BUCKET AND CUTTING TOOTH DEVELOPMENTS FOR THE BUCKET WHEEL EXCAVATORS OF MÁTRA POWER STATION LLC

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Abstract: The paper deals with the presentation of the concept, design and results obtained by testing of new bucket and cutting tooth for the Bucket Wheel Excavators used in Matra open pit lignite mines. The results of this approach led to serious improvements in energy consumption, reliability, productivity and other parameters which are documented and illustrated in the paper.

Key-words: Bucket-wheel excavator, bucket, tooth, energy, lignite.

1. INTRODUCTION

Bucket wheel excavators are used for removing surface refuse at the open-pit lignite mines of RWE Mátra Power Station LLC. The occurrence of useful minerals does not enable production to be performed at one single mine. The two mines – situated at about 60 km distance from each other – are located near to the settlements of Visonta and Bükkábrány. In spite of the considerable distance most of the refuse covering the lignite consists of sand and sandy clay, respectively, and gravel at both mines. In spite of this similarity, however, the two refuse layers show significant differences, as well. While the greatest difficulty at Bükkábrány is caused by the high abrasiveness of the stripped material – at Visonta hard sandstone ribs are encountered frequently. The locations of these cannot be foreseen in most cases. If the excavator is operated with the usual mining parameters when reaching such sandstone ribs, then rupture failures can be avoided only with cutting structures are capable of withstanding the higher stresses acting on these occasions.

Because of the long-standing problems of mining technique – high cutting tooth wear, frequent failure of buckets, high specific power demand – RWE specialists

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requested in year 2000 the collective of the Geotechnical Equipment Department of Miskolc University to compile a research and development program. We had opportunities for presenting the steps of this development process ongoing for the past eight years as well as the partial results achieved also during this series of conferences. The tangible results, however, could not be presented as yet. We present, therefore, in this article of ours only the major steps of the development process and then its results experienced at the mines during operation.

2. BUCKET AND CUTTING TOOTH DEVELOPMENT

The objective was to elaborate a testing and planning methodology ensuring the verification of the new components (buckets, cutting teeth) developed following the review of the excavators' cutting structures used until then having more advantageous features than those of the earlier ones. The most important features among these are listed below.

The new cutting structures ensure:

- Breaking with a lower specific power demand than the previous one;
- Longer service life for the cutting tools;
- Simpler fabrication & renewal and easier cutting teeth replacement;
- The drives of both the bucket wheel and the upper turntable to be operated without overload with the use of the recommended optimal technology.

Building on the experiences obtained in the course of our earlier works, we had elaborated a series of development steps – as described below – employed also in this case:

- Review of the excavator in respect of geometry, technology, dynamics and energetics;
- Formulation of the optimal technology;
- Bucket and cutting tooth improvement based on information obtained in the above two steps;
- Preparation of fabrication documents for the new designs;
- Implementation of modifications required eventually on the basis of the initial operating experiences.

2.1. Excavator review steps

1. Gathering of basic data characteristic of the machine and its operating mode in respect of engineering, geometry and technology. Preparation of a kinetic diagram about the movement of the bucket wheel and the buckets. Calculation of the basic swinging, cutting and breaking data.

2. Determination of the machinability material properties of the mined rocks in laboratory. Two material properties – the specific cutting force [f_v, N/cm^2] and the ratio of the average cutting force to mean pressing force – played the most important role in our calculations. The dynamic and power-demand parameters can be deter-

mined and then the bucket designed with respect to strength in knowledge of these properties. They also facilitate optimisation for the expected technologies.

Cutting tests were conducted with so-called large samples taken from the mines and similar in size to natural occurrences on a planning machine modified for this purpose. Cutters with various edge geometrics, so-called etalon cutters were designed for these tests. Two of these modelled the worn cutting tool.

3. Gathering and analysis of the characteristic failure and wearing forms of the buckets and cutting teeth. Exploration of causes. This had to be done separately for each excavator type. The most significant findings of the analyses for the excavators operating in RWE's mines and the conclusions drawn from these were as follows:

- Abrasive wear of the cutting teeth and cutting edges is typical when mining sand, sandy clays & gravel in usual rock environment. This condition can be improved by choosing some material more resistant to the abrasive effect.
- The wear of cutting teeth is frequently asymmetric: indicating some cutting tooth adjustment error not fitting for the technology.
- The wear of cutting tooth holders takes place in a relatively short time, meaning that the combined design of the holder and cutting tooth does not protect the holder against wear.
- Cutting edges on the sides undergo considerable wear in some cases, meaning unequivocally incorrect positioning of the cutting tooth.
- The breaking out of cutting teeth is a not infrequent occurrence when stripping hard ribs (sandstones) and even the break-away of cutting tooth holders takes place sometimes. Cutting edges become cracked and the entire bucket body undergoes permanent deformation. This means that the strength of the entire cutting structure is insufficient for meeting the increased demands.

The experimental results collected are taken into consideration for the positioning & adjustment of the bucket & cutting teeth and the elaboration of the new cutting tooth design.

4. The review of technological processes is being conducted over several shifts for each machine type in order to select the proper cutting parameters in parallel with setting the limits of the optimum range for mining performance. The new bucket design is being developed as fitting for these parameters. The operation of the old buckets will be checked also with the applications of these parameters in order to enable comparisons.

2.2. Main steps of bucket and cutting tooth development

1. Review of the geometry of cutting edges and cutting teeth on the basis of the three-dimensional (3D) model of old buckets (Figure 1) and the cinematic diagram of movements. Determination of the cutting angles, relief angles and angular adjustment errors suitable for the optimal technological parameters.

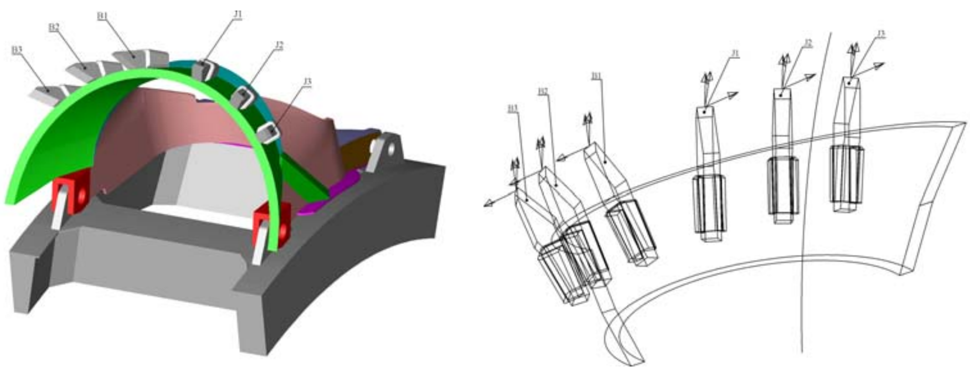

Fig. 1. 3D model of old bucket's and cutting teeth geometry

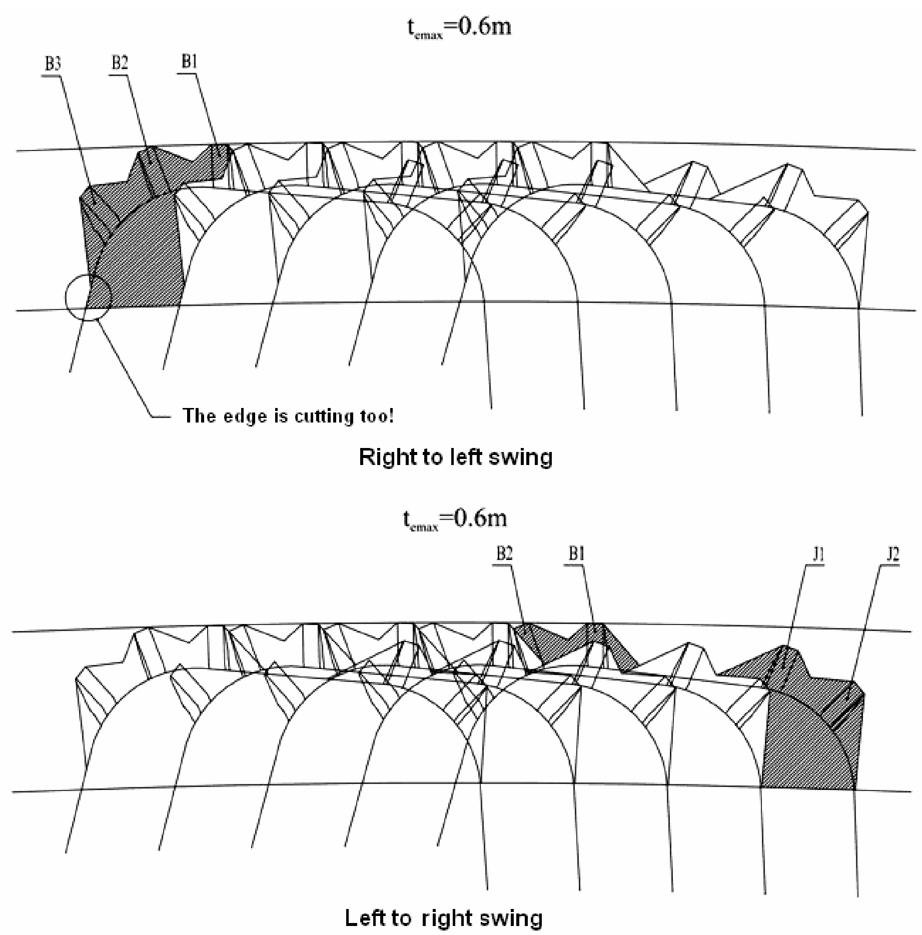

Fig. 2. Chipping patterns obtained with the old buckets

2. Drawing of the chipping patterns (Figure 2) obtained by mining with the old buckets and then the analysis of same. The investigation of mining conditions, cutting edge design, the positioning along it and the combined performance of cutting teeth at the same time.

The analyses completed according to the above two points facilitates the development of the new design. Our most significant finding related to the buckets of the excavators operated at Visonta and Bükkábrány is that symmetrical cutting under the same conditions with the cutting wheel positioned asymmetrically on the boom can be ensured in both swinging directions only with asymmetric bucket and cutting edge designs, respectively.

3. Strength review of old buckets with finite elements method. Determination of rated and dynamic peak loads acting on the buckets on the basis of the information obtained from rock cutting tests and machine specifications. Identification of the weak points of design – in necessity of strengthening – on the basis of test & analysis results. (Figure 3)

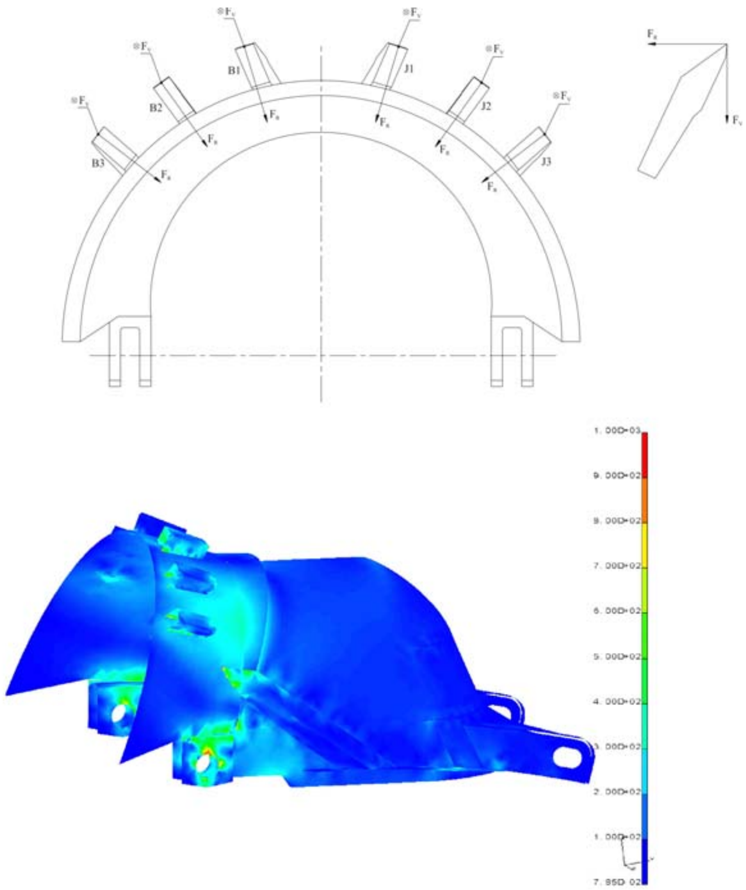

Fig. 3. Strength pattern of old buckets with FEM

The results of the development project described in this article can be summarised in the following six points:

1. New cutting teeth were designed in order to eliminate the deficiencies experienced with the cutting teeth in use previously. The results of rock machining performed in laboratory were taken into account to the greatest extent in the course of design engineering. Two cutting teeth – built on the same principle but differing in size – were designed for the five machine types (cutting tooth No.1 & 2).

The design of the cutting teeth employed originally has left several desirable features unrealised. Only the most significant ones of the changes related to these and their effects are listed below:

- The width of the cutting edge was increased by choosing a negative side angle for the cutter tip.
- The cutting teeth were installed also on top of the cutting edge. This is not only more advantageous in respect of force transmission but offers a more precise solution also for the adjustment of the cutting teeth than the previous one.
- The collar portion of the cutting tooth protects the cutting tooth holder against wear.
- Cutting teeth do not jam because of being seated on top, they are easier to replace.
- The mode of the attachment of cutting teeth was redesigned in order to enable their easier replacement.

The design drawing and model view of cutting tooth No.1 are shown in Figure 4.

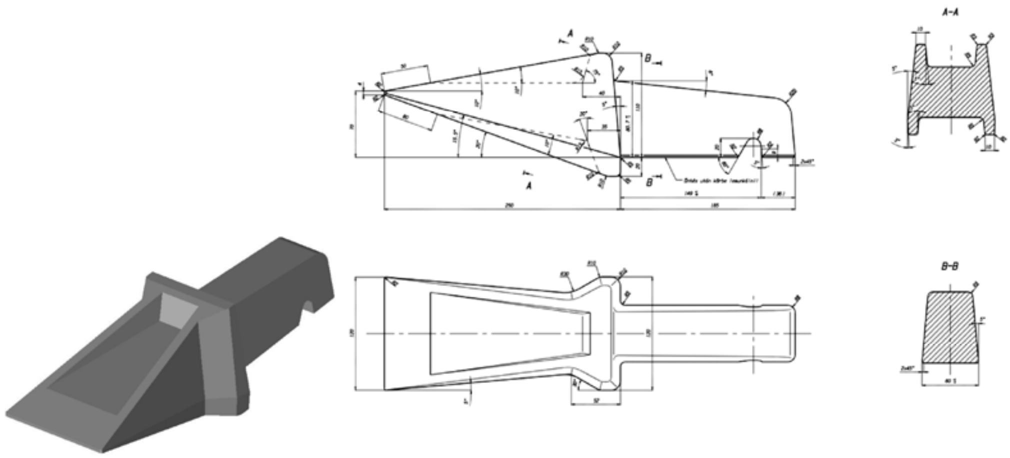

Fig. 4. The design drawing and model view of cutting tooth

2. We were forced frequently to design new cutting edge geometrics in the course of the engineering process. Cutting edges consisting of flat plates were designed instead of the earlier curved cutting edges. Asymmetric cutting edges consisting of five and seven flat plates, respectively, were obtained in this way for the new designs com-

prising six and eight cutting teeth (Figure 5). Fabricating accuracy has been improved considerably thereby. The completed buckets are of the same size within close tolerance limits enabling their easier installation and interchangeability.

The cutting teeth and edges have been set for the optimal technological processes so that the operating edge geometry would be favourable around 0° angular adjustment error, enabling the cutting tooth wear patterns to become symmetrical.

The operating experiences have supported the correctness of the theory that the cutting teeth have to be set in the direction of the mean resultant vector determined for the optimal technological parameters.

3. A multiangular bucket backing is being designed for the multiangular, asymmetric cutting edge, with the filling and dumping conditions also taken into consideration. Lining the backing built up in this way with adhesion reducing inserts can be done easily due to the flat plates.

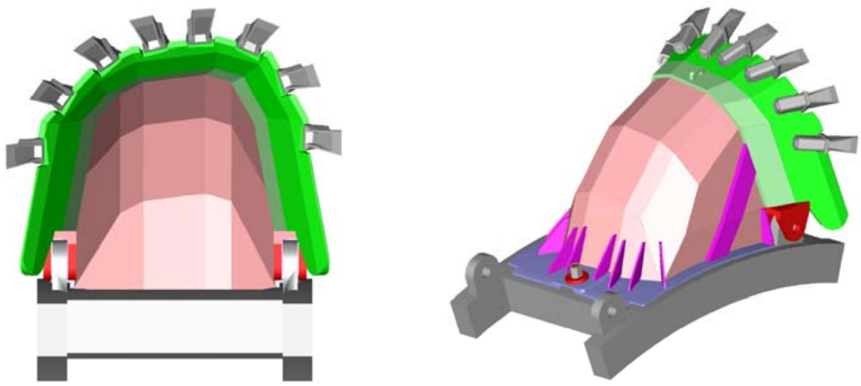

Fig. 5. Asymmetric cutting edges consisting of five and seven flat plates

4. The surroundings of the seating surface have been ribbed for supporting the cutting edge. A design more resistant to cyclical fatigue stresses than earlier solutions could be achieved thereby. A new back attachment method has been chosen also in order to mitigate the harmful effects of cyclical stresses. This was initially a wedged then a bolted joint.

5. The stressing review of the newly designed buckets indicated values approaching the limit stress causing failure at some places, mainly when dynamic loads were added. Increasing material thickness would have caused surplus weight and fabricating difficulties in some cases. For this reason we endeavoured preferably to resolve this problem by the improvement of material qualities and selecting high-strength, fine-grained structural materials for critical components (cutting edges, fixing lugs, support skirts).

6. An accepted solution is to close the back by chains in the case of open buckets. In the case of the buckets designed by us the closing elements are made of rubber bands. This multiplies the service life compared to chains according to operating experiences.

The assembly drawings and detail drawings of the buckets for fabrication are prepared on the basis of the finalised 3D spatial model.

The complete development, design engineering and commissioning period encompassed more than seven years. Eleven new buckets and two new cutting teeth have been designed during this period for five different types of bucket wheel excavators. These are shown in Table 1.

The results achieved speak for themselves and – as expected – their direct effects were demonstrated in two fundamental areas: in the extended service life of the buckets and the reduced number of cutting teeth consumed. The extended service life of the buckets is clearly shown by the numbers in Table 2, indicating the average service life extension achieved in the two mines instead of the increases obtained separately for each excavator. The 4.2 times and 3 times extensions of the life cycles exceeded our initial expectations.

Table 1. **The complete development, design engineering and commissioning period**

Machine Model	**Item No.**	**Mining Plant**	**Type of fabricated bucket & cutting tooth**
SRs 1200	MT4 MT5	Visonta	Closed, open and loosening (cutting tooth No. 1)
SRs (H) 401	MT10 MT11 MT12	Bükkábrány	Closed & open (cutting tooth No. 2)
SRs 1400	MT6	Visonta	Closed, open and loosening (cutting tooth No. 1)
SRs 2000	MT7	Visonta	Closed & open (cutting tooth No. 1)
VABE 1300	MT9	Visonta Mine	Closed (cutting tooth No. 1)

Table 2. **The extended service life of the buckets**

	Bucket cycle time [days]		**Ratio**
	Old	New	
Visonta Mine	90	380	4,2
Bükkábrány Mine	180	540	3,0

The effect of the extended service life is well illustrated by the diagram shown in Figure 6. At Visonta Mine the specific costs per one million m^3 inert material (refuse) because of the expenses of fabrication started in 2004. The fabrication process executed over several years in a scheduled manner was completed in 2007 and the beneficial effect of the new buckets became sensible already in 2008.

The development project at Bükkábrány Mine was completed by 2005 and the first set of buckets was installed. The positive effect of this appeared already in 2006. Based on the good experiences, another set was fabricated in 2007. Because of the extended service life of these no additional set needed to be fabricated in 2008 and thus expenses of this type were reduced.

The extended service life of the buckets is only one of the beneficial effects. The adjustment of the cutters as required for the particular process reduces also the power demand of mining.

This is true for the power consumption of both the motor driving the bucket wheel and the motor swinging the boom. Taking only averages into account again, it can be stated that the current consumption of the bucket wheel motor decreased nearly by 30%, while that of the boom swinging motor dropped even more, by about 40%. These statements can be verified in Figures 7 and 8, showing the current consumption of the bucket wheel motor (bottom red curve) during a three-hours production period operating with the old (Figure 7) and the new (Figure 8) buckets, respectively.

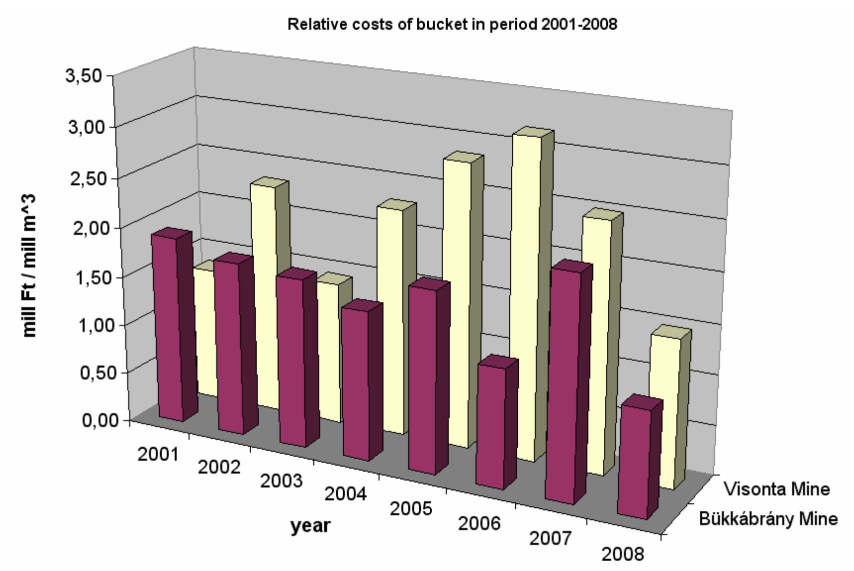

Fig. 6. The effect of the extended service life

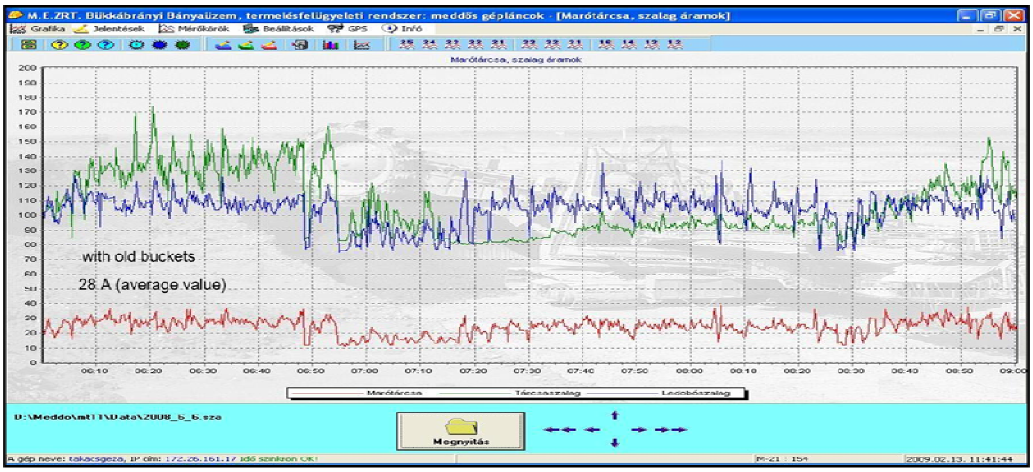

Fig. 7. Current consumption of the bucket wheel motor with old buckets

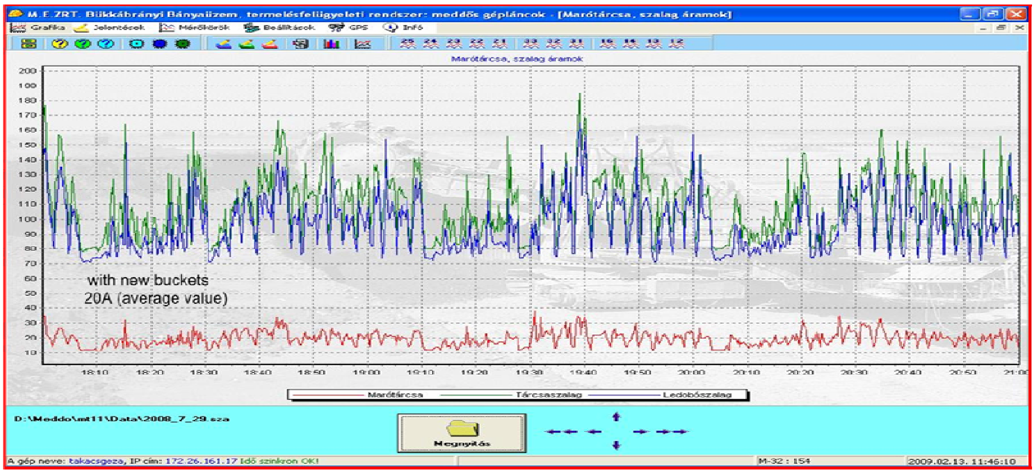

Fig. 8. Current consumption of the bucket wheel motor with new buckets

No additional explanation is necessary with regard to the reduction achieved in the power demand of mining operation. The operation of the drive motors at lower load levels has, however, also an additional benefit which entails material savings indirectly. Namely the overloading of both drive trains was a frequent occurrence previously. Overload protection intervened in most cases but failures involving breakage and causing more severe damages had occurred even in spite of this. The durations of machine outages due to unexpected failures entailing long periods of time for repairs and restoration were not negligible either. Following the installation of the new buckets machine outages due to shutdown because of overloading dropped back to the level acceptable as normal if the machine was operated with optimal technology.

The number of cutting teeth consumed had decreased dramatically. This is verified unequivocally by the comparison of the respective data recorded in years 2007 and 2008, respectively.

This reduction can be seen in Figure 9 showing the numbers of cutting teeth consumed during the stripping of one million m^3 refuse at the Bükkábrány Mine compared to the 2007 January quantity as the baseline.

The variation of associated costs is shown in Figure 10. As detectable, this is somewhat less than the rate of reduction seen in respect of quantities.

3. CONCLUSIONS

The new buckets, the new cutting tooth shape and the cutting tooth setting matched to the technological process comprise only one reason for the quantitative reduction. Another contributor is the process whereby the cutting edges of worn teeth are renewed by deposit welding with the use of a wear-resistant material as filler metal. The cost of renewal is less than the price of a new cutting tooth but – naturally - influences the variation of costs and, therefore, lower reduction can be seen in respect of costs on the average than that seen in the number of teeth consumed.

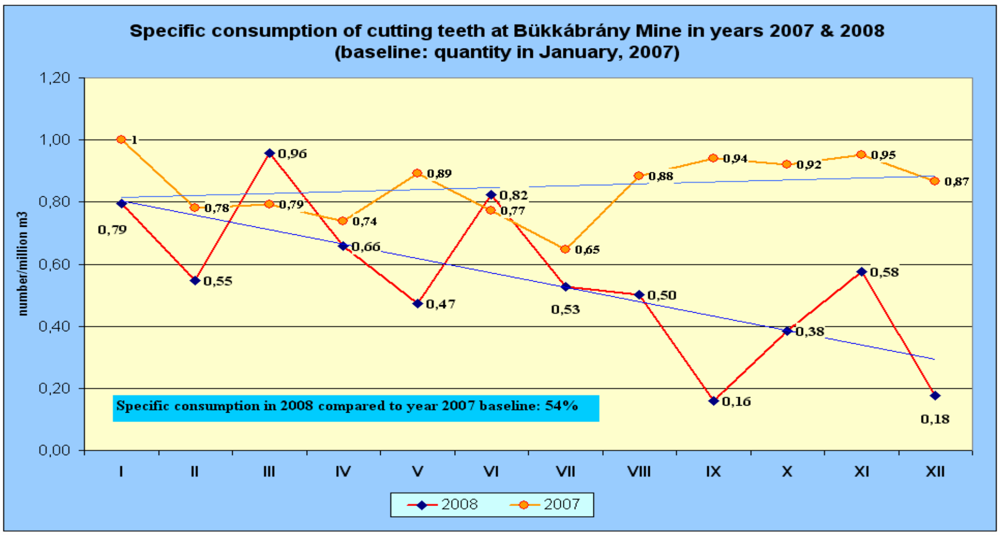

Fig. 9. Teethe consumption by M. Ton production

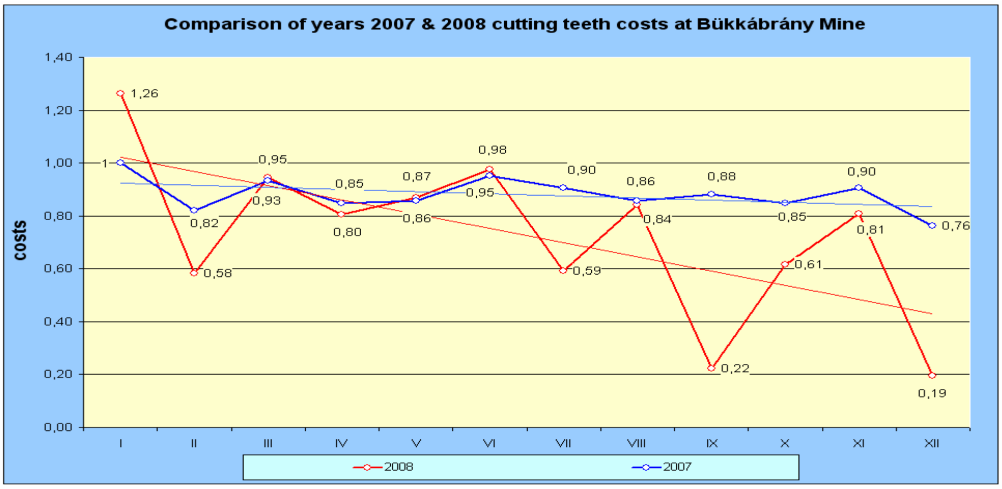

Fig. 10. Cost associated to teeth consumption

In regard of this topic presentations were held at several international conferences [2, 3, 4, 5, 6], technical article published [7] and a PhD paper [1] prepared about the research works.

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