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The Design – in Faults as a Causes of the High Performance Machines Failures

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High capacities and key roles in the technological processes cause the extremely high financial losses in the case of high performance machines failures. This paper presents case studies of bucket wheel excavators, stackers and bucket chain reclaimers failures caused by design – in faults. Besides that, paper gives a redesign solutions which are developed by University of Belgrade – Faculty of Mechanical Engineering.

Keywords: High performance machines, design-in faults, redesign

0 INTRODUCTION

The high performance machines (HPM), such as bucket wheel excavators (BWE), Fig. 1, bucket chain excavators (BCE), Fig. 2, and bucket chain reclaimers (BCR), Fig. 3, are the backbones of the open pit coal mining and thermal plant mechanization systems. Their exploitation in harsh working conditions provides fertile ground for the occurrence of various types of failures [1-10]. In reference [11] it was stated that there are four main reasons for the collapse of high-capacity earthmoving and lifting/conveying machines:

- design faults, so-called ‘designing-in’ defects;
- manufacture faults causing the so-called ‘manufacturing-in’ defects;
- exploitation faults (by analogy, these causes can be named ‘operating-in’ defects);
- extreme environmental impacts – unusual occurrences (extreme storm, earthquake, fire); by analogy, these causes can be named ‘environment-in’ defects.

Common denominators to all failure of machines, particularly the HPM, are very high financial losses and serious risks to the worker’s safety and life [12]. When it comes to BWE, BCE and BCR, financial losses caused by production delays due to the principal machine failure in a surface mining system, i.e. coal storage and shipment, often significantly exceed the financial losses caused by direct material damage. The size of the negative economic effects caused by failures is remarkably revealed in the fact that the total cost of failure in USA and Europe is of order of 4% of GNP [13].

Researches presented in this paper are focused on HPM vital parts damages caused by design – in folts and their redesign.

Fig. 1. *Bucket wheel excavator SRs 1201*

Fig. 2. *Bucket chain excavator ERs 1000*

Fig. 3. *Bucket chain reclaimer Metalna 300*

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1 FAILURE AND REDESIGN OF THE BWE BUCKET AND BUCKET WHEEL

BWE SRs 1201.24/4, Fig. 4, was put in exploitation in 2003. During exploitation some drawbacks in buckets' leaning zones were observed, as follows:

- Damages of the pins and bushing of the bucket eyes, Fig. 4;
- Damages and plastic deformations of the bucket wheel front supporting eyes, Fig. 5;
- Plastic deformations of the bucket wheel rear supporting eyes, Fig. 6;
- Bucket "opening" in the rear support zone, Fig. 6.

In order to eliminate the presented drawbacks, it was necessary to redesign the bucket supporting zones, Figs. 7-10.

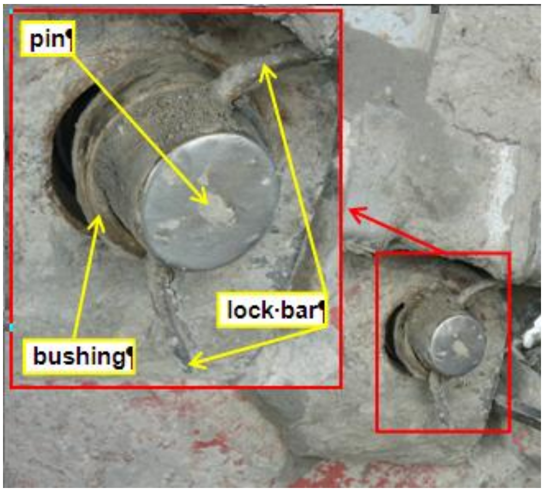


Fig. 4. *Pushed out bushing of the front bucket eye*

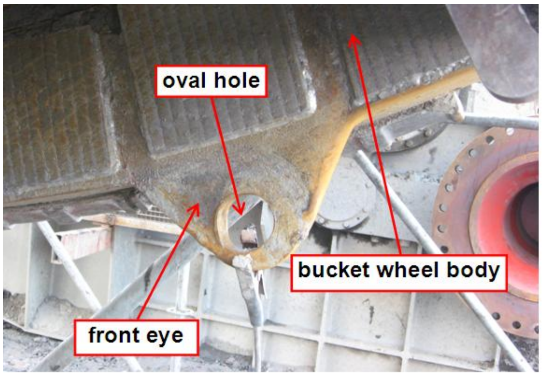


Fig. 5. *Plastic deformations of the front bucket wheel eye*

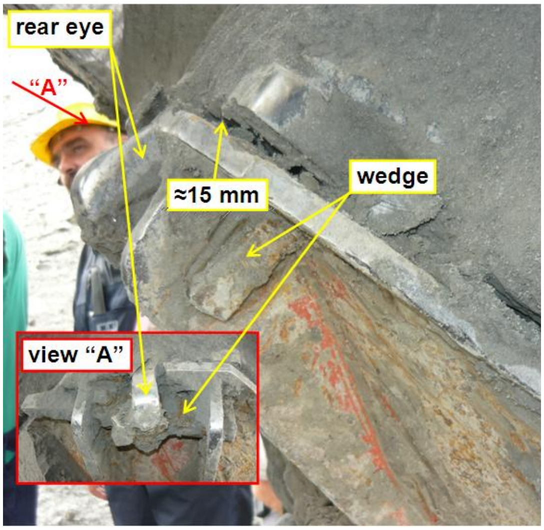


Fig. 6. *Plastic deformations of the rear support eye and bucket "opening" in the rear support zone*

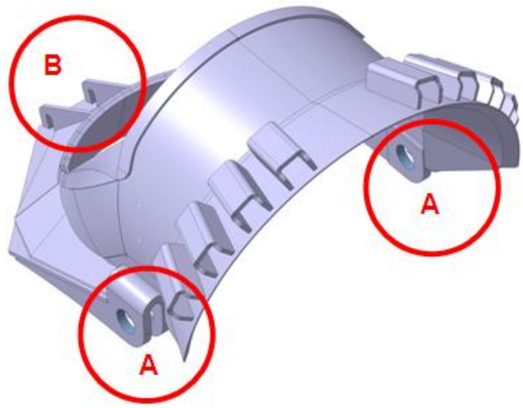


Fig. 7. *3D model of the original bucket: zones of redesign*

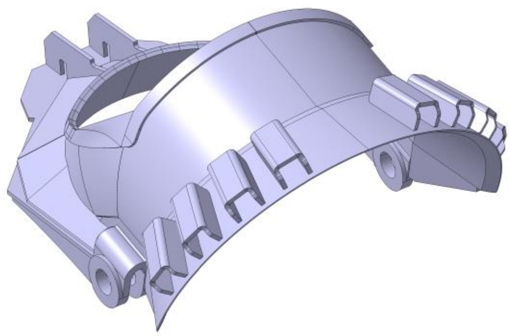


Fig. 8. *Redesigned bucket*

Fig. 9. *Welding of the redesigned front support eye*

Fig. 10. *Welding of the redesigned rear support eye*

Obviously, redesign of the bucket cause the change of its weight. In considered case, reconstruction of one bucket with its supports on bucket wheell incerease weigth for $\Delta G_B = 43.2$ daN. Having in mind that total number of bucket is $n_B = 14$, total weight increase can be calculated as

$$\Delta G = n_B \Delta G_B = 14 \times 43.2 = 604.8 \text{ daN} \qquad (1)$$

Fig. 11.

Center of gravity location, Fig. 11, is calculated by using Varignon's theorem

$$x^*_{GN} = \frac{G_N x_{GN} + \Delta G_{PU} x_{\Delta GPU} + \Delta G x_{\Delta G}}{G_N + \Delta G_{PU} + \Delta G} =$$

$$= \frac{7705.3 \times 0.011 + 450 \times 7.95 - 6.1 \times 33.083}{7705.3 + 450 + 6.1} = \qquad (2)$$

$$= 0.424 m$$

So, the increase of the redesigned buckets' weight cause the change of the center of gravity location. For horizontal position of the bucket wheel boom shifting of the center of gravity is

$$x_{GN} - x^*_{GN} = 0.449 - 0.424 = 0.025 \text{ m} \qquad (1)$$

which is allowable.

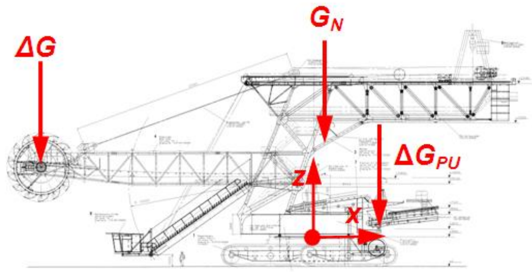


Fig. 11. *Scheme for calculation of the center of gravity location after buckets redesign*
(superstructure weight G_S=7705.3 kN, *x_{GN}=0.449* m; *part of conveyor weight ΔG_C=450* kN, *$x_{\Delta GC}$=7.95* m*; total weight increase ΔG=6.1 kN, $x_{\Delta G}$ = - 33.083* m*)*

Buckets and bucket wheel were redesigned in october 2009. Validation of the applied solution is done by expert's evaluation of the machine behaviour during exploitation as well as by visual inspection of the critical zones.

2 FAILURE AND REDESIGN OF THE BCE STRUCTURE

BCE ERs 1000, Fig. 2, is in use in open pit mine ''Kolubara''. During perennial exploitation cracks were observed on the column heads of supporting truss of the counterweight boom (CWB) Fig. 12. These cracks have been weld repaired, but after some time they appear again, being longer and longer.

The cracks propagation could lead to catarstrophic consequences – collapse of the machine, such as described in [1,6]. The goals of the study presented in the paper were to:

- Diagnose the cause of cracks occurrence;
- Define the reconstruction design of the truss columns, Fig. 13;
- Verify the reconstructed structure by numerical-experimental analysis, Figs. 14 and 15.

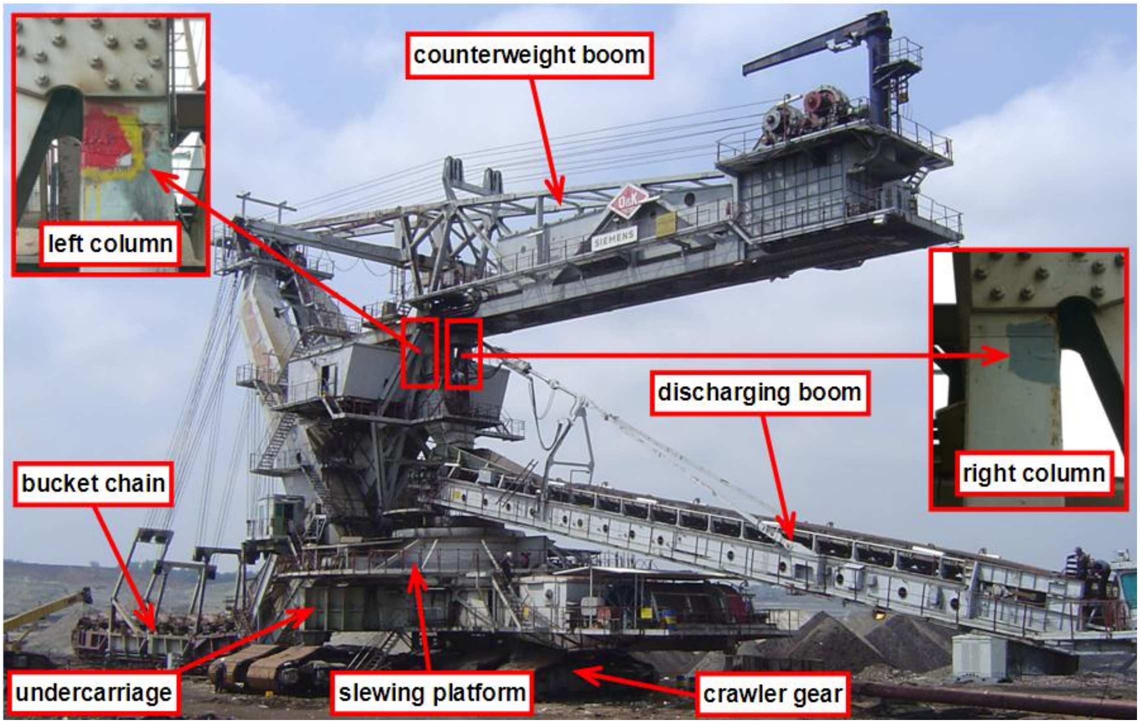
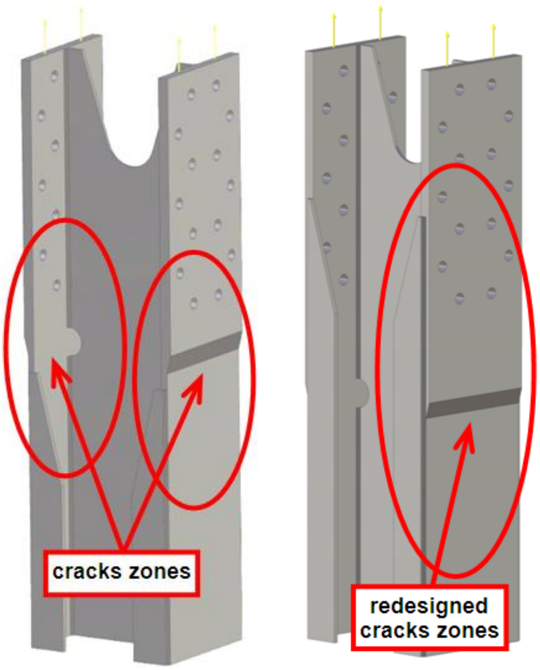


Fig. 12. *Cracks on the CWB supporting truss columns*



(a) (b)

Fig. 13. *3D models of the original (a) and redesigned (b) column head*


Fig. 14. *Set up and connection of strain gauges*

Based on the results of a comparative numerical analysis of the original and redesigned structure of the column head, the authors conceived a reconstruction solution that meets the following requirements:

- a significantly lower stress state (≈ 3 times) in crtitical zones, where peaks do not exceed allowable values;
- a very short time for manufacturing of the redesigned columns' parts;
- the possibility of performing reconstruction in field conditions, without dismantling the BCE superstructure components.

Experimental analysis of the stress state of the redesigned column heads was carried out in June 2010, during BCE testing immediately after the finished reconstruction.

Visual inspection performed in April 2011 proved that there are no defects in the structure of the redesigned column heads. The validity of the presented reconstruction, besides experimental investigations, unquestionably confirms failureless exploitation, where BWE excavated more than $1.4x10^6$ t of coal after the reconstruction.

3 FAILURE AND REDESIGN OF THE BCR STRUCTURE

Design-in faults led to buckling of the rigid portal bracing, Fig. 15, and collapse of the machine structure.

Fig. 15. *Detail of rigid leg*

After the reconstruction of the truss substructure in critical zone, stress levels became considerably lower. Besides that, increasing of bracing and horizontal truss stiffness, Figs. 16 and 17, as well as increasing of torsional stiffness of portal legs, Fig. 18, led to displacements decreasing [14-17].

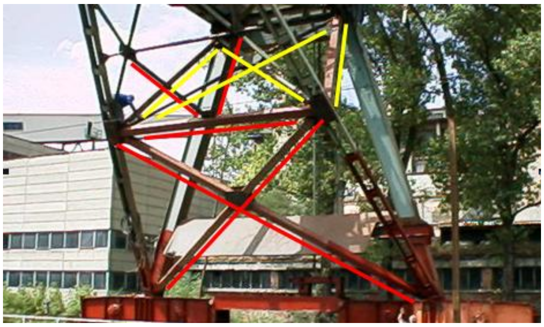


Fig. 16. *Redesigned bracing truss*

Exploitation expirience after the structure reconstruction confirmed the validity of applied redesign solutions as well as calculation procedure.

Fig. 16. *Redesigned bracing truss*

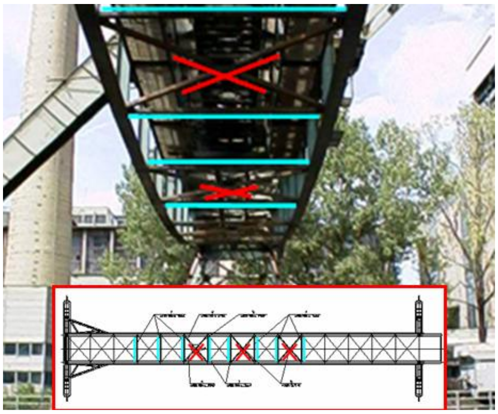


Fig. 17. *Redesigned horizontal truss*

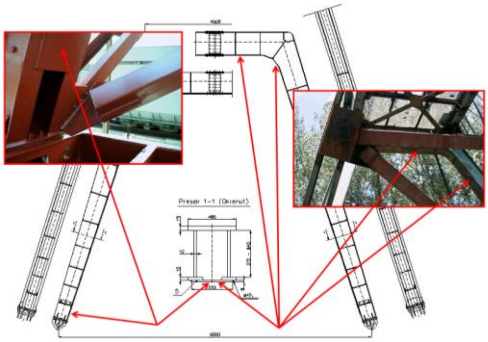


Fig. 18. *Closing of the portal cross-section*

4 CONCLUSION

The fundamental problems of any machine subsystem's redesign, therefore the BWE, BCE and BCR substructures as well, are caused by the restriction ensuing from installation conditions and functionality. Special difficulties result from the relative complexity of the considered structures, as well as the nature of external operational loads. The mentioned loads are of an outsandingly dynamic and stochastic nature, so that calculated loads are assumptions, in the full sense of the word. And exactly because of that, comparative stress analysis presents an indispensable and inevitable part of the redesign process.

Finally, the validity of the presented reconstructions, besides expert evaluations and experimental investigations, unquestionably confirms failureless exploitation.

Acknowledgement

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