

with teeth, there can occur some preceding cracks of the medium independently on each of the teeth. Large concentrated thrusts at edges of teeth facilitate penetration into workable medium (of considerable fragility). It is of large importance for the value of forces during excavation process. Hence, excavators intended for low-cohesion grounds (limestone, sandstones, slits) are, in principle, provided with teeth (Fig. 6)[3]. Introducing excavators into media of more and more cutting resistances causes that the importance of teeth for such machines becomes more and more essential.

According to bibliography data [4] [5] [6], for the media with specific cutting resistance over 150 kN/m, at least 75% of work necessary for loosening the excavated material falls to the teeth.

Accordingly, for hardly-workable grounds tending to brittle

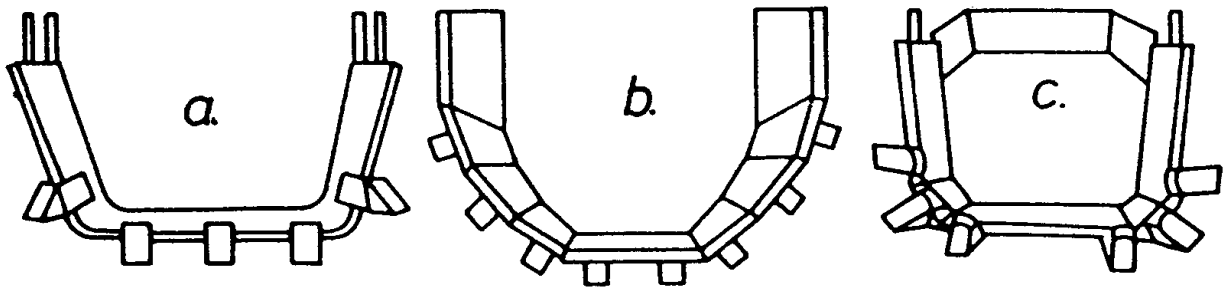

Fig. 6. Exemplary ways of shaping the cutting edge of the bucket [3]:
a) trapezoidal edge, b) arched edge, c) asymmetrical bow-shaped edge
Rys. 6. Przykładowe sposoby kształtowania krawędzi tnącej czerpaka
a) krawędź trapezowa, b) krawędź łukowa, c) krawędź niesymetryczna pałąkowata

fracture, the main loosening work shall be done by teeth, while the knifes, set back with respect to the teeth, should cut off just small inter-teeth sectors of the rock being worked out.

In media of such high firmness (with specific cutting resistances $k_L \geq 120$kN/m), the dominant phenomena are those which can no more be treated with specific cutting resistances k_L or k_A. The models of the forms:

$$F_{u1} = k_L \cdot L$$

$$F_{u1} = k_A \cdot A$$

where: k_L – specific cutting resistance [kN/m], k_A – specific cutting resistance [kN/m^2], F_{u1} – tangential cutting force on the bucket wheel [kN], L – cutting knife length of the sickle cut [m], A – slice cross-section of the sickle cut [m^2].
lose their practical meaning because not only the dimensions of the slice being loosened, but also the shape of cutting blade of the bucket, the type, geometry and wearing conditions of the teeth in use, and also kinematic conditions of blade penetration into cohesive ground have the decisive influence on the values of force actions in the working process under investigation.

Such way of bucket operations is not within the notional categories of conventional mechanics of cutting through and slicing the grounds with bow-and-blade knifes [4]. The operational mechanics of the bucket for hardly-workable cohesive rock media is more related to the model of destructing a spatial structure of cohesive media using multi-tooth system of biting jaw (by comparison with biomechanical arrangement of human jaw). In this relation, the process of excavation the cohesive media using a single bucket of the bucket wheel should be treated as the effect of a complex, spatially shaped cutting edge (supporting jaw) including teeth seated in properly spaced and shaped pockets (gums) and appropriately protected against falling out. However, it is impossible to eliminate all disadvantageous effects related to operation in hard mineable soils in modern BWEs, but endeavours should be made to seek such structural solutions and to select operating parameters of mining systems so as to attain the best possible condition. This requires elaboration of appropriate teeth and proper shape of buckets where these teeth will be mounted so as the resultant effects of bucket wheel operation provide the lowest possible energy consumption per unit of mass (volume) of excavated material.

The effect of blow (e.g. in a stone or hard interbedding) during excavation operation can be either elastic strain of the bucket or local permanent strain, or – in extreme case – its total destruction. A kind of such or another effect depends on both the magnitude and direction of blow force and the point where the load is applied to the bucket.

Guidlines for design and production of buckets

Teeth of a bucket are the most exposed to blows constructional components. Hence, this seems to be rational to shape the buckets so as their teeth are the weakest structural link to protect bucket body against destruction.

Successive protecting element should be the tooth pocket. The remaining components (knife, knife support, bucket body, rim and attachments) should feature a higher strength. While calculating strength values with FEM method, assumption shall be made that the knife support and bucket rim create its main load bearing structural framework.

The bucket body should allow its filling at possible low resistances and its fast dumping. The bucket body has, in its longitudinal cross-section, the arched shape with radius greater than the bucket height (Fig. 1). The bucket body shape in it transverse cross-section is usually consistent with the shape of cutting edge (Fig. 6). The bucket body side wall inclination angle is as a rule 20 to 30^o [7].

The bucket body subjects to very high forces during excavating hard mineable soils. For this reason, the bodies should be, in such case, made totally with sheet metal (as opposed to the buckets with chain mats which facilitate dumping the body), and even strengthened with additional ribs (Fig. 7)[8]. The bucket body sheet gouge should be of about 15 mm. The knife support sheet gouge should be of about 40-50 mm, and it should be even additionally strengthened as in case of the body. The bucket body and the support knife are usually made out of S235JR or S355J0 steel grade.

The knives of buckets, as they transmit large forces resulted from the mounted teeth, subject to abrasive wear and also impact wear, and as they may not be replaced directly on excavator and as they are expensive components, are the most sensitive elements of the buckets. The most frequent damages of knives include tearing away their elements or the whole units, breaking and abrasive wearing (Fig. 2). Knives are made out of abrasion-resistant materials then subjected to heat treatment (most often these are of 35SG steel grade). The knife sheet gouge thickness for hard minerable soils should be about 50 mm. To protect the knives against intense abrasive wear, they should be provided with overlaying welding on both their sides.

Facing by welding should be made using powder welding electrodes which allow to get padding welds of high abrasive resistance and relatively high resistance to dynamic (impact)

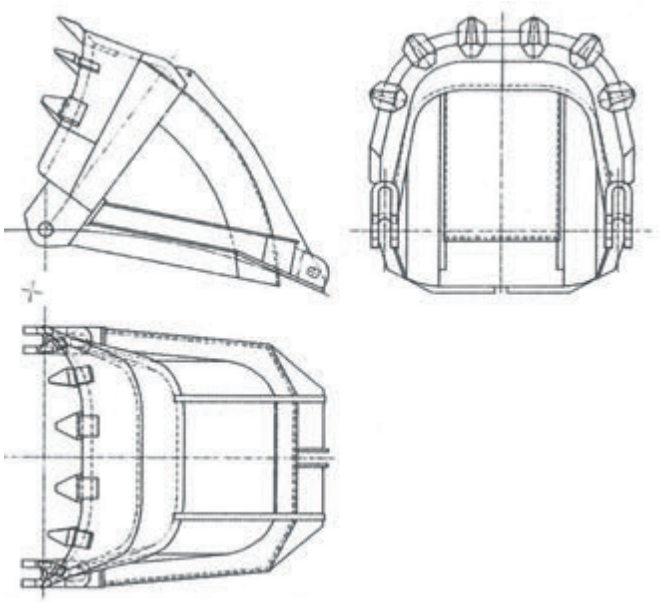

Fig. 7. Bucket for hard mineable soils in BWEs: KWK 1500, KWK 1200, SchRs 1200 at lignite open pit mine Turów [8]
Rys. 7. Czerpak do urabiania utworów trudno urabialnych na koparkach KWK 1500, KWK 1200, SchRs 1200 w KWB Turów [8]

loads [9]. The knife should have the shape allowing to get proper selection of teeth setting angles on the bucket [10] [11]. As concerns the strength properties of knives, the strength analysis shall be made allowing for real loads on the bucket wheel and geometry of teeth mounting, to be able to design the knives adopted to excavation the grounds of specific properties (hard mineable soils in this case) (Fig. 9) [12].

The bucket can be fastened on the circular rim of the bucket wheel in 3 or 4 points. Experimental comparative analysis of loads for these two types of mounting (especially for hard minerable soils) proved that the 4-point support system of the bucket (Fig. 8) ensures better distribution of stresses than that of 3-point system [4]. It also results from experimental studies, which have been carried out in this research for strength properties of buckets, that:

- in the case of excessive clearance Δl at front mounting points of the bucket, as a result of side forces, the loads are transferred non-uniformly causing bucket deformations as shown in Fig. 9;
- elimination of internal (welding-induced) stresses in

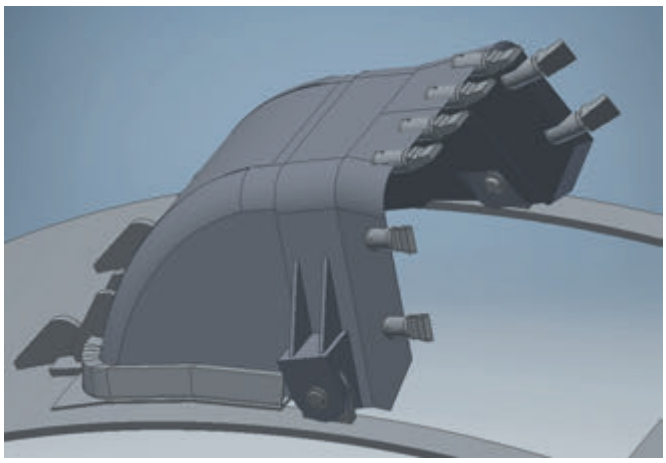

Fig. 8. Prototype of bucket for hard mineable soils in BWE SchRs 4600 [12]
Rys. 8. Prototypowy czerpak do urabiania utworów trudno urabialnych na koparce SchRs 4600 [12]

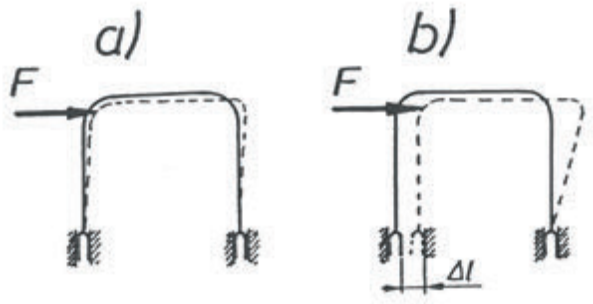

Fig. 9. Nature of bucket deformations due to clearance Δl in its fastening points on the rim of bucket wheel [4]
Rys. 9. Charakter deformacji czerpaka na skutek luzu Δl w punktach jego mocowania na pierścieniu koła czerpakowego [4]

complete buckets by appropriate heat treatment has very advantageous influence on their durability.

Not only the bucket construction is essential for the value of impact loads generated (which is of special importance for hardly-workable grounds), but also geometry of ground cutting and also the number of buckets on the bucket wheel.

Number of buckets on the bucket wheel

On the basis of studies and operating experience [7] [13], it was found that the more buckets on the wheel the lower is the dynamics of the excavation process and the higher is the excavated material break up (Fig. 10) [14]. However lower dimensions of the slice cross-section cause larger energy consumption during excavation process. However, in case of excavation the hardly-workable cohesive rocks the two first factors are of decisive meaning. For non-cohesive grounds, the most important is the energy consumed by excavation process. However, selection of buckets for a given excavator must be preceded by studies including experiments and numerical modal analysis. This research allows 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 at open pit mine Bełchatów or in new mining system of BWE SRs 1200 at open pit mine Konin [13].

Summary

To sum up the above description, the buckets intended for excavation the hard mineable soils should:

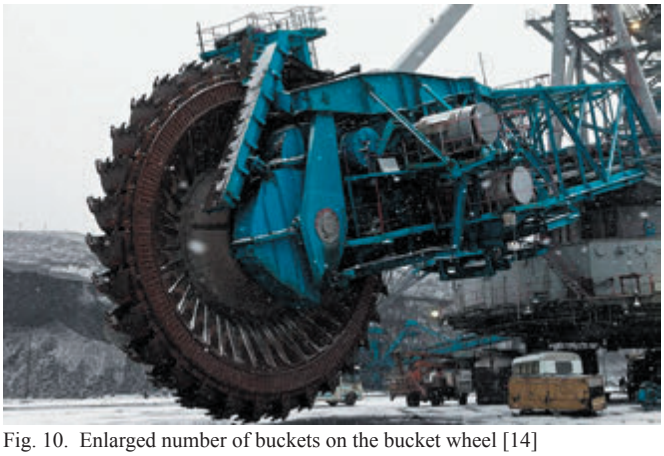

Fig. 10. Enlarged number of buckets on the bucket wheel [14]
Rys. 10. Zwiększona liczba czerpaków na kole czerpakowym [14]

- be obligatorily equipped with teeth,
- be shaped so as the teeth are the weakest structural link protecting the bucket framework against damage; a tooth pocket should be a successive protective element. The remaining elements (knife, knife support, bucket body, attachments) should be of elevated strength. The bucket should be dimensioned with the FEM method, the calculations should take into account real loads present on the bucket wheel. In calculations, the knife support and the bucket rim should be assumed as the main load bearing framework,
- be shaped so as the resulting effects of the bucket wheel ensure possibly low energy consumption per unit of mass (volume) of the excavated material,
- have bodies which allow their filling at possibly low resistances, and their fast emptying,
- the bucket body should be totally made out of steel plate (as opposed to the body with chain mats) and, as needed, reinforced with additional ribs; sheet gouge thickness should amounts to at least 10-15 mm,
- the knife support should be made out of sheet gouge of considerable thickness, min. 40-50 mm, and also additionally reinforced, as needed,
- the knife should be of the shape which allows to select proper positioning angles for teeth,
- the knife should be made out of abrasion resistant materials and then it should subject to heat treatment. The knife should be min. 50 mm thick. To protect against intense abrasive wear, the knife surfaces should be additionally weld padded on their both sides,
- the bucket should be fastened to the bucket wheel in four points: two front and two rear attachments,
- the construction of the front attachments should prevent excessive side clearance of the bucket fastening,
- following fabrication, the bucket should be heat treated to eliminate internal (welding) stresses,
- the number of buckets on the bucket wheel should be higher than that for excavators operating in easily- and medium--workable grounds. The number of buckets on the bucket wheel of a given excavator should be selected with modal analysis, so as excitation generated during working does not coincide with any resonance frequency.

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Literatura / Bibliography

[1] Dudek D.: *Elementy dynamiki maszyn górnictwa odkrywkowego.* Oficyna Wydawnicza Politechniki Wrocławskiej 1994
[2] Pajer G., Kurth F., Pfeifer M., Hojdar J.: *Tagebaugroßgeräte und Universalbagger*. VEB Verlag Technik, Berlin 1979
[3] Hawrylak H. i zespół: *Analiza procesu ciągłego urabiania skał zwięzłych narzędziami roboczymi o ruchu złożonym. Realizacja – Wyniki – Wnioski.* Prace Naukowe CPBP O2.05. Wyd. Politechniki Warszawskiej, Warszawa 1990
[4] Lasmanowicz A., Welik S., Włodarczyk J.: *Opracowanie oraz badania nowych rozwiązań czerpaków i elementów skrawających wielonaczyniowych koparek kołowych.* Raport IKEM Politechniki Wrocławskiej, Nr 27/85, Wrocław 1985
[5] Korzeń Z.: *Mechanika procesu przecinania ośrodka rozdrobnionego elementarnymi profilami liniowymi.* Prace Naukowe Instytutu Konstrukcji i Eksploatacji Maszyn Politechniki Wrocławskiej, Nr 38/9, 1981
[6] Wocka N.: *Urabianie koparkami kołowymi w warunkach dużych oporów kopania (Operation of bucket wheel excavators under hidh diggingresistance)*. Górnictwo Odkrywkowe nr 1, 1989
[7] Szepietowski W.: *Zespół urabiania wielonaczyniowej koparki kołowej.* Redakcja Górnictwa Odkrywkowego Wrocław 2006
[8] Wocka N.: *Czerpaki do urabiania utworów bardzo trudno urabialnych koparkami kołowymi.* Węgiel Brunatny nr 3, 2007
[9] Alenowicz J.: *Zastosowanie zębów wymiennych napawanych w koparkach wielonaczyniowych górnictwa odkrywkowego [The application of exchangeable padded teeth in multi bucket wheel excavators used in open cast mining]*. Górnictwo Odkrywkowe nr 1, 2000
[10] Alenowicz J., Musiał W.: *Kinematyka współdziałania zębów czerpaków koparek kołowych z calizną w czasie urabiania [The kinematics of the co-operation of bucket wheel excavator teeth with the solid rock mass in the excavating process]*. Górnictwo Odkrywkowe nr 4-5, 1999
[11] Rusiński E., Moczko P., Pietrusiak D., Cegiel L., Michalczyk A., Olejarz J.: *Badania i modernizacja czerpaków koparek kołowych [Investigation and modernization of buckets of surface mining machines]*. Górnictwo Odkrywkowe nr 4-5 2014
[12] Rosik R.: *Czerpak o nominalnej pojemności 4600 l do urabiania nadkładu o zwiększonych oporach urabiania.* Opracowanie IGO Poltegor, nr arch. 6165/IGO. Wrocław 2011. Praca niepublikowana
[13] Rusiński E., Moczko P., Pietrusiak D.: *Drgania jako czynnik degradacji maszyn i urządzeń górniczych - identyfikacja i minimalizacja oddziaływań. Węgiel Brunatny gwarantem bezpieczeństwa energetycznego [Vibrations as a degradation factor of mining machines and equipment – identification and reduction of negative influence]*. Monografia. AGH Kraków 2016
[14] www.dailymail.co.uk
[15] Materiały Politechniki Wrocławskiej