Dariusz ULBRICH, Jarosław SELECH, Dawid ROMEK, Mateusz SIEŃKOWSKI, Konrad WŁODARCZYK, Jakub KOWALCZYK, Żaneta STASZAK, Jacek MARCINKIEWICZ
Politechnika Poznańska, Instytut Maszyn Roboczych i Pojazdów Samochodowych, Poland
e-mail: jaroslaw.selech@put.poznan.pl
Received: 2018-03-02 ; Accepted: 2018-03-23

ANALYSIS OF THE COSTS OF REGENERATION OF EXCAVATOR BUCKETS USED FOR BROWN COAL EXCAVATION

Summary

The paper presents the most frequently applied multibucket excavator solutions used in brown coal surface mining. The authors have analyzed the design of the excavator bucket individual components in terms of its wear during operation and the possibility of regeneration. The main aim of the performed analyses was to determine the costs of regeneration of the excavator buckets for selected multibucket excavators. Four selected excavators have been subject to the cost analysis. The cost of regeneration was estimated based on the prices of individual components such as bucket teeth, knives, forging, face as well as labor time needed to carry out full bucket regeneration. Based on the performed calculations and the experience of the mining personnel, it has been observed that in terms of economy, regeneration of an excavator bucket is more cost effective than purchasing a new one. However, severe mine working conditions as well as random damage sometimes force a purchase of new buckets for the excavators.
***Key words**: excavators, excavator buckets, brown coal, mines*

ANALIZA KOSZTÓW REGENERACJI KOPAREK WIELONACZYNIOWYCH STOSOWANYCH W KOPALNIACH WĘGLA BRUNATNEGO

Streszczenie

W artykule przedstawiono najczęściej wykorzystywane rozwiązania koparek wielonaczyniowych stosowanych w kopalniach odkrywkowych węgla brunatnego. Ponadto przeanalizowano budowę poszczególnych części czerpaka pod kątem jego zużycia podczas pracy, jak również możliwości regeneracji. Głównym celem wykonanych analiz było określenie kosztów regeneracji czerpaków, dla wybranych koparek wielonaczyniowych. Analizie kosztów poddano 4 wybrane koparki pracujące w kopalniach węgla brunatnego w Polsce. Koszty regeneracji oszacowano na podstawie cen poszczególnych części, takich jak np. zęby, noże, odkuwki, płaszcz, jak również liczby roboczogodzin niezbędnych do wykonania pełnej regeneracji jednego czerpaka. Na podstawie wykonanych obliczeń oraz doświadczeń pracowników kopalni należy stwierdzić, że pod względem ekonomicznym regeneracja czerpaków jest bardziej opłacalna niż zakup nowego. Niemniej jednak ciężkie warunki pracy w kopalni oraz losowe uszkodzenia powodują konieczność zakupu nowych czerpaków koparek wielonaczyniowych.
***Słowa kluczowe**: koparki, czerpaki koparek, węgiel brunatny, kopalnie*

1. Introduction

Constant wear of the components of machinery used in surface mining (multibucket excavators, regular bucket excavators, loaders, bulldozers or stackers) forces their frequent renewal due to their exposure to abrasion. This fact increases the costs of the excavator operation. The problem of abrasive wear becomes increasingly important in the context of constantly growing requirements set for machinery operating in coalmines.

In surface coalmines, some of the machines such as multibucket excavators operate round the clock, hence, the high costs of their purchase and operation are fully compensated by their use. This would not be possible to ensure without equipment guaranteeing long periods of trouble-free operation. Operation of excavators with worn bucket components significantly reduces their efficiency and increases the cutting forces, extends the bucket filling time and increases energy consumption, let alone the premature wear of other machine components. From the investigations carried out in 2009 related to the wear of bucket teeth of excavators operating in American copper mines and their impact on the costs of production loss, we know that leading to an unplanned (emergency) renewal of bucket teeth caused by abrasive wear, costs the mine 13.8 times more than a planned renewal of the same [1].

In order to resolve the described problems and ensure appropriate operating requirements, scientific centers as well as manufacturers of machines continue to carry out experiments of different level of advancement. An important aspect in the development of innovative design solutions is the ongoing search for modern materials and methods of their processing that contribute to the durability of the components, thus guaranteeing reliability and extended maintenance-free operation.

Poland is a country where much of the energy is produced from coal, 23% of which is generated by power stations fueled with brown coal [2]. The energy generated from the combustion of brown coal is one of the cheapest types of energy. Poland has numerous natural resources of this fossil fuel and the power stations are usually located close to these resources. Brown coal is excavated in surface mines. Contrary to conventional mines, surface mines are characterized by the fact that all mining operations are carried out on the ground level. The works consist in removing the capping i.e. the medium lying above the excavated fuel. Then the medium is excavated and the pit is filled. The entire area of the surface mining is subsequently recultivated in a variety of ways depending on the local needs. Surface mines are divided into levels, depending on the depth of the coal deposition (or other excavated medium), type of capping medium and excavators assigned for the works. Fig. 1 presents an example surface mine located in Poland.

Fig. 1. Surface brown coal mining [1]
Rys. 1. Powierzchniowe wydobycie węgla [1]

2. Multibucket excavators

Multibucket excavators are built from several buckets that constantly sweep the excavated medium and put it on the conveyor. The medium is conveyed to the bucket wheel stacker or,if the main medium is excavated, to its final destination such as the railroad station or sometimes, directly to the power plant. Surface mining excavators can be divided into bucket wheel and bucket chain excavators. Bucket chain excavators are based on a chain holding the buckets together (Fig. 2). The possibility of adjusting the length of the chain depending on the excavation site is an important factor influencing their wide application. Bucket chain excavators additionally allow an easy avoidance of ground obstacles such as rocks. Unfortunately, despite the said advantages, bucket chain excavators cannot properly operate in above-ground operations during bucket filling. A downside of a bucket chain excavator is the high friction among the bucket, the chain and the processed medium. This generates high energy losses during excavation and damages the chain leading to stoppages in the mining operations [3-5].

Fig. 2. RS-400 bucket chain excavator [1]
Rys. 2. Koparka wielonaczyniowa RS-400 [1]

Currently, bucket wheel excavators based on tracked undercarriage are being widely applied owing to their unique features (much smaller turning circle and no need to relocate the rails as it was in the case of other types of excavators) - Fig. 3.

Fig. 3. Tracked undercarriage of the SRs-1800 excavator [1]
Rys. 3. Podwozie gąsiennicowe koparki SRs-1800 [1]

Bucket wheel excavators are more efficient than bucket chain ones. It is because the cutting speeds are greater and the bucket unloading is more frequent. An additional advantage of bucket wheel excavators consists in their lower weight compared to bucket chain ones, despite the same amount of processed medium, which reduces the costs of operation. Besides, bucket chain excavators continuously dig the level, on which they are standing, thus risking a landslide.

Buckets are vessels allowing excavation of the medium from the excavation site. Today, only open buckets are used (buckets of the shape of a bowl with two open spaces). The only existing classification among them is into chain buckets and full buckets. Chain buckets are such that have a chain located on its face serving the purpose of protecting the bucket from the sticking medium and providing better passage of the medium following its dilution. Full buckets are conventional buckets with a face. The buckets of multibucket excavators are classified into a variety of types depending on the machinery, on which they are fitted and the type of work they are designed to perform. Example of buckets is shown in Fig. 4.

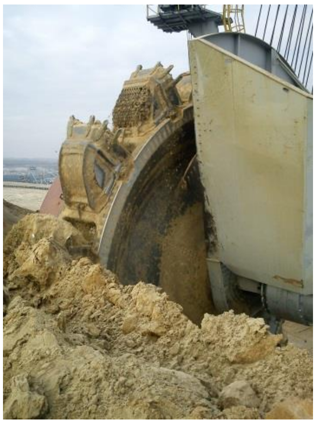


Fig. 4. Full and chain buckets fitted interchangeably on the bucket wheel of a SchRs-900 excavator [1]
Rys. 4. Czerpaki pełne oraz łańcuchowe zamontowane na koparce wielonaczyniowej SchRs-900 [1]

3. Wear and regeneration of the excavator buckets

The wear of multi bucket excavators depends on the processed medium and its composition. The procedure of assessment of the bucket condition consists in a visual inspection of each bucket and a comparison with the technical guidelines contained in the technical documentation. The inspection is performed in relation to the bucket knives, teeth or bucket corners (parts extremely exposed to damage resulting from rock impact). There are procedures determining the maintenance-free operation time of buckets and their components until the entire set is sent for renewal. This issue, however, varies depending on the excavator and its role in the mine. Examples of applications of excavators have been presented in Fig. 5.

a)

b)

c)

Fig. 5. Damage to the excavator buckets; a) SchRs-900, b) Rs-560, and c) Rs-400 excavators [1]
Rys. 5. Uszkodzone czerpaki koparek; a) SchRs-900, b) Rs-560, c) Rs-400 [1]

A regeneration of an excavator bucket begins with its removal from the machine. The next stage is a thorough cleaning to eliminate the remains of soil and coal. Then, a visual inspection is carried out that qualifies the bucket for regeneration or scrapping. In the latter case, another inspection takes place aiming at selecting parts that can be reused (for example the bucket face) in the process of regeneration of other buckets of the same type. The sleeves used for the fitting of the buckets are always renewed during regeneration, irrespective of their condition, and then the buckets undergo a geometry check on specially prepared wheel recesses (Fig. 6). If the bucket does not match the bucket wheel, it is transported to a device that permanently deforms the bucket (pressing and drawing) to adapt it to the wheel recess.

Fig. 6. Bucket wheel recess [1]
Rys. 6. Miejsce koła łyżki koparki [1]

For each regenerated bucket a set of parts is prepared that will replace the parts previously removed. These components are knives, teeth and their fittings, bucket corners, chains and their fittings, bucket frames, parts of the bucket face and bucket connecting links to the wheel/chain. The knives are the most important cutting component of a bucket. They come into direct contact with the excavated medium and they serve as fitting spots for the teeth. They are also some of the most frequently renewed parts during regeneration. The worn knives are entirely cut out from the bucket and scrapped. They are replaced with new cast ones of the shape of an arch. In many cases, upon welding of the knives to the bucket, they are hardfaced. In the mining industry, hardfacing is done with a 62 HRC wire. Hardfacing guarantees higher durability and extended life. The teeth are deigned to crumble the processed medium and enable the bucket to cut into it. These bucket components are the most frequently renewed ones. In most cases the teeth are renewed on the excavator without bucket removal. Prior to welding, they are also hardfaced for reinforcement. Example teeth fitted on the bucket have been shown in Fig. 7.

The corners of the buckets are cast and then reinforced at the tips. The corners are heavily hardfaced to ensure the highest possible durability, which is why it significantly increases the cost of production of these components.

The chains are to prevent the bucket from the sticking medium and are to dilute the medium and facilitate its passage from the bucket. They are an important component of the bucket but are also frequently renewed. In fact, the chains do not wear easily (one in three regenerations indicates a chain wear), yet their fittings are much weaker, which eventually leads to the renewal.

Fig. 7. New teeth fitted on the excavator bucket [1]
Rys. 7. Nowe zęby zamontowane na łyżce koparki [1]

4. Costs of regeneration of the excavator buckets

The cost of regeneration (repair or renewal) of damaged machines, equipment or subassemblies is one of the significant components of the costs of operation, on which a machine user can have actual influence [11, 12]. A reduction of these costs can be achieved by the application of modern, organizationally and economically justified technologies extending the excavators' life cycles. Such an effect can be achieved through increasing the durability of the components and subassemblies that are heavily exposed to wear or damage. This is ensured by an economically justified repair incorporating a wide use of new and regenerated spares [13-17]. The above can substantially reduce the material costs related to the machine operation and its maintenance.

It is noteworthy that, aside from the reduction of costs, one has to bear in mind the environmental aspects of the modifications and subsequent scrapping of end-of-life machinery and equipment. Regeneration of machinery is to be understood as modification through application of a variety of technological processes that ensure new quality parameters on components exposed to wear (in the discussed case increasing the resistance to abrasive wear) that exceed the original parameters of the unmodified material [18-20].

The economic efficiency of the application of advanced durability-boosting techniques on excavator components exposed to wear is a complex problem. The economic factors conditioning such actions are:

– unit cost of part modification,
– cost related to machine stoppage resulting from frequently renewed parts,
– economic market analysis in terms of spares and replaceable subassemblies,
– analysis of the possibilities of regeneration of worn parts after the modification has been performed,
– organization of the forms of collaboration in purchasing/sale of modified spares good for regeneration,
– preparation of the calculation of costs of modification and pricing policy for the modified spares**,**
– comparison of the costs of modified and unmodified components.

Hence, the main aim of this analysis is to determine individual cost components of regenerated and non-regenerated buckets and their comparison in the entire life cycle. In this paper, the costs of regeneration of selected excavator buckets have been referred to the cost of new buckets and the amount of processed medium as shown in Tab. 1.

The costs given in the table are only the costs of bucket regeneration. Below, additional costs incurred by the mines for selected multibucket excavators have been listed.

For the SRs-1800N excavator, the price of a single new bucket could cover a regeneration of 3 to 5 such components. Owing to the fact that for the regeneration of a bucket, new or lightly used spares are used including their reinforcement, the durability of both the new and the regenerated bucket is comparable. The application of bucket corners is the main factor influencing the costs of operation and regeneration of these buckets. These are very expensive components in terms of design, contrary to the teeth. The cost of production of a single corner amounts to PLZ 1000. The corners are hardfaced for strengthening, which, in this case increases the price twice. It is noteworthy that new buckets are purchased without the corners. Generally, statistically, 680 corners are renewed per annum, which costs the mine approx. PLZ 1 360 000. The corners are durable and even a heavy impact on the rock that damages the bucket permanently leaves the corner intact, which, again, enables its further use in the regeneration of another bucket. A regeneration of a single bucket requires approx. 14 hours.

For the SchRs-900 excavator, the price of a single new bucket could cover a regeneration of 7 used ones. This bucket is characterized by the application of, as we call it, esco teeth. All teeth of this type are purchased as new at the manufacturer. The cost of a single esco tooth amounts to approx. PLZ 210. The teeth are the most frequently deteriorating and renewed component of any bucket. In a month, aside from the bucket regeneration on the excavator, approx. 30 to 40 esco teeth are renewed. Together with the process of regeneration, it gives, on average, 540 teeth per annum, which translates into a cost of PLZ 113 400.

The Rs-560 excavator is characterized by the fact that renewal is not carried out on single buckets. It is not necessary owing to the fashion, in which the excavator operates (random incidents of rock impact are entirely eliminated). For this reason, once in three months the entire bucket chain is renewed and replaced with a new chain already having regenerated buckets.

Table 1. Costs of regeneration of excavator buckets for selected excavators used in brown coal mining
Tab. 1. Koszt regeneracji czerpaków koparki dla wybranych koparek pracujących w kopalniach węgla brunatnego

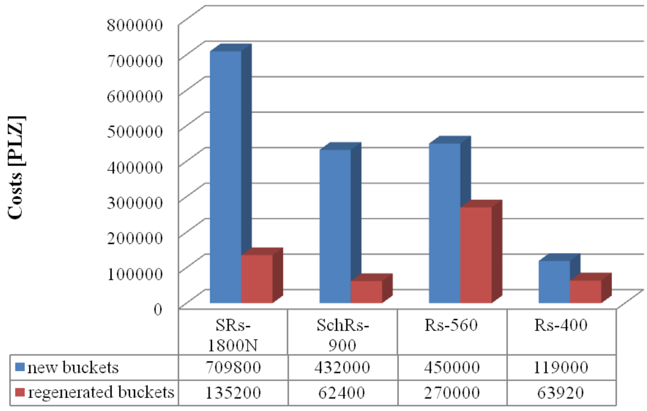
Type of excavator	Bucket capacity [l]	Amount of processed medium [m^3/year]	Number of new buckets	Number of regenerated buckets	Cost of a new bucket [PLZ]	Cost of bucket regeneration [PLZ]
SRs-1800N	850	1 336 000	23	17 - 26	14 700 - 27 300	5 200
SchRs-900	710	888 428	24	24	18 000	2 600
Rs-560	560	76 916	-	100	4 500	2 700
Rs-400	400	66 470	-	34	3 500	1 880

Source: prepared by the authors based on [1] / Źródło: opracowanie własne autorów na podstawie [1]

The low durability of the buckets (3 months) results from the operation of the excavator on the capping where the material abrasion is relatively high. The teeth of these buckets must be renewed when the excavator is not in operation. Despite the fact that there are only two teeth on each bucket, approx. 400 teeth are renewed per annum. A single tooth is cast and hardfaced as ordered by the mine, which gives the cost of approx. PLZ 85 per piece. Taking the teeth used for the regeneration into account, the average cost of the tooth renewal amounts to approx. PLZ 51 000. All buckets wear rather evenly. This is good for the time of their regeneration that amounts to approx. 9 hours.

The Rs-400 excavator has buckets fitted with the teeth forged from hardened steel of the value of PLZ 40 per piece. Within a year, approx. 100 teeth are renewed. The total cost of the teeth renewal amounts to PLZ 10 800. Buckets of chain excavators are simple in design, that is why the time needed for their regeneration is rather constant and amounts to approx. 8 hours.

The annual costs of purchasing new buckets and regenerating worn ones for a selected coalmine have been shown in Fig. 8. For the SRs-1800N excavator, 26 new and regenerated buckets per year were adopted for calculations.



Source: prepared by the authors based on [1]
Źródło: opracowanie własne autorów na podstawie [1]

Fig. 8. Comparison of the costs of purchasing new buckets and regenerated ones for selected excavators per annum
Rys. 8. Porównanie kosztów zakupu nowych oraz regenerowanych czerpaków koparki dla wybranych koparek

5 Conclusions

Multibucket excavators are widely applied in surface mining in brown coal excavation. Since these machines operated under very heavy conditions, their components are subject to wear and tear. The buckets having direct contact with the medium are particularly exposed to these two factors. The analysis of the costs of regeneration and purchasing of buckets for selected multibucket excavators has shown that in most of the cases (normal wear and insignificant damage) it is more economically justified to perform the process of regeneration. This reduces the time and the cost of the operation, the latter being reduced by the application of selected components (in good technical condition) retrieved from damaged buckets assigned for scrapping. A regeneration serves the purpose of not only restoring the bucket's condition, but also its maintenance and adaptation to the existing operating conditions. The process of regeneration very often increases the bucket durability compared to a new one because new buckets are not typically hardfaced, which is the case in regenerated buckets. Nevertheless, one should be mindful of the fact that the strength of regenerated buckets continuously deteriorates and components that do not have to be renewed from time to time become weaker with each subsequent cycle of work until eventual scrapping.

6. References

[1] Sieńkowski M.: Zużycie i regeneracja czerpaków koparek wielonaczyniowych na przykładzie kopalni PAK KWB Konin S.A., MSc thesis, Poznan, 2014.
[2] http://wysokienapiecie.pl/rynek/1468-rynek-energii-w-polsce-w-2015, 30.09.2017.
[3] Alenowicz J.: Budowa i rozwój koparek wielonaczyniowych kołowych. Górnictwo Odkrywkowe, Poltegor-instytut, 2008, 1, 5-10.
[4] Bajcar A.: Wybrane aspekty doboru koparek wielonaczyniowych stosowanych w górnictwie odkrywkowym. Górnictwo Odkrywkowe, Poltegor-instytut, 2013, 1, 69-73.
[5] Alenowicz J.: Regeneracja łańcuchów urabiających koparek wielonaczyniowych górnictwa odkrywkowego. Górnictwo Odkrywkowe, Poltegor-instytut, 2002, 4, 60-77.
[6] Owsiak Z.: Zużycie i metody zwiększania trwałości narzędzi rolniczych pracujących w glebie. Inżynieria Rolnicza, 2000, 6(17), 31-37.
[7] Kostenecki P., Wierzcholski K.: Analiza zużycia prostego elementu roboczego pracującego w glebie. Tribologia, 1992, 6.
[8] Łabęcki M., Gościański M., Kapcińska D., Pirowski Z.: Badania tribologiczne, wytrzymałościowe i strukturalne wybranych materiałów stosowanych na elementy maszyn rolniczych pracujących w glebie. Journal of Research and Applications in Agricultural Engineering, 2007, 52(2), 43-51.
[9] Napiórkowski J.: Elementarne procesy zużywania tworzyw wielofazowych w piasku luźnym. Inżynieria Rolnicza, 2000, 2(120), 71-77.
[10] Talarczyk W.: Zużycie elementów roboczych maszyn w procesie uprawy gleby. Prace Przemysłowego Instytutu Maszyn Rolniczych, 1993, 2, 36-42.
[11] Selech J.: Ocena wpływu stanu warstwy wierzchniej materiału na składowe procesu zużycia ścierno-korozyjnego. PhD thesis, Poznan, 2005.
[12] Fopp A.: Badania wpływu składu mechanicznego i wilgotności gleby na zużycie ścierne stali, w aspekcie opracowania ujednoliconej metodyki badań laboratoryjnych. PhD thesis, DrOIN 54992, Poznan, 1969.
[13] Tomczyk W.: Sposób określenia wielkości puli podzespołów przeznaczonych do regeneracji. Zeszyty Naukowe AR Kraków, 1994, 13.
[14] Tomczyk W.: Metodyka ustalania efektów ekonomicznych regeneracji. Zeszyty Naukowe AR Kraków, 1994, 13.
[15] Wojdak J.: O znaczeniu regeneracji, Eksploatacja maszyn, 1986, 4.
[16] Wojdak J.: Wybrane zagadnienia metodyczne regeneracji części. Eksploatacja maszyn, 1988, 4.
[17] Wojdak J., Sędłak P.: Oszczędność energii w procesach regeneracji części maszyn, Inżynieria Rolnicza, 1999, 5.
[18] Selech J., Kurczewski P.: Life Cycle Costing (LCC), jako nowoczesny model zarządzania kosztami cyklu życia na przykładzie obiektów technicznych. Problemy Eksploatacji, 2012, 84(1), 99-108.
[19] Selech J., Paczkowska M., Kinal G., Baran B., Chruściński W.: The comparison of effects of thermal spraying eutalloy 10112 and laser alloying with silicon nitride of cast iron out most disk coulter. Journal of Research and Applications in Agricultural Engineering, 2015, 60(1), 88-92.
[20] Paczkowska M, Selech J., Piasecki A.: Effect of surface treatment on abrasive wear resistance of seeder coulter flap. Surface Review and Letters, 2015. DOI: 10.1142/S0218625X16500074.

The research was supported by statutory resources appropriated to Institute of Machines and Motor Vehicles, Poznan University of Technology as the Grant No. 05/51/DSPB/3551.