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THE OPERATION OF BUCKET WHEEL EXCAVATORS WHEN ENCOUNTERING INCLUSIONS WITH EXCESSIVE MINING RESISTANCE

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Abstract

The Bucket Wheel Excavator (BWE) is the main piece of harvesting equipment used in open-pit lignite or brown coal open-pit mines worldwide. Despite the continuous increase in size, productivity and technical sophistication in recent decades, they have not adapted to the changes of operating environment. In this respect, the increasingly frequent occurrence of hard inclusions – in terms of layers, boulders and other forms – has revealed a consistent failure of BWE-s to meet this challenge. This paper, inspired by the research project RFCR-CT-2015-00003-BEWEXMIN „Bucket wheel excavators operating under difficult mining conditions including un-mineable inclusions and geological structures with excessive mining resistance" deals with preliminary considerations and results that aim to contribute to solving this problem.

***Keywords**: excavator, lignite, mining, excavatability, hard intrusions.*

1. Foreword

In open-pit mines, both for coal harvesting and overburden rock removal, the use of Bucket Wheel Excavators (BWEs) is a traditional technology used mainly in Europe.

In recent years, in many European open-pits, the geological and rock environment has become increasingly harsher.

The occurrence of hard to excavate intrusions is more frequent, which has led to an increase in downtime due to failures, increased energy consumption, reduced productivity and overall increased production cost. Existing BWEs are not suited to operation in such conditions.

The main cause of this situation is that the original BWEs were designed initially for the loading of bulk material.

Their conversion and adaptation to coal and overburden rock harvesting from mine faces dates back to early 1950's, when the design, manufacturing and operation norms where established in Germany and later in other countries [1, 2].

These machines were originally used in easily mineable rocks, mainly lignite and brown coal. Later, on the basis of experience, BWE's became widespread in other countries, such as Poland, Czech Republic and Romania.

There they were used in more varied mining environments, different from the original single rock-type environment.

The main problems were the increased values of cutting force and energy consumption - the importance of their variability - and lower seam thickness.

The original earlier design norms were shown to be inadequate mainly due to the dynamic loads specific to the new operating environment, in terms of equivalence coefficients of dynamic load replacement with a corresponding static load [3].

Even the newest Europe wide norm (DIN 22261), uses the former dynamic coefficients, even though experience has demonstrated that the real value of dynamic loads is much higher.

That is the reason that the main goal of the BEWEXMIN project is to develop proposals able to address the above mentioned negative effects in terms of prediction and avoidance.

This goal can be fulfilled by the adaptation of existing BWEs to the new conditions and extending the results toward the design of new ones [4–6].

On the other hand, it is desirable to develop a continuous monitoring system which can predict potential failure due to the occurrence of dangerous loads in critical parts of the load bearing structural elements, in accordance with the prevailing operating conditions.

The research has identified three directions: establishment of the requirements set to the load bearing structure of the BWE, bearing in mind the minimization of dynamic loads; based on this, the next directions would be the development of the monitoring system, and, finally, the continuous survey of the face, involving different geophysical devices, in order to detect real time possible occurrences of hard inclusions.

2. Short overview of performed research

In recent years the use of excavators on the faces of open-pit mines throughout Europe has clearly shown the increase in hard structures and interlayers that present excessive mining resistance.

These occurrences cause consistently serious problems during the operation of BWEs.

Such occurrences were seldom encountered before, and only observed in some open-pit mines, in various countries.

This is the reason for the lack of focus on studying this phenomenon and even when it was studied, the focus was mainly on unique problems at a specific mining location; the results were rarely published.

When searching the literature we find only references regarding the dynamic overload of the driving system of the bucket wheel and its avoidance. There is a general lack of mining environment description, making it difficult to correlate it with the observed failures.

The former research has focused on bucket design and drive overload protection using hydraulic safety clutches [7].

The results were not very encouraging, and the conclusion was that it is not possible to design and set-up a BWE in such way as to be universally applicable for any kind of mining environment in terms of safety, reliability and productivity.

The sparse boulder size related to the bucket's dimension has an important influence on the extent and severity of damage, because in the case of large bucket volume, greater than 4 m^3, the boulder can be extracted from the face and it produces damage to the on board conveyor flow.

If the boulder size exceeds that of the bucket, then the impact with teeth and bucket cutting edge produces high dynamic loads on the mining system and load bearing structure.

Because the BWEs used in Germany mainly utilize high volume buckets, the German specialists have focused their attention mainly on belt conveyor protection.

Even if the available sensors were well known and well developed, the results were in this case also inadequate in relation to the investment, mainly from point of view of data processing software. A detailed report on these issues can be found in [5].

The common weakness of previous research is the lack of any correlation between damages and mining environment: between cause and effect.

Another difficulty encountered is the optimal location and number of sensors to be implanted in such a way that the acquired data provide maximum information about the stress-strain state of the boom's elements and the processing itself.

Apart from these experimental approaches, we may consider also theoretical ones, i.e. such theoretical model developments that describe the effect of an external variable or impulse load on the load carrying structure and the bucket wheel.

Such a model of the time variation of an impulse load has been developed based on the collision between two elastic-plastic bodies. [6]

Seeking answers to the mentioned (as yet) unsolved problems, the team of Petroșani University, has developed a bucket wheel 3D CAD model (**Figure 1.**) with which, by simulation, we obtained its influence on the wheel axle torque. (**Figure 2.**)

Additionally, we developed a model of the boom and we studied the spectra of its vibrations, excited by the mentioned resultant variable load. (**Figure 3.**)

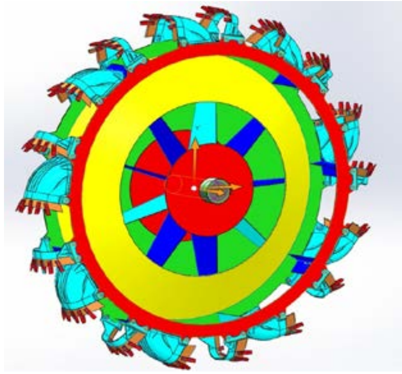

Figure 1. *3D model of the bucket wheel*

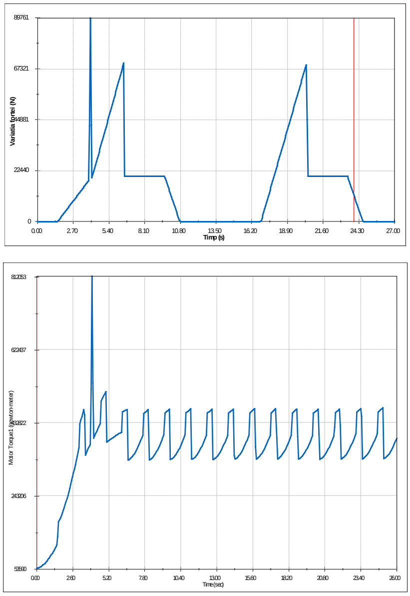

Figure 2. *The impulse load time variation (top) and the effect on the wheel axle torque (bottom)*

At the same time, we mounted strain gauges on different parts of the boom structure and on different bucket wheels to continuously measure data that were transmitted by wireless system to be recorded. (**Figure 4.**) Because the strain gauge's use is very problematic and unreliable, we also used accelerometers.

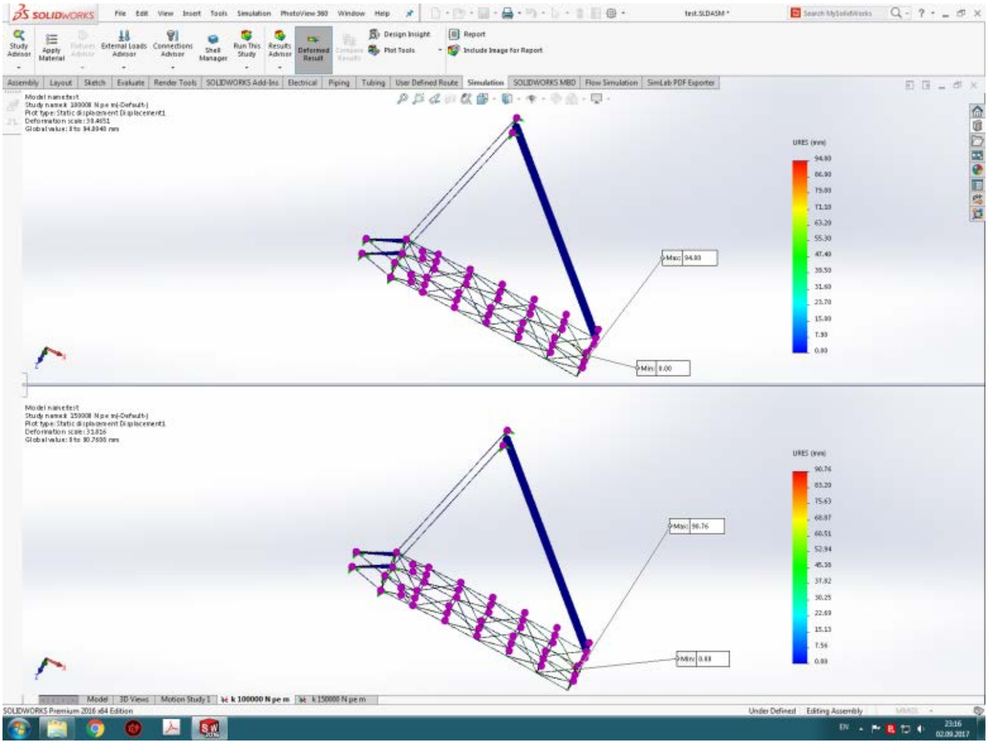

Figure 3. *Strain simulation of boom under dynamic load*

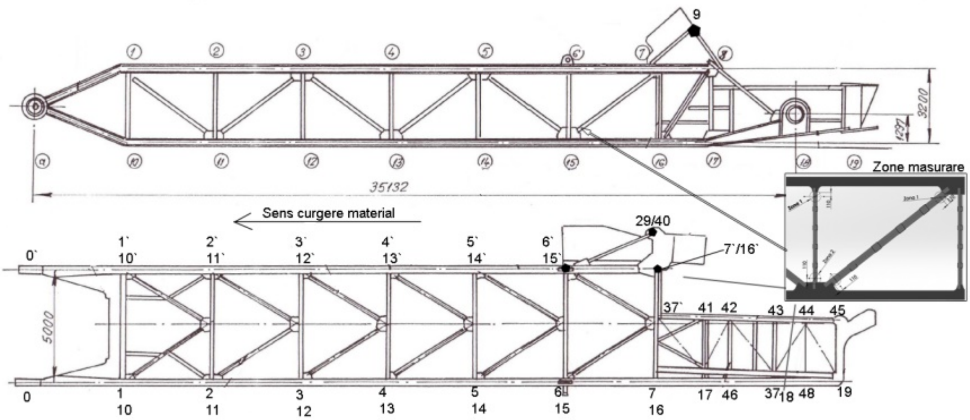

Figure 4. *Location of transducers mounted on BWE boom*

The correlated data processing is ongoing, but preliminary results show an acceptable concordance with theoretical results.

3. Results

The measurements performed so far have demonstrated that the load's signature has a vibration shape, is variable and consists of the superposition of two components.

One is the proper vibration of the BWE's structure masses including the bucket wheel, the other is the vibration due to the influence of the excavating forces and other dynamical excitations.

The two components have close frequency spectra, and it is difficult to discriminate from the general spectral picture the spectrum of vibration produced by cutting force variability. The solution to this problem is the second main goal. The third research direction is to make a connection between BWE operating parameters, the structure's dynamic characteristics and the properties of the excavated rock environment in order to assess the real stress-strength state at critical points.

As result of this issue it will be possible to realize an adaptation of existing BWE-s to operations involving rocks with hard to excavate intrusions, and on the other hand to provide norms and design methods towards the development of a new generation of BWE-s.

The envisaged monitoring system would be useful not only to predict and avoid failure due to sudden excessive loads, but to assess the degree of fatigue and thereby to establish the remaining lifetime of the load bearing structural elements.

7. Conclusion

The research performed so far in the above mentioned three directions has revealed the following: in the direction related to real time recognition of the occurrence of a boulder - in order to allow the avoidance of its collision with the bucket wheel - the partners have used many geophysical tools in real faces containing hard intrusions, or in “implanted|”, ones to find the deviation within different physical properties of the intrusions compared to that of the basic rock. In some cases, as in the sandstone inclusions at Huşnicioara openpit, the results were not satisfactory.

On the basis of the second research direction, which focuses on establishing the effect of a sudden increase of cutting force on the structural elements of the BWE (tooth, bucket, bucket wheel, on board belt conveyor, boom, drive system etc.), we propose structural and constructive modifications or operating procedures in order to prevent or avoid any possible failure.

Such solutions could involve a monitoring system which utilizes filtering software able to detect the unwanted change, and an expert system to assist the decision taken by the operator or the automatic steering system.

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