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Study of functional performance improvements for cutting teeth mounted on bucket wheel excavators operating in Oltenia coal basin – Romania

The values of the resultant forces acting on the cutting teeth of BWEs can either be calculated or determined using experimental methods. Based on this, the position and parameters of the working organs during the cutting process are designed and built. The stresses and deformations of the teeth during the cutting process are influenced by their positioning on the excavator bucket, which is determined by the fitting mode of the teeth. In this paper, the stresses and deformations in the case of an existing tooth holder are analysed and a new type of tooth holder is proposed, using SolidWorks® software for this analysis.

Key words: *deformation, stress, rotor, cutting tooth, BWE, tooth holder, FEM, FEA*

1. INTRODUCTION

At the request of the Oltenia Energy Complex, we conducted a comparative study regarding the forces and deformations on an existing and new tooth holder that was implemented in the Oltenia open pit mines using finite element analysis. FEA is a numerical analysis method used to solve problems in various fields of engineering. In mechanical engineering, it is widely used to solve structural, vibrational, and thermal problems.

2. INFLUENCE OF LOCATION OF CUTINGTEETH ON BUCKET ON GEOMETRIC AND STRENGTH PARAMETERS

The positioning and orientation of the cutting teeth on the edge of the bucket influences their geometry and strength [1, 2]. Overall, the magnitude and direction of the velocity vector are determined by the variation of swivel velocity v_p (the range of variation being determined by the type of swivelling mechanism). Swivelling velocity v_p is composed of cutting speed v_t, which is considered constant [3].

To study the influence of teeth placement on the geometric and strength parameters, we defined the following planes:

1. The setting plane – defined by the cutting edge of the tooth and its positioning face (Fig. 1).
2. The rake plane – defined by the cutting edge of the tooth and its rake face (Fig. 1).
3. The symmetry – perpendicular to the cutting edge and through the middle of the cutting edge (Fig. 1).
4. The cutting plane – defined by the tooth's cutting edge and the resultant vector of velocity (Fig. 2).
5. The velocity plane – perpendicular to the cutting plane; contains the resultant vector of velocity (Fig. 2).

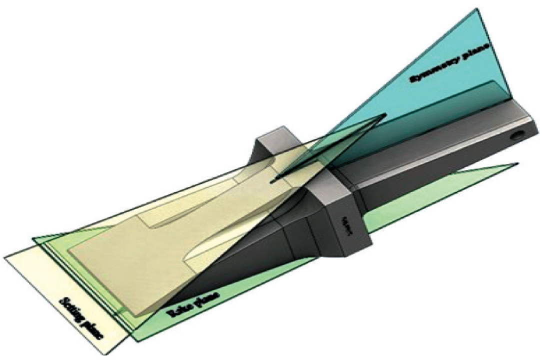

Fig. 1. Planes of setting, rake, and symmetry

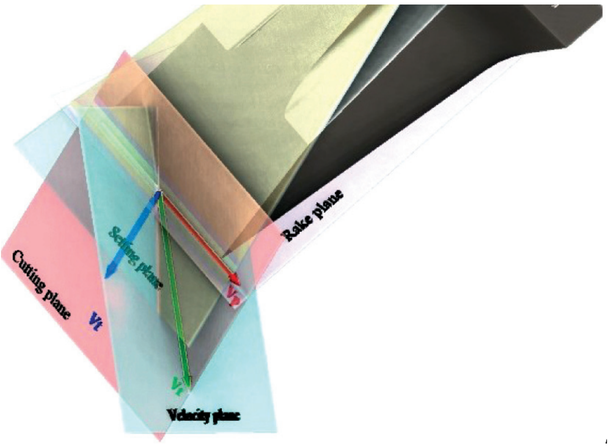

Fig. 2. Swivelling, cutting, and resultant velocities; cutting and velocity planes

If the resultant vector of velocity is perpendicular to the cutting edge of the tooth, then the velocity plane and symmetry plane overlap.

In Figure 2, the setting angle is measured between the setting plane and the cutting plane, and the angle of sharpening is measured between the cutting plane and the rake plane. Here, we noted the swivelling velocity as v_p, the cutting speed as v_t, and the resultant speed as v_r.

The angle between the line resulting from the intersection of the cutting plane with the symmetry plane and the resultant velocity vector designates the angle of the tooth positioning on the cutting edge of the bucket. Placing the tooth on the cutting edge is done through its holder [4].

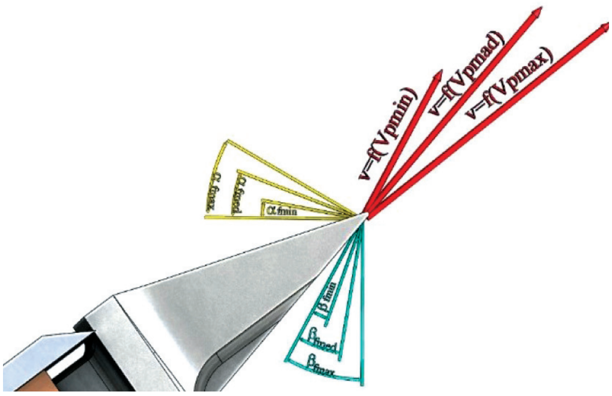

Fig. 3. Characteristic angles in operation

In operation, the characteristic angles (Fig. 3) are as follows:

- the set angle of operation β_f, which is the angle between the resultant velocity direction and the intersection line between the set plane and the velocity plane;
- the cutting angle in operation, which is the angle between the resultant velocity, direction, and intersection line between the rake plane and the velocity plane;
- the sharpening angle in operation, which is the angle between the intersection line of the set planes and the velocity plane, respectively, and the intersection line between the clearance plane and the velocity plane;
- the raking angle in operation α_f is complementary to set angle β_f.

3. DETERMINATION OF STRESSES AND DE FORMATIONS FOR CHISEL-TYPE CUTTING TEETH USING OLD TOOTH HOLDER

In past research from the University of Petro?ani conducted for the Oltenia Power Complex, three types of cutting teeth for BWEs were proposed. Figure 4 shows the construction of such a tooth, and Figure 5 shows the type dimensional differences between the three types of teeth [5, 6].

Fig. 4. Cutting tooth chosen for analysis

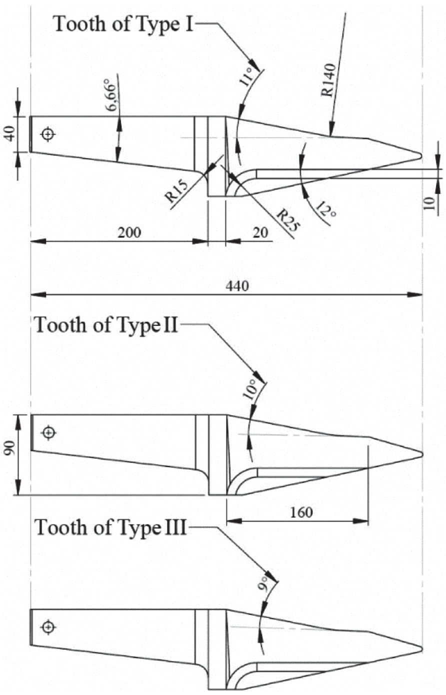

Fig. 5. Type dimensions of the proposed cutting tooth

The dimensions correspond to the three distinct categories of the excavated material, each having its specific cutting resistance:

Overburden rocks that are easily dislocated, having a low specific cutting resistance (A = 200 – 450 N/cm);

Overburden rocks and lignite with a medium specific cutting resistance (A = 450 – 800 N/cm);

Lignite having a higher specific cutting resistance (A = 800 – 1200 N/cm).

The stresses on the cutting-tooth are as follows: F_x = 60 kN; F_y = 18 kN; and F_z = 10 kN.

In relation to tooth surfaces, we will have the following component forces [7]:

$$F_{y1} = F_x \cos\alpha - F_y \cos\gamma = 25.857 \cdot 10^3\ \mathrm{N} \qquad (1)$$

$$F_{x1} = F_x \sin\alpha - F_y \sin\gamma = 36.198 \cdot 10^3\ \mathrm{N} \qquad (2)$$

$$F_{z1} = 10 \cdot 10^3\ \mathrm{N} \qquad (3)$$

Figure 6 shows the deformation, and Figure 7 shows the von Mises stress resulting from the FEA on Type I when the tooth is mounted with the old tooth holder.

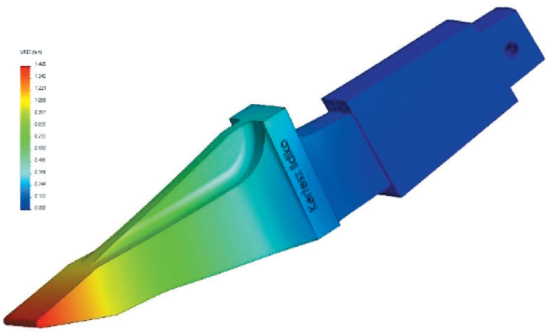

Fig. 6. Type I cutting-tooth deformation, when mounted with the old tooth holder

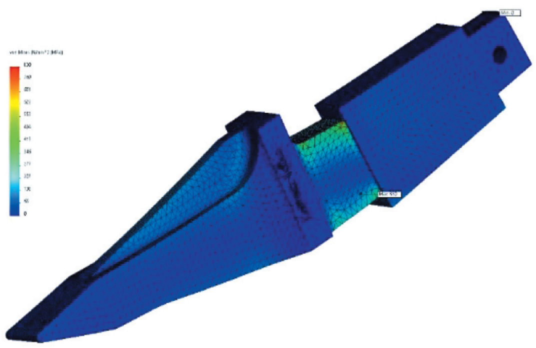

Fig. 7. Type I cutting tooth von Mises stress when mounted with old tooth holder

One can observe that the maximum deformation occurs in the area of the tip of the tooth, and the most stressed points of the tooth structure are those corresponding to its tail (between the tooth-support and the shoulder of the tooth).

4. PROPOSED SOLUTION TO REDUCE STRESSES ACTING ON CUTTING TOOTH

As shown in the previous paragraph, the maximum stress points are located where the section of the tooth-holder assembly presents vaulting. In the present case, it is the area of switching from the tooth-holder section to the actual tooth section. Next, we propose and analyse a type of tooth holder that will better encompass the tooth's tail. Figures 8 and 9 show the details of this new version of tooth holder.

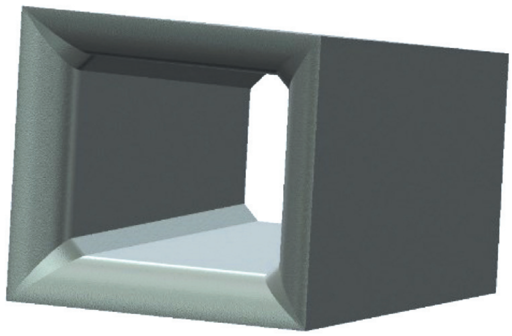

Fig. 8. Proposed holder for fitting cutting tooth to bucket

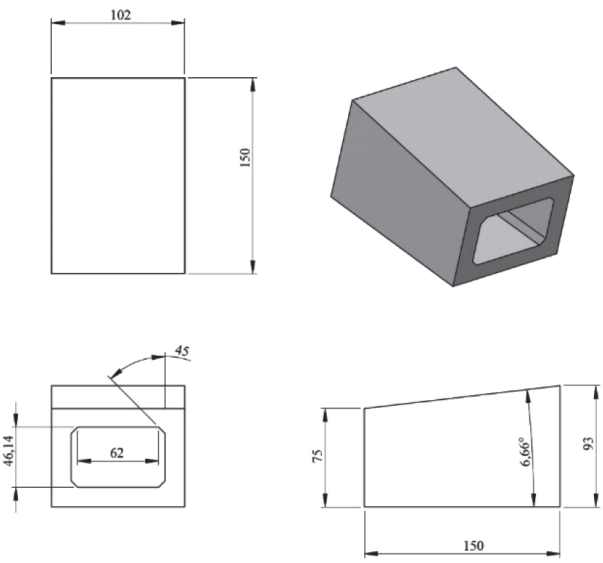

Fig. 9. Dimensions and geometry of proposed new tooth support

5. DETERMINATION OF STRESSES AND DEFORMATION FOR CHISEL-TYPE CUTTING TOOTH USING NEW TOOTH HOLDER

By imposing the stresses from Paragraph 2, we determined the deformations and stresses of the three type dimensions of the tooth proposed for analysis when it is mounted on the buckets with the new tooth holder proposed in Paragraph 3 [8, 9].

Figures 10, 12, and 14 show the deformations, and Figures 11, 13, and 15 show the von Mises stresses corresponding to the three types. The results obtained using the FEA for these tooth-type dimensions are summarized in Table 1.

The results obtained after the FEA of the three types of teeth are summarized in Table 1.

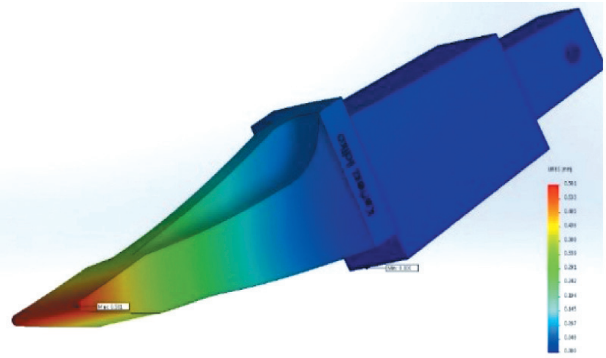

Fig. 10. Type I tooth deformation when mounted with new proposed tooth holder

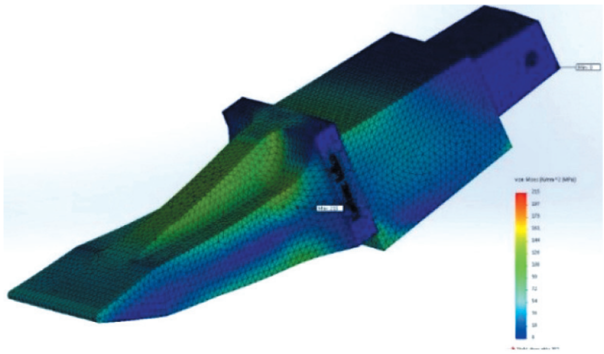

Fig. 13. Type II tooth von Misses stress when mounted with new proposed tooth holder

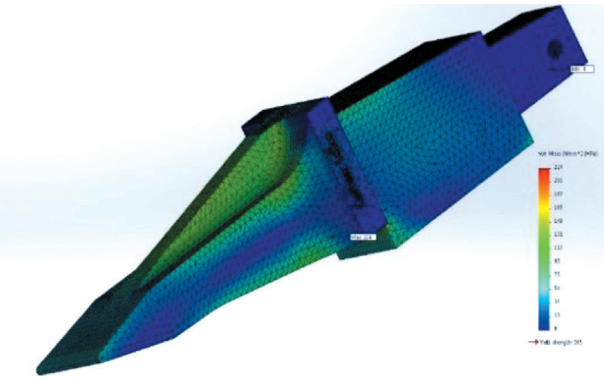

Fig. 11. Type I tooth von Misses stress when mounted with new proposed tooth holder

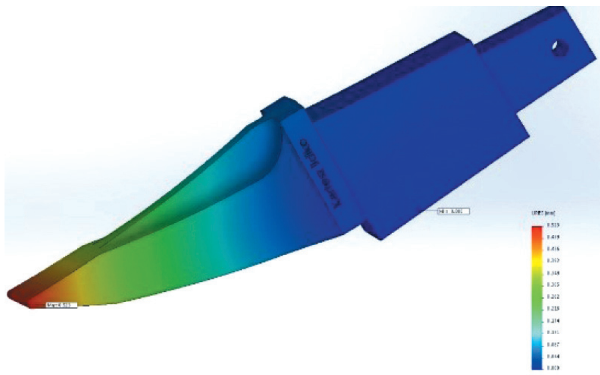

Fig. 14. Type III tooth deformation when mounted with new proposed tooth holder

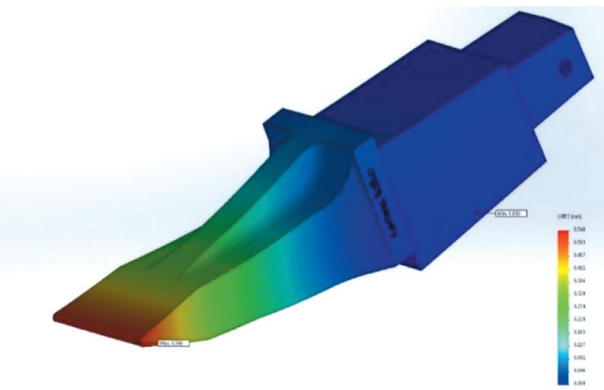

Fig. 12. Type II tooth deformation when mounted with new proposed tooth holder

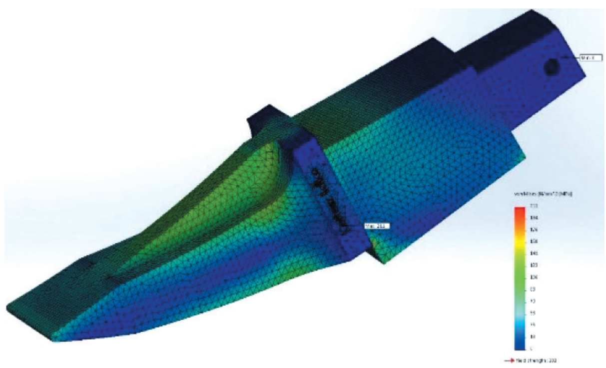

Fig. 15. Type III tooth von Misses stress when mounted with new proposed tooth

Table 1

Summarized results obtained for three types of teeth after FEA

No.	Type of tooth	Holder type	Angle	Deformation	Stress
			[°]	[mm]	[N/mm^2]
1	I	old	11	1.465	829
2		new		0.581	224
3	II	new	10	0.548	215
4	III	new	9	0.523	211

6. CONCLUSIONS

The simulation of the cutting-teeth behaviour when mounted on the BWEs using FEA was based on the results [10] obtained over the years by the Department of Mechanical, Industrial, and Transport Engineering during research contracts aimed at improving the performance of BWEs operating in the Oltenia Coal Basin.

The analysis was done on three type dimensions of teeth using FEA. An assembly of a tooth and tooth support was used in all cases. For each scenario, we created CAD geometry, FEA geometry, stresses, restrictions, and material.

For the Type I tooth, we conducted the analysis in two cases: with the existing old cutting-tooth holder and the proposed new tooth-holder (which better encompasses the tooth's tail when mounted). For all three types of teeth, it was concluded that:

– in the case of tooth mounting by a holder of the old type, the von Mises tension is maximal in the area of the tooth's tail being located between the holders and the shoulder;
– mounting the cutting-tooth into the old tooth holder causes the von Mises stress to be maximal in the tail area of the tooth at the intersection of the support and the joint;
– mounting the cutting tooth into the proposed new tooth holder makes the von Mises stress maximal at the clearance area corresponding to the setting plane of the tooth;
– regardless of the tooth-holder type used, the maximum deformation appears at the tip of the cutting tooth. It was observed that, in the case of the old tooth holder, the deformations are larger than in the case of the new proposed tooth holder;
– it is shown that increasing the sharpening angle results in decreases in both the deformations and von Misses stresses of the cutting tooth.

The results of this analysis are similar to the past results obtained using analytical methods of research conducted by the Mechanical, Industrial, and Transport Engineering Department [11].

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