STUDY REGARDING THE POSSIBILITIES TO IMPROVE THE PARAMETERS OF TEETH ON THE ROTOR EXCAVATORS IN OPERATION AT JILT SUD AND JILT NORD OPEN CASTS

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Abstract: This paper presents the geometrical parameters suitable for the typo-dimensions of teeth used on the rotor excavators in operation at Jilt Sud and Jilt Nord open casts that have been determined by laboratory experiments on the behaviour to cutting of sterile rocks and of lignite.

Key words: rotor excavator, teeth, geometrical parameters, shape, stresses

1. GENERALS

The researches that have been carried out, the results that have been gained, the comparisons that have been made and analysed, the observations and the measurements carried out in the field have all led to the conclusion that two typo-dimensions of teeth are being recommended for use at Jilt Sud and Jilt Nord open casts for cutting of lignite and of sterile rock with the view to increasing the working efficiency of the rotor excavators.

The determination of the typo-dimensions of teeth is quite complex and calls for a compromise because of the contradictory influences of certain parameters that characterize the cutting operation over the shape and the geometrical parameters of

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teeth. The information on the cut of lignite and of the sterile rocks has been settled during personal researches in the laboratory.

The comparative study shows that the mechanical stress acting on teeth during the dislodging of sterile rocks from the coal basin is either below the level occurred during the cut of lignite, or is comparable or even higher than the level of lignite. This analysis doesn’t take into account the wear of teeth which can become one of the most important quality parameters.

2. ANALYSIS OF THE SHAPE AND OF THE GEOMETRICAL PARAMETERS OF TEETH

By considering the geometrical parameters and the aspects mentioned above, it results that maximum two typo - dimensions of teeth are necessary for use at Jilt Open Cast Mining Unit, one for cutting of lignite and the other one for the sterile rock. Fig. 1 shows the drawing with assembly of the tooth on the bucket and the forecasted geometrical.

![Fig. 1. Drawing with assembly of the tooth on the bucket](image)

<table>
<thead>
<tr>
<th>No.</th>
<th>Geometrical parameters</th>
<th>Symbol</th>
<th>Typo - dimension for each tooth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1st variant</td>
</tr>
<tr>
<td>1.</td>
<td>Rake angle</td>
<td>$\alpha$</td>
<td>51°</td>
</tr>
<tr>
<td>2.</td>
<td>Positioning angle</td>
<td>$\beta$</td>
<td>11°</td>
</tr>
<tr>
<td>3.</td>
<td>Sharpening angle</td>
<td>$\delta$</td>
<td>28°</td>
</tr>
<tr>
<td>4.</td>
<td>Cutting angle</td>
<td>$\gamma$</td>
<td>39°</td>
</tr>
<tr>
<td>5.</td>
<td>Lateral longitudinal angle</td>
<td>$\xi$</td>
<td>5°</td>
</tr>
<tr>
<td>6.</td>
<td>Lateral cross angle</td>
<td>$\theta$</td>
<td>3°</td>
</tr>
<tr>
<td>7.</td>
<td>Width of the cutting edge</td>
<td>$b$</td>
<td>120 mm</td>
</tr>
</tbody>
</table>
Considering the drawing with the assembly of the tooth on the bucket (Fig. 1) and the data in the table 1, there has been designed the shape of the tooth with the main parameters of the tooth shown in Fig. 2.

![Geometrical parameters of the suggested tooth](image)

Both typo – dimensions have a lateral longitudinal angle of 5° and lateral cross angle of 3° for avoiding frictions between the massive and the tooth on its lateral sides.

One can notice that the two typo – dimensions of the tooth have the same shape, with different geometrical parameters of the active part. The first typo – dimension is a slenderer variant, with a larger recess and a diminished sharpening; it is intended to cut lignite and the sterile rocks with a smaller specific strength \((A = 200 \text{ to } 450 \text{ N/cm})\). The second typo – dimension is much more robust, with a smaller recess and a larger sharpening; it is intended to cut sterile rocks, such as the sandy clay, clay sands and grey clays with the specific strength to cutting of \(A = 450 \text{ to } 800 \text{ N/cm}\), where the wear is more intense than in the case of lignite.

The official use of these suggested teeth requires the work documentation for the teeth and for the bucket because the location of the teeth on the bucket depends on the geometrical parameters of the teeth. As for the material recommended for the execution of the teeth of the excavator, we have determined the following limit characteristics for the material based on researches: strength to tearing: \(\sigma_t \geq 1000 \text{ MPa}\); flowing limit: \(\sigma_c \geq 700 \text{ MPa}\); specific elongation: \(\varepsilon > 5\%\); Brinell hardness: 3000 to 3600 MPa; resilience: 80 to 100 J.

The typo – dimensions of the suggested teeth can be validated during testing performed in real working conditions (a given excavator, well-known sterile rock, well-known lignite and bed, an open cast settled beforehand, etc.).

3. **STUDY ON THE STRESS ACTING UPON THE SUGGESTED TEETH**

Based on the values reached by the cutting and penetrating forces determined
during testing operations, there have been determined the stress in the most stressful fibres, on different sections along the length of the tooth with the help of a suitable software.

Figure 3 shows the proposed tooth together with the shape of the cross section area of its two distinct ranges (x = 0 …. 70 mm and x = 70 … 280 mm). The laws of variation have been determined along the length of 70 mm measured from the top of the tooth depending on the abscissa x of width b, height h, cross section area A and the strength modulus Wz. Due to the complex geometry of the tooth, along the range x = 70 … 280 mm, we have determined the geometrical characteristics of the cross section area for different values taken by abscissa x. The sections A – A and B – B show the shape of the cross section area together with its geometrical parameters used in the calculation.

\[
\begin{align*}
\text{For the range } x &= 0 \ldots 70 \text{ mm, section } A - A \text{ in Fig. 4, the relations have been obtained for the geometrical characteristics of this section:} \\
- \text{ width and height of tooth} & \quad b=120-2x\tan5^\circ, \text{ mm} ; \quad h=x(\tan21^\circ+\tan10^\circ), \text{ mm} \\
- \text{ area and strength modulus} & \quad A=bh, \text{ mm}^2 ; \quad W_z=\frac{bh^2}{6}, \text{ mm}^3 \\
\end{align*}
\]

The stress σ in the most stressed fibres from the current section on the range x₁ = 0 … 70 mm has been determined with the help bending strain together with the traction strain.
\[ \sigma = \frac{N}{A} + \frac{M}{W_z} = \frac{F_x}{A} + \frac{F_y x_1}{W_z}, \text{MPa} \] (3)

The variation chart \( \sigma = f(x) \) is given in Fig. 4.

The following equations for the calculation of the geometrical characteristics of the section have been determined for the range \( x = 70 \ldots 280 \text{ mm} \) (section B – B in Fig. 4):

- the ordinate of the geometrical centre of the area \( A \) form the section B – B:
  \[ y_c = \frac{b_1 h_1 (h_1 + h_2) + b h_2^2}{b_1 h_1 + bh_2}, \text{mm} \] (4)

Fig. 4. Variation of the maximum strain inside the tooth along the range 0 \ldots 70 mm

- the component areas (\( A_1 \) and \( A_2 \)) of the area \( A \) form the section B – B:
  \[ A_1 = b_1 h_1, \text{mm}^2; A_2 = bh_2, \text{mm}^2 \] (5)

- the total area form the section B – B:
  \[ A = b_1 h_1 + bh_2, \text{mm}^2 \] (6)

- the coordinates of the geometrical centres of the sections \( A_1 \) and \( A_2 \):
  \[ y_1 = h_2 + \frac{h_1}{2}, \text{mm}; y_2 = \frac{h_2}{2}, \text{mm} \] (7)

- moments of inertia vs. the personal central axes of the areas \( A_1 \) and \( A_2 \):
\begin{align*}
I_{z_1} &= \frac{h_1 b_1^3}{12}, \quad \text{mm}^4; \quad I_{z_2} = \frac{h_2^3 b}{12}, \quad \text{mm}^4 \\
- \text{distances between the central axis } z \text{ of the cross sections } A \text{ and the axes of the centres } z_1 \text{ and } z_2 \text{ of the component areas, } A_1 \text{ and } A_2: \\
a_1 &= y_1 - y_c, \quad \text{mm; } \quad a_2 = y_c - y_2, \quad \text{mm} \\
- \text{moment of inertia of the cross section } A \text{ vs. its central axis } z: \\
I_z &= I_{z_1} + I_{z_2} + a_1^2 A_1 + a_2^2 A_2, \quad \text{mm}^4 \\
- \text{the strength modulus of the cross section } A: \\
W_z &= \frac{I_z}{y_{\text{max}}}, \quad \text{mm}^3
\end{align*}

where: \( y_{\text{max}} = \max(y_1, y_2) \), \( y_1 \) and \( y_2 \) are the distances from the axis \( z \) up to the farthest point of the cross section \( A \).

The stress in the most stressed fibres has been determined with the help of bending strain together with the traction strain.

The maximum values of the cutting and penetrating forces determined based on the experimental testing are \( F_x = 44718 \) N and \( F_y = 22359 \) N.

The normal effort and the bending moment have been determined with the help of these values in a current abscissa cross section \( x_1 \) of the tooth:

\[ N = F_x, \quad \text{N; } M = F_y x + F_x \cdot e, \quad \text{N} \cdot \text{m} \]

where: \( e \) is the distance between the axis of the force infliction \( F_x \) and the neutral axis in the range \( x \).

The variation chart of the stress \( \sigma \) within the range 70 … 280 mm is shown in fig. 5.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig5.png}
\caption{Variation of the maximum strain inside the tooth along the range 70 … 280 mm}
\end{figure}
According to fig. 4 and 5, everybody can see that the maximum stress is near the top of the tooth. For example, 5 mm away from the top of the tooth the stress reaches a value of 3419 MPa.

After analysing the charts with the stress variation $\sigma$ (Figs. 4 and 5) in relation to the abscissa $x$, the following conclusions can be drawn:

- as moving off the top of the tooth, the stress $\sigma$ shall decrease sharply from a value of about 3419 MPa (5 mm away from the top of the tooth) until around 68.89 MPa inside a cross section situated at 70 mm away from the top of the tooth;
- inside the range 70 … 106 mm, the stress shall increase from 68.89 MPa to 129.28 Mpa;
- inside the range 106 … 230 mm, the stress display a slow variation, decreasing abruptly from 129.28 to 78.6 MPa;
- inside the range 230 … 250 mm the stress is approximately constant;
- inside the range 250 … 280 mm the stress display an abrupt variation going up to the maximum value of 159.31 MPa very close to the tooth carrier (the area where the tooth is embedded);
- the stress variation within small range along the length of the tooth (excepting an interval of about 35 mm nearby the top of the tooth) shows that its geometry gives it a behaviour similar to the bars of equal strength to bending.

The stresses inside the tooth were also determined by the finite element method. Fig. 6 shows the 3D representations of the two suggested typo – dimensions of the tooth made with SOLID EDGE software.

![Fig. 6 Constructive shape of the tooth: a – first variant; b – second variant](image)

Figs. 7 and 8 show the discretizations of the teeth from the first typo – dimension and from the second typo – dimension and Figs. 9 and 10 show the stresses
that arise in the two structures of the tooth (the stress is expressed in MPa).

Figs. 9 and 10 show that the most stressed points (within the contact area with the tooth carrier, at its upper side) see values of 428.3 MPa for the first variant and 422.9 MPa for the second variant. According to the analysis of the results gained by the two above said methods (the classical method the finite element method), one can see that these results are almost similar.
4. DESIGN OF THE SUGGESTED TEETH FOR JILT SUD AND JILT NORD OPEN CASTS

Considering all the researches that have been carried out up to now, we have designed a new type of tooth, in two variants; they are shown in figs. 11 and 12 as work drawings.

Fig. 11. Drawing of the designed tooth - first variant

Fig. 12. Drawing of the designed tooth - second variant
When designing this tooth, we have taken into consideration that it shall cut lignite and sterile rocks. Consequently, we have adopted the width $b = 120\, \text{mm}$. The lateral sides have an inclination of $5^\circ$, aspect that reduces the occurrence of high friction forces between the tooth and the excavated material, even in the case of location errors of the teeth on the buckets. This inclination is beneficial both for the occurrence of forces on the tooth and from an energetic point of view.

The laying surface of the tooth is being provided with two symmetrical recesses that decrease its weight, without influencing decisively the mechanical strength. A curved surface was applied on the surface of the recess that provides on one hand an easier slide of the chip and, on the other hand, an advantageous shape for the tooth subjected to wear when self-sharpening occurs.

In the area where the bottom of the tooth is attached to its active part a shoulder has been fit up, so that it covers the tooth carrier reducing considerably its wear.

Compared to the teeth already in use, the cross section area of the bottom part has been increased for reducing clearance in the tooth carrier and thus providing a position of the tooth as close as possible to the one required by the cutting operation; if the tooth is mounted correctly on the bucket, it means an orientation of the tooth after the speed vector that results from the cutting speed $v_c$ and the swivelling speed $v_p$.

In the case of $E_{E_r} - 1400\leq 630$ excavator, operating at the recommended parameters and at an average swivelling speed (0.26 m/s), it results that the tooth should have an inclination of $6^\circ$ on the swivelling direction and speed wise, i.e. to the left and to the right, accordingly.

As for the material of the tooth, the following steel brands are being recommended: 41MoCr11, T35MoCrNi08, T34MoCrNi09 or T40MnNi07 which have the characteristics near the ones previously recommended. After testing there shall be finalized the material of which the teeth shall be made in series.

The teeth shall be cast and the bottom of the tooth should be processed mechanically to reach the final sizes. Then, they shall be subjected to a shallow hardening with the view to getting a hardness of 40 ... 45 HRC on the area subjected to an intense wear during mining operations.

REFERENCES