DYNAMIC BEHAVIOR AND STRESS FIELD OF EXCAVATOR SchRs740 EXTENDED BOOM

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Abstract

Bucket wheel boom represents the most loaded and the most responsible part of the excavator structure, participating only with 6 to 13% in the entire excavator weight. Its length is selected depending on the technological requirements of mining deposit, and it has to be adjusted with the designed possibilities of the excavator. At the request of mining technology that is in compliance with the soil-mechanical properties of deposit, conditions are created for the selection of excavator optimal parameters, and therefore to determine the required length of the boom. In this paper, analysis of dynamic and static behavior of boom extended from 1 to 10m with a step 1m was done. The maximum possible extension is defined as the aspect of structural performance, dynamic behavior and stress field. Finite Element Method (FEM) is used to obtain natural frequencies, displacements and stresses.

Keywords: bucket wheel boom, increasing the boom length, dynamics, stress, FEM

1. Introduction

One of the basic prerequisites for the efficient operation of the excavator is the adjustment of structures, primarily the bucket wheel boom of the excavator, and working conditions. It involves the use of such structures that will best suit the specific conditions of the working environment, but also that structural loadings are within acceptable limits, in order to stay long in exploitation. Bucket wheel boom is the most exposed to a wide range of both static as well as dynamic loads. In order to determine the behavior of the bucket wheel excavator SchRs740 boom structure, firstly the static and dynamic loads are analyzed. Then, development of the model was performed, and ultimately finite element analysis. FEM will determine the level of membrane, bending and equivalent stresses and deformations, as well as, values of free frequencies of the structure. Based on theoretical considerations on the one hand, as well as relevant diagnostic indicators of certain design solutions on the other side (concentration of stresses, deformation energy, distribution of potential and kinetic energy on the main oscillating modes), can be marked weak points and found design solutions depending on technological requirement, that best suit the specific conditions of the working environment on opencast mines. In this case technological requirement is increasing the bucket wheel boom length of the excavator SchRs740.

Analysis of the dynamic behavior and condition of the BWE elements using the finite element method, are shown in many papers [1, 2, 7, 8, 9, 10]. In [3, 7, 8] experimental results are compared with appropriate theoretical basis. Modelling of the BWE SchRs740 bucket wheel boom in this paper was carried out because of the technological requirement to increase the length of the boom.

2. FEM model of the BWE SchRs740 Bucket Wheel Boom

The basic procedure in diagnostics of the structure is its computer modelling and the corresponding static, dynamic and thermal calculation using a numerical method FEM. The FEM is a universal method that can help in solving various problems both related to the behavior of steel structures and in mining and metallurgical industry.

The software package KOMIPS is developed at the Faculty of Mechanical Engineering in Belgrade [5], which enable modelling and calculation of complex structures and problems.

The most sensitive, the most important and most difficult manageable procedure of the calculation process is structure modelling. One of the most important factors is modelling represents experience and user's intuitive. Modelling, in fact, is mapping the physical to computational model according to technical documentation, selection of the type or types of finite elements and defining of physical model discretization by finite elements, nodal points, boundary conditions and loads.

For modelling of the excavator SchRs740 boom, software package KOMIPS is used. Taking into account the appearance of the excavator SchRs740 boom structure, and to all the above mentioned in relation to the finite element method, the structure was modelled by beam elements (elements of short beam).

Beside the truss steel structure of the boom, all the other elements that affect the rigidity of boom structure were taken into account. That means that model includes following elements: transverse stiffeners, shafts of the wheel and return drum, torque leverage of both gearboxes, parts of the belt structure and stays. Finally, the boom model consists of 290 beam elements and is shown in Figure 1.

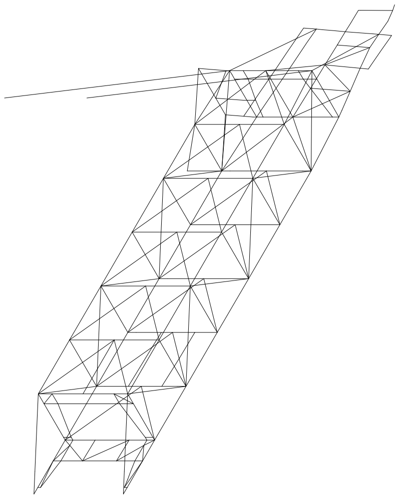


Figure 1 Model of the boom, beam elements

3. Calculation of the Free Frequencies of BWE SchRs740 Bucket Wheel Boom Oscillations

The excavator boom for which is made dynamic analysis is shown in Figure 2.

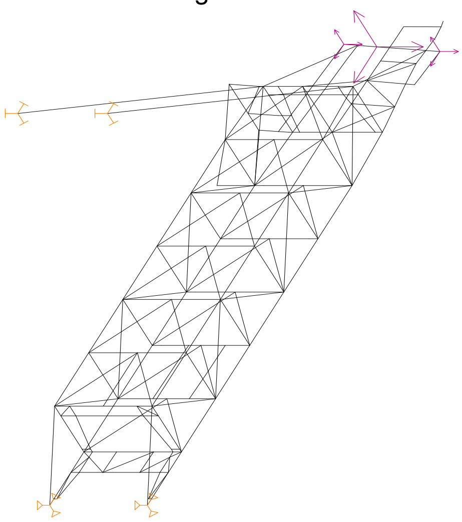
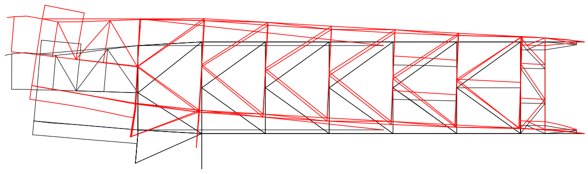


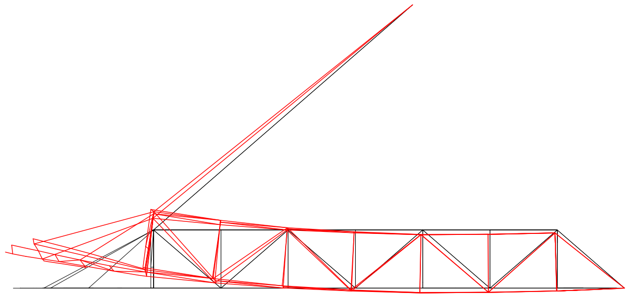
Figure 2 Dynamic model of excavator boom, boundary conditions and loads

Boom is located in an elastic environment, that means model included the stays and the yoke.In points that are bearings of the boom is prevented translation in all three directions. In points of connection stays and yoke all the moves (translations and rotations) are prevented. In points that represent attachments of the boom and the stays the rotation in the joint around the axis parallel to the bearing axis is allowed. Masses of the gearboxes (by around 8t) and the wheel (about 20t) are taken into account as a concentrated mass in dynamic calculations, as can be seen (Fig. 2). The actual length of the basic boom is 34.93 m, and its weight is 64.869 t.

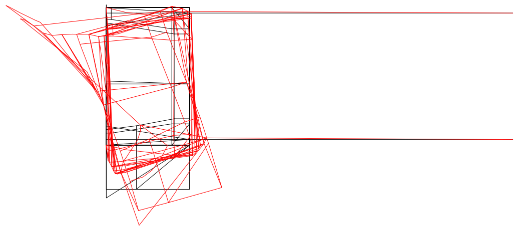
The first three oscillating modes and corresponding free frequencies are shown in Fig. 3.



Bending in the horizontal plane, the first mode, 1.44 Hz



Bending in the vertical plane, the second mode, 3.98Hz



Torsion, the third mode, 5.47Hz

Figure 3 First three oscillating modes, the original boom structure

4. Extension of the Bucket Wheel Boom

Boom has been extended in a step of 1 m, without changing the cross-sections of beams, height and width of the truss. From 1 to 5 m beam was extended, so that the extension was uniformly distributed on five segments in the middle, which are almost structurally identical (there are small differences, i.e. reinforcement in the lower band of the first and in the upper band of the last segment). Total extension of 6m distributed to these five segments means extending of one segment for 29.56% of the length. That is negative in many aspects of the structure stiffness. For this reason, the total extension of the boom for 6 m involves a new segment and the entire extension now is distributed to six (5 + 1) segments. Numerically it is checked that by the addition of this segment are retained the dynamic characteristics of the structure, regardless of the weight increase (about 1 ton). That confirms that such conceptual solution for extension from 6 m has grater stiffness compared to a solution where the extension of 6 m is distributed to five segments. That is why the further extensions are done by retaining the inserted segment, and the total length is now distributed to six segments.

During this calculation the original stays of the existing boom were used for each additional extended boom. In addition, stays position was dictated by the geometry (length) of the yoke and stays, which means that it is not the same for the original and the extended booms (Fig. 4)

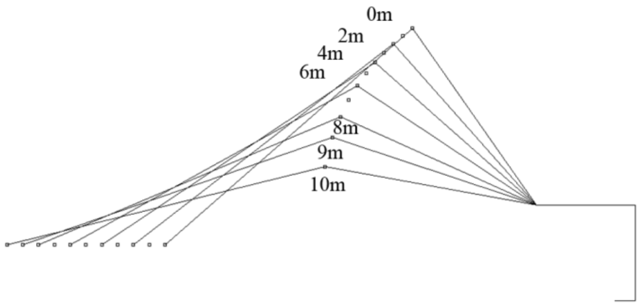


Figure 4 Geometry changes of the yoke-stays by the boom extension

Therefore, with extension of boom the position of stays is changed, i.e. the angle made by boom structure and stays is smaller. In addition, 10 m represents the end border up to which can be used existing stays and yoke, because for the each subsequent extension the two circles representing the yoke and stays would not intersect at all.

However, from Fig. 4 it can be seen that at 10 m extension geometry yoke-stays is disrupted (the angle between the stays and boom is very small, and between the yoke and stays is very large).

These variations necessarily require a change in the geometry of the mechanism for the lifting /lowering of the bucket wheel boom, which implies the necessity of elements redesigning (pulleys, ropes, rope drums, drive).

In addition, for the extension of 10 m the total weight of the boom was increased by about 7.6t, which would have consequences on the supporting structure of the whole excavator. However, this is not the subject of this article, consideration here is limited only to the boom structure. Results of dynamic calculation are presented in Table 1 for the boom extended from 1 to (fictitious) 10 m.

Table 1. Results of dynamic calculation

Boom length[m] + extension [m]	Total boom weight [t]	Free frequency [Hz]		
		Bending, horizontal plane	Bending, vertical plane	Torsion
35+0	64.869	1.44	3.98	5.47
35+1	65.532	1.39	3.89	5.39
35+2	66.198	1.34	3.80	5.29
35+3	66.867	1.29	3.69	5.16
35+4	67.538	1.26	3.56	4.99
35+5	68.211	1.22	3.41	4.79
35+6	69.862	1.19	3.22	4.60
35+7	70.526	1.16	3.00	4.31
35+8	71.191	1.13	2.72	3.98
35+9	71.855	1.11	2.35	3.59
35+10	72.524	1.07	1.83	3.10

5. Stress and Deformation Field in the BWE SchRs740 Boom under the Workload

Numerical calculation of structure loaded by the reference workload (static analysis) and its own beams weight (dead load)is done. The boundary conditions are the same as for the dynamic calculation. As fictional workload is concerned, the overall digging force of 25 t was distributed in real terms in the three forces (vertical 1, lateral 0.3 and radial 0.15). It was not taken into account the weight of gearboxes and bucket wheel, as well as other loads (weights) to which a bucket well boom is exposed in real working conditions. That's why it was obtained the stress levels significantly lower than expected (by calculation is obtained a stress of about 40 MPa). The aim of this analysis was to show the trend of changes in the stress by increasing the boom length. Load is entered on the bucket wheel perimeter (concentrated force at one point), simulated by rigid beam. Figure 5 provides the appearance of elastic structure outline exposed to fictional workload for the existing boom.

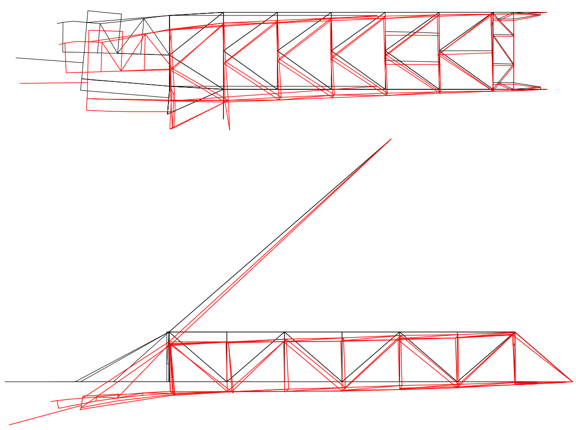


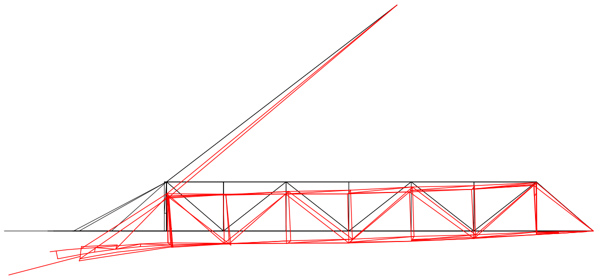
Figure 5 Displacement outline, original boom

The change of stress in an element of the lower band of the first segment (near boom bearing), which indicates respectively a high level of stress in the case of basic and extended booms, is given in Table 2.

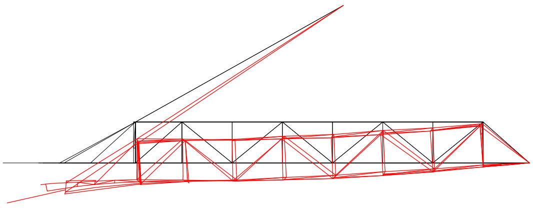
Table 2 Change of stress in one element

Boom extension [m]	Stress [MPa] (fictional)	Stress increasing [%]
0	39.97	0
1	41.44	3.68
2	43.31	8.36
3	45.82	14.64
4	48.29	20.82
5	51.37	28.52
6	54.16	35.50
7	57.89	44.83
8	64.09	60.34
9	71.25	78.26
10	89.38	123.62

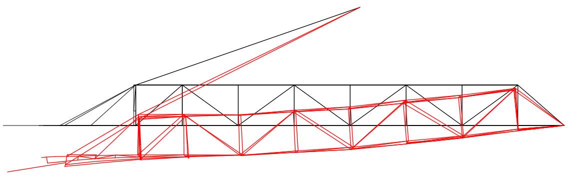
It may be noted that by the boom extension of 6 m stress in this element is increased by more than 30% of the stress value in the same element of the existing excavator boom. In addition, it can also be noted that a large extensions of the boom (8, 9 and 10 m) are not technically acceptable. Displacement outline for the boom extended for 2, 6 and 9 m can be seen in Figure 6.



Boom extended for 2 m



Boom extended for 6 m



Boom extended for 9 m

Figure 6 Change of the displacement outline by the change in length, static calculation

The excavator boom acts as a beam with overhang. Workload is a force at the end of overhang, and the whole beam is continuously loaded by its own weight (dead load). It can be seen that for a small extensions the boom remains rigid, while for the big it becomes elastic. Table 3 shows the total deflection for all steps of the boom extension.

Table 3 Deflection change by the boom extension

Boom extension [m]	Deflection [mm] (fictional)	Deflection increasing [%]
0	30.43	0
1	31.39	3.15
2	32.39	6.44
3	33.76	10.94
4	35.29	15.97
5	37.27	22.48
6	38.92	27.90
7	41.91	37.72
8	47.14	54.91
9	55.60	82.71
10	81.26	167.04

6. Conclusion

Bucket-wheel excavators are complex systems with a large number of functionally important elements. In order to find out a valid criterion for defining the structure elements and also for the assessment of technical conditions, it is necessary extensive diagnostic tests. The first step is modelling the structure with derived optimizations.

Bucket wheel boom can be classified as a very responsible construction, because failures of certain elements on the bucket wheel boom can lead to a breakdown condition of the BWE.

Conclusions and recommendations based on the all foregoing is that, without changing of the truss structure, the maximum boom extension is 5m.

7. Acknowledgement

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8. References

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