Cutting elements of bucket wheel excavators in lignite opensast mines: Methodology and performed solutions

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CUTTING ELEMENTS OF BUCKET WHEEL EXCAVATORS IN LIGNITE OPENSAST MINES: METHODOLOGY AND PERFORMED SOLUTIONS

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Abstract

Bucket and cutting elements geometry (teeth and hardened steel) have very powerful impact on effective operation of bucket wheel excavator, and that`s why, problems of optimal geometry of elements in specific conditions always are of special interest in mining science and technique. If we want to achieve satisfactory utilization of bucket wheel excavator, it is necessary to modulate geometry material characteristics and technological parameters, as regards bucket wheel excavator work regime, and bucket wheel working performances, and also bucket wheel excavator.

Keywords: bucket wheel excavator, cutting elements, optimization.

1 Introduction

Excavation of material by the bucket wheel excavator is a very complex physical-mechanical process, and indicators of effectiveness for this process depends on a number of different factors, from which should be particularly emphasized physical-mechanical properties of the materials to be excavated, the selected technology of block parameters, sub-benches and cuts, geometry and condition of cutting elements, etc. Geometry of cutting elements on the bucket wheel of the excavator is having huge impact on the efficiency of this machine. Determination of

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optimal geometry of cutting elements for specific working conditions is a permanent issue. Common situation is that manufacturers are supplying these machines with buckets and cutting elements-teeth which are not adjusted to specific conditions on lignite open cast mines in Serbia (all bucket wheel excavators in Serbia are manufactured in Germany). This implies that operators of these machines must seek suitable and optimal solutions during operational stage.

In order to achieve acceptable performance utilization of the excavators it is necessary that bucket geometry, as much as it is possible to adjust to materials features and technological parameters i.e. the excavator mode of operation. It is understandable that such complex requirements is difficult to be meet, and that is why still in the literature there are not deeper funded recommendations, which geometry of buckets and cutting elements (blades and teeth) should be chosen for excavation of certain materials. If we add to this the fact that within one mine physical and mechanical properties of materials can be noticeably changed (both via benches length and height), then the problem becomes even more complex.

In general, geometry of the buckets must meet wide range of the criteria:

- process of cutting and filling the bucket must be achieved with minimal consumption of energy;
- to eliminate or minimize material sticking to internal surfaces of the bucket;
- to ensure complete discharge of the bucket within the discharge sector, and to eliminate appearance of oversized lumps in the excavated material;
- to eliminate or minimize spillage of the material from the bucket;
- to reduce uneven loading caused by periodical entrance and exit of teeth into and from the cut into acceptable limits;
- to simplify manufacturing technology and to increase reliability and to ensure easy and quick replacement of buckets and teeth.

Tooth is a component of bucket assembly, which has dual role during excavation: disintegration of the material and its excavation (followed by transport of the material over it). As basic cutting element, tooth must meet numerous requirements through its geometry and mechanical properties, which are conditioned with technological process and type of excavated material.

Most frequent lacks are:

- unsatisfactory geometry of cutting part (wrongly accepted main angles of cutting wedge, inappropriate width of tooth and facet),

- unsatisfactory shape of the tooth (oversized or undersized length, critical cross-sections are with small moment of inertia, unnecessary amount of steel along the one side of the tooth i.e. unacceptable weakening of the other side of the tooth),
- to high toughness or brittleness, intensive wear i.e. large wear surface at the back of the tooth,
- inappropriate tooth mounting on the bucket (inserting system, locking and fixing, positioning along the bucket and number of teeth),
- imperfections of tooth manufacturing process (casting, cooling and steel production technology).

The consequences of abovementioned are: bending and fracture of the teeth, pulling out, excessive wear of the teeth and the bucket, increased cutting resistance, and consequential increased power, additional loading of corresponding excavator structure, intensive vibrations and oscillations of excavator's main structure, unsatisfactory grain size of the excavated material, decreasing efficiency and productivity of excavator. Therefore, teeth must be manufactured according to several criteria, where most important are: favourable geometry related to cutting, high wear resistance, high mechanical strength and easy replacement.

2 Cutting elements optimization - methodology

Optimization of cutting elements of bucket wheel excavator must be done in appropriate methodology. Components for appropriate and acceptable engineering method are:

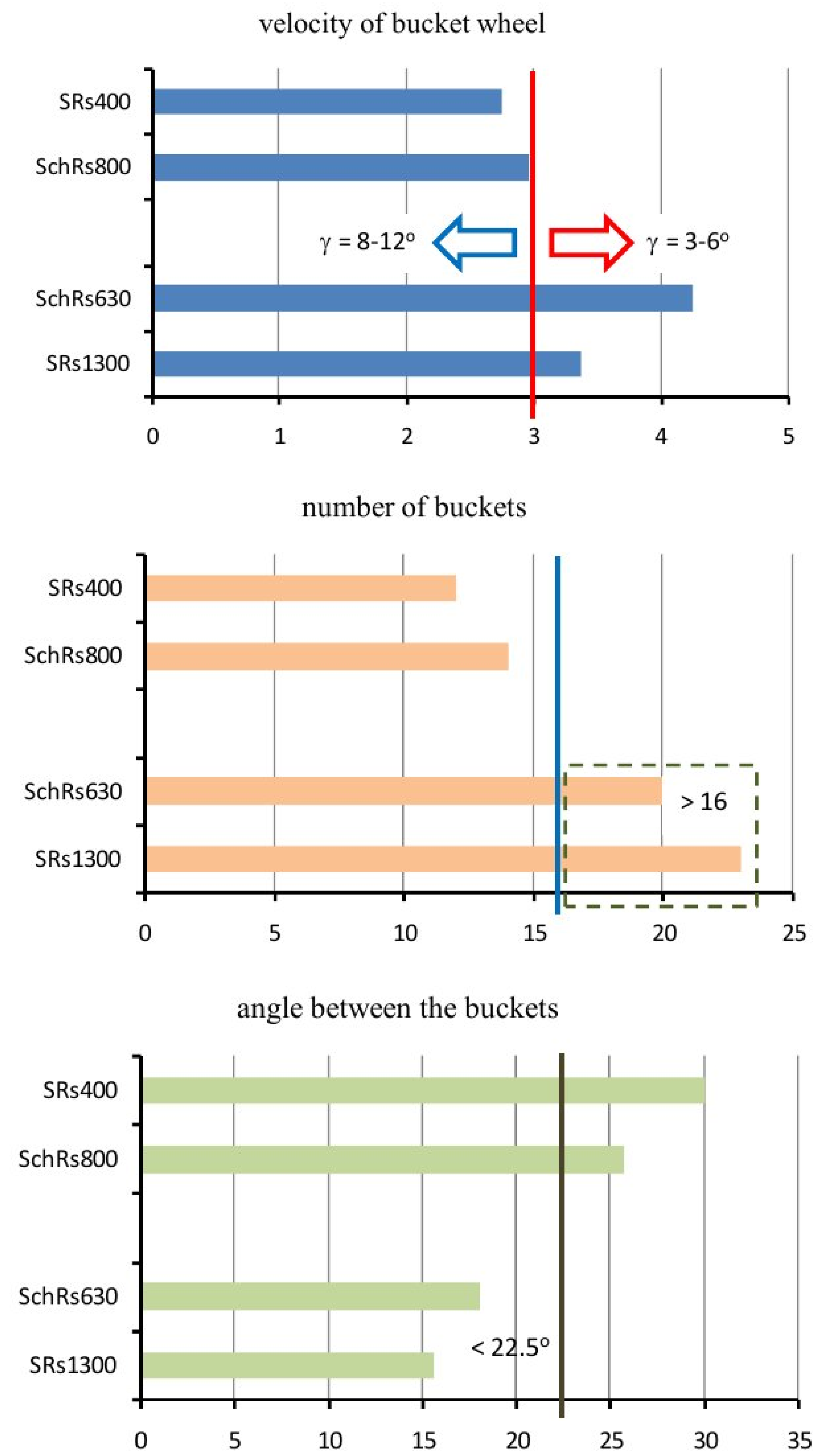
- analysis of working environment i.e. rocks,
- analysis of technical and technological parameters of excavator, especially of bucket wheel,
- definition of forces and wear level acting on the cutting elements and buckets.

Design process of cutting elements/teeth for bucket wheel excavator should strive to the following: avoiding of teeth failure (in case of breaking, within neglecting numbers which means that there is no correlation between geometry and material of the teeth – or there is a subjective factor/excavator operator or casting issue), prevent tooth deformation during operation (sufficient strength in each cross-section of the tooth), excavator should have minimal oscillations after the period of teeth running-in (later on, during operation, excavator should also have small oscillations), teeth installation without major problems (which is not an issue that should be neglected), slow wearing and self-sharpening, proper geometry definition of tooth front and side edges to reduce transversal resistance. Components of material cutting and ripping during excavation are also having impact on the design process of cutting elements. Tooth designed for cutting/ripping combination are massive and with significant higher strength in typical cross-sections of loaded parts, also, they are relatively narrower (for the stability during ripping), etc. Major parameters for such selection are given in Table 1.

Table 1 Methodology for selection of cutting elements for excavators of A and B type at EPS

<table>
<tr><th colspan="2">Excavator class B</th><th colspan="2">Excavator class A</th></tr>
<tr><td>Parameters</td><td>Methodological approach</td><td>Parameters</td><td>Methodological approach</td></tr>
<tr><td>High velocity of bucket wheel</td><td rowspan="6">Smaller values of free angles – from 3 to 6°; smaller cutting angle – to 30°; smaller wedge angle – to 25°; number of teeth per bucket – optimal 7, due to support; possibility for increasing of tooth's cutting width; higher cutting performance than ripping; longer cutting part of the tooth.</td><td>Low velocity of bucket wheel</td><td rowspan="6">Larger values of free angles – from 8 to 12°; larger cutting angle – to 40°; larger wedge angle – to 30°; number of teeth per bucket – optimal 7, due to support; reduced tooth's cutting width – as wedge; higher ripping performance than cutting – more precisely combination; shorter cutting part of the tooth.</td></tr>
<tr><td>More bucket of smaller volume</td><td>Fewer bucket of lager volume</td></tr>
<tr><td>Smaller angles between buckets</td><td>Larger angles between buckets</td></tr>
<tr><td>Larger diameter of bucket wheel</td><td>Smaller diameter of bucket wheel (relatively large in relation to whole geometry of excavator)</td></tr>
<tr><td>Higher torque</td><td>Smaller torque (relatively high torque in relation to total mass)</td></tr>
<tr><td>Operation mainly in vertical cuts</td><td>Combined operation with vertical and horizontal cuts</td></tr>
<tr><td>Smaller lumps</td><td></td><td>Larger lumps</td><td></td></tr>
</table>

One of the most important parameters is establishment of angle toward the block, so-called free or rear angle (γ). This is the angle between the tooth trajectory and direction of ripped pieces of excavated material. Recommended value of this angle for operation in soft rocks is $\gamma = 3 \div 5^{o}$, while for operation in overburden it is $\gamma \geq 8^{o}$. Small values of rear angle ($\gamma < 2^{o}$) are increasing friction resistance. Large values of this angle are causing extreme oscillation of structure with some operational parameters, thus reducing the safety of the machine. Most important issue is to retain the rear angle (γ), since its reduction is causing sudden increase of friction force, which on its own part causes increase of digging resistance. As it can be seen in Table 1, recommendations for this angle are provided for coal measured rocks at open cast mines and excavators. Framework and critical parameters for selection of cutting elements for bucket wheel excavators operating on Serbian open cast mines are presented on Figure 1.



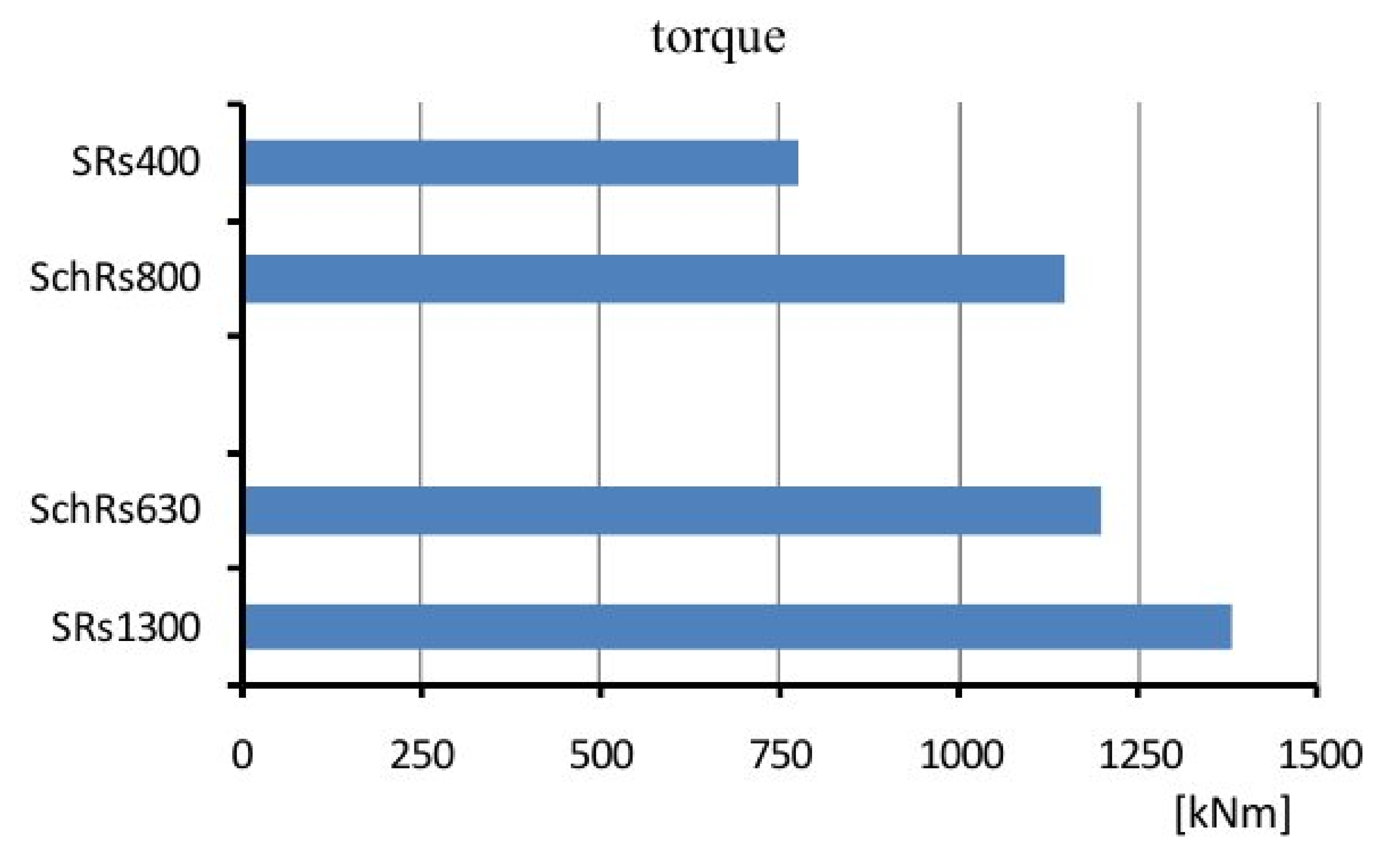


Fig. 1 Parameters for selection of cutting elements

3 Performed solutions of cutting elements

- ***Tooth for overburden on excavator SchRs 630 (G1)***

Excavator SchRs 630 (G1) was operating on overburden excavation since November 1994. This excavator was equipped with refurbished trapezoidal buckets with volume of 630 litres (drawing no. 1.652.097-J). These were made by repairing original buckets with volume of 900 lit (drawing no. 881295 - drawing Tamnava-East Field opencast mine, T-G-007). Originally installed teeth are shown on Figure 2 - T-G-113/1, T-G-115/1 and T-G-116/1.

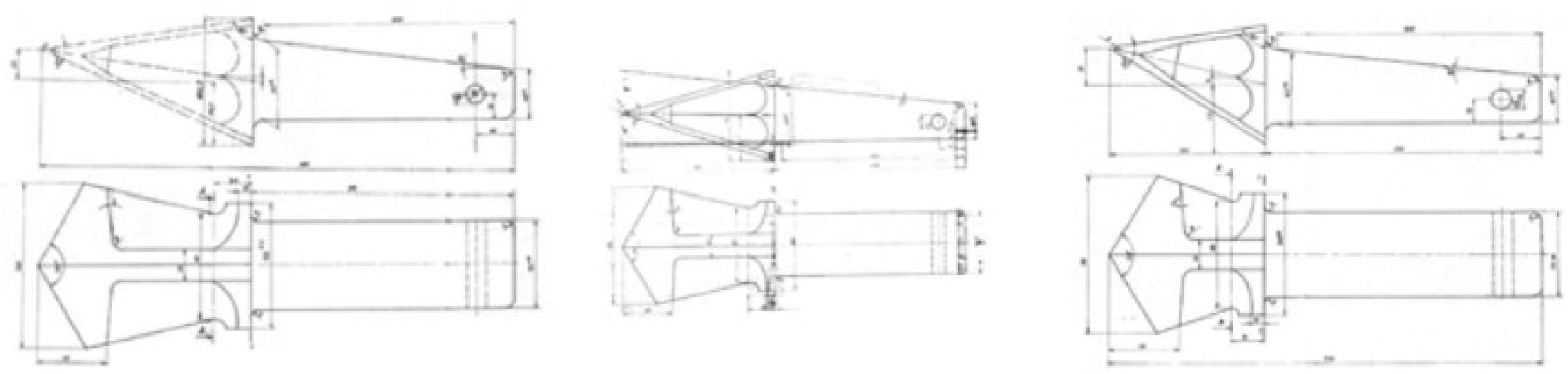


Fig. 2 Teeth T-G-113/1, T-G-115/1 and T-G-116/1

All mentioned teeth are distinguished by length and basic parameters of their cutting parts.

Teeth are installed on the bucket in symmetrical manner, where each tooth has its own installation position.

Teeth are short, with poor geometry of cutting part and short life (wearing material lost during excavation until replacement is 4% of total mass of the tooth). Furthermore, tooth is not protecting the pocket from the wearing.

Length of the back surface exposed to wearing (friction) is extremely large (150 mm), thus making digging resistance also very large (worn tooth is shown on Figure 3).

Fig. 3 Presentation of worn tooth

- ***Tooth for overburden on excavator SchRs 630 (G4)***

Excavator G4 started operation on overburden system with bucket 1.652.097-J and overburden tooth TZ-G3-002 (6 pieces per bucket) (Figure 4). The prototype of this tooth was made in mechanical workshop of Tamnava-West Field opencast mine, with the purpose to improve technical parameters of excavation with C 700s excavator (G3). Because of great results the tooth is installed on G4 and due to appropriate materials (CrNiMo) it operates successfully on excavation of various materials (selective mode of operation).

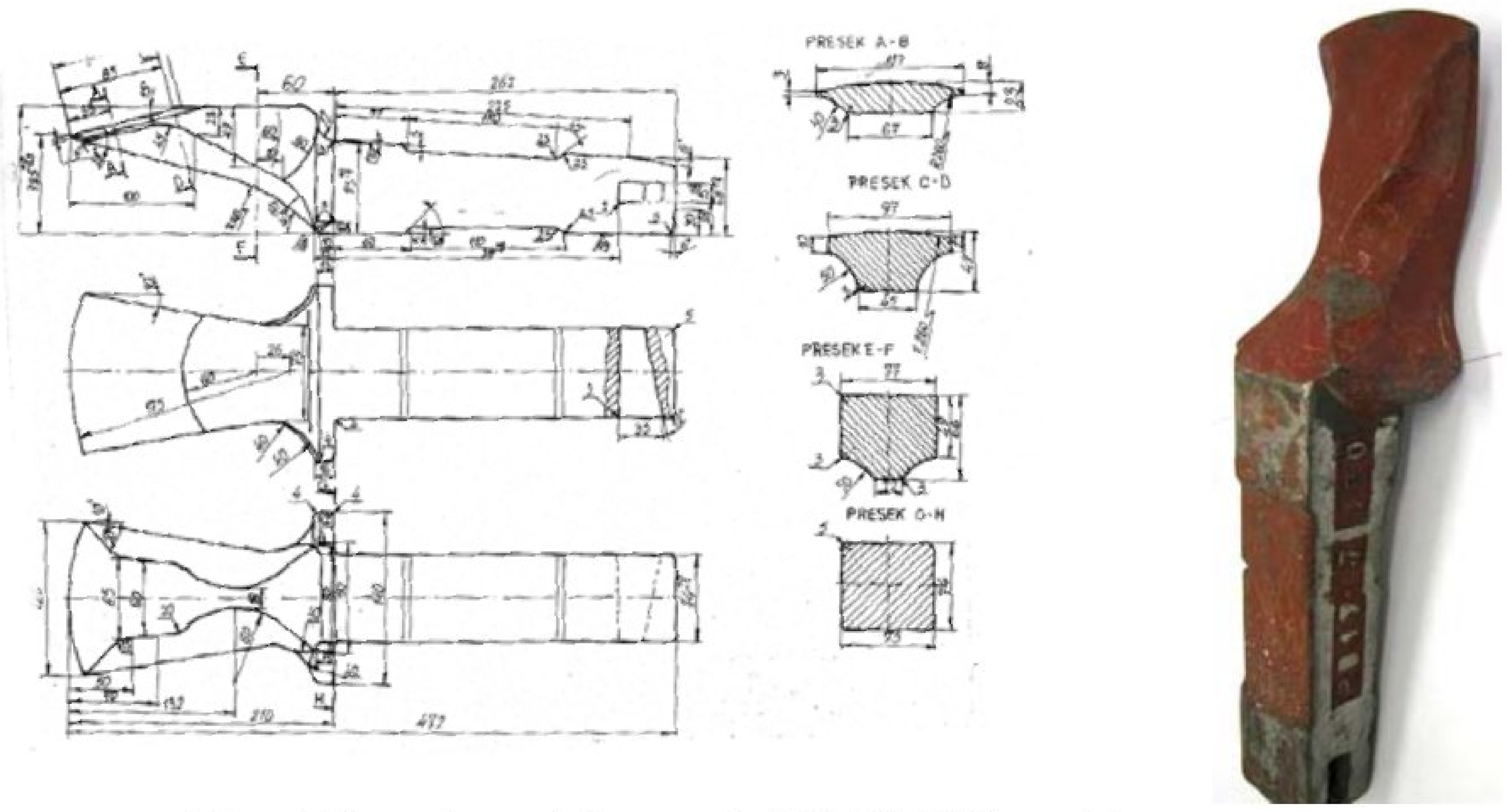


Fig. 4 Drawing of the tooth TZ-G3-002 and its prototype

It is already mentioned that tooth TZ-G3-002 successfully operates on excavation of overburden with trapezoidal buckets, but optimal results were achieved when this teeth were installed on bucket TZ-G-146 (Figure 5 shows this bucket and tooth wearing process).

With trapezoidal shape of bucket's tooth there is no possibility for good arrangement of pockets, and all teeth are not engaged during cutting. Therefore, wearing of the teeth is asymmetrical.

Installation and securing (fixing) of this tooth is simple. It provides a good protection for the pocket and good lump site of excavated material.

Due to appropriate selection of the tooth material (CrNiMo) there is no breakage. Also, tooth can be welded with KASTOLIN (or similar) electrode, and significantly prolong its operational life.

Fig. 5 Tamnava-West Field mine, excavator SchRs 630 (G-4), tooth TZ-G3-002/U

Bucket wheel excavator G-4 operates in alteration on excavation of interburden (sands) and coal, hence the tooth TZ-G3-002/U with armoured tip is suitable for such operation (Figure 6).

Fig. 6 Bucket with armoured teeth (welded)

Specific consumption of TZ-G3-002/U teeth for 1,000,000 m^3 was 109 pieces in 2011, up to 211 pieces in 2010.

- ***Tooth for bucket wheel excavators SRs 1201 and SRs 1301***

Manufacturer of bucket wheel excavator SRs 1201.24/4 for Field D opencast mine, delivered buckets with drawing no. 510152-20001a1, with following noticed lacks:

- inappropriate position of pockets along the edge of the bucket;
- non-functional chain mesh;
- significant sticking of material within the bucket;
- inappropriate solution of connection on third support;
- buckets were equipped with described teeth T-G-113/1, T-G-115/1, T-G-116/1.

Tooth holder T-G-113/1, T-G-115/1, T-G-116/1 was adapted for this bucket wheel excavator. This activity resulted in tooth TZ-G3-002/JA, which is installed on excavators SRs 1201 (Figure 7) and SRs 1301 (Figure 8) operating on Field D opencast mine.

Fig. 7 Bucket wheel of excavator SRs 1201

Fig. 8 Bucket wheel of excavator SRs 1301

- ***Tooth for bucket wheel excavator SchRs 630 (G1) in coal***

Teeth (drawing no. 1618297) were installed according to original documentation of manufacturer, at the start of operation of this excavator in coal (November 1995).

These teeth were made by casting, from material of increased toughness with welded cutting part. Teeth were in operation for several months, with typical bending in the neck region.

Next version of the tooth (drawing no GTZ-1) was made by casting without welding. This solution experienced failure (breakage) in the neck region. This tooth is shown on Figure 9.

Holders are strengthened and minor corrections were made on tooth geometry.

These corrections did not reduced number of earlier problems, but these resulted in increased transversal digging resistance.

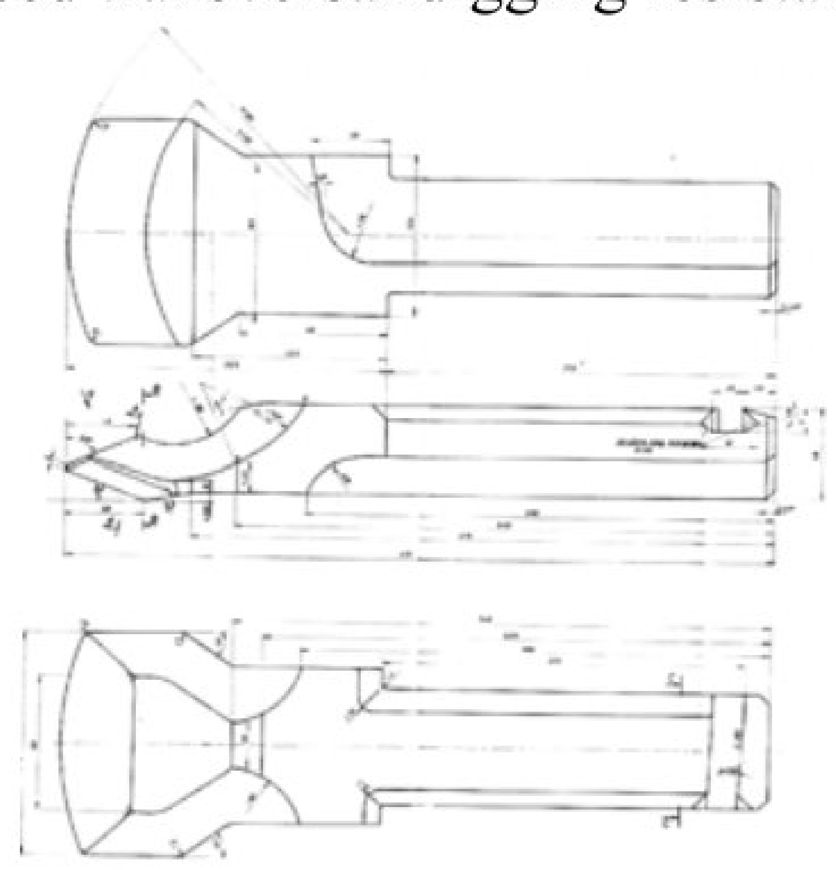


Fig. 9 Drawing of the tooth GTZ-1

Teeth KTZP-630/3 was in operation since May 1998 to January 1999, with following correction on back surface (changed angle) and altered installation and fixing method. This resulted in tooth TZ-G-087 (as shown on Figure 10).

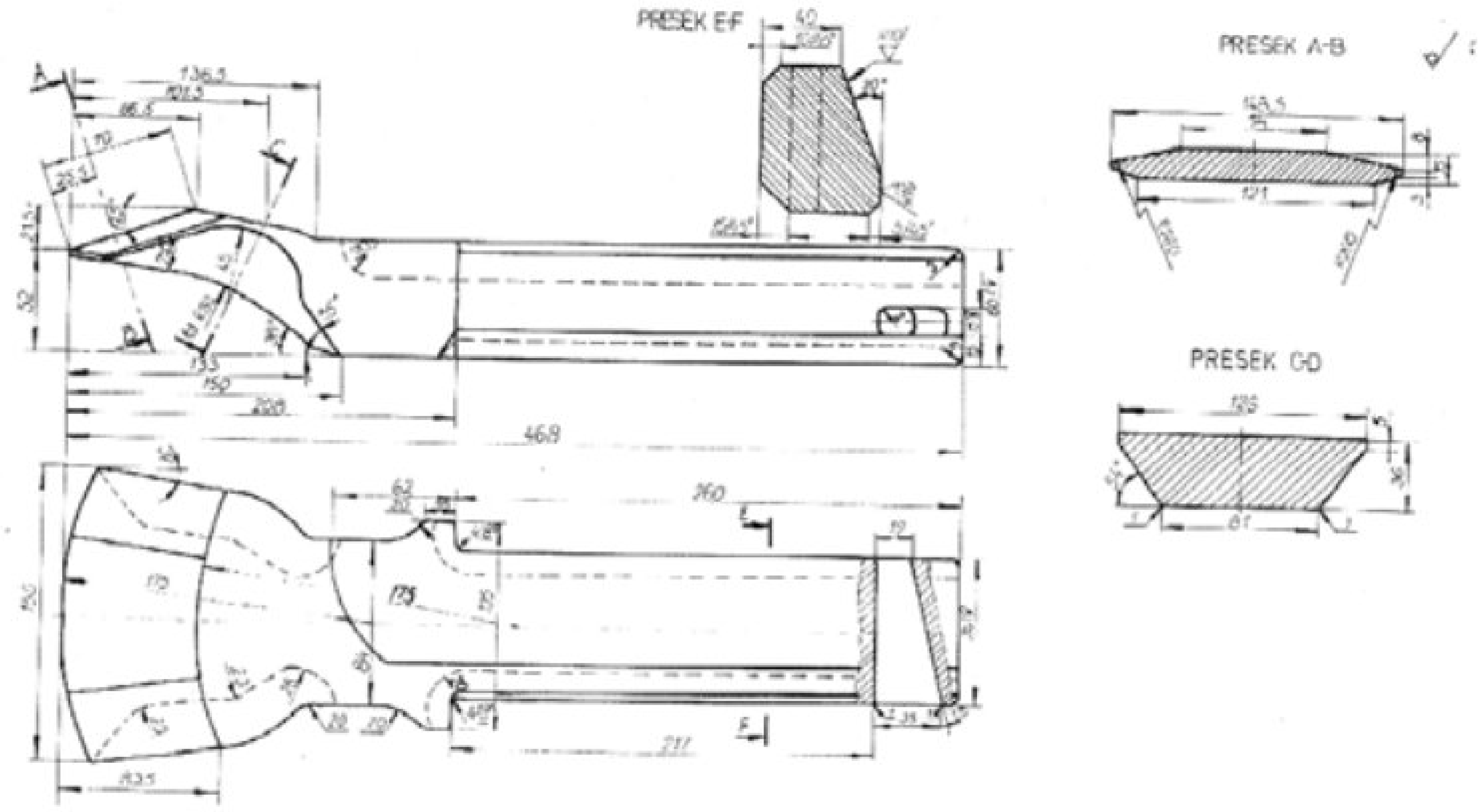


Fig. 10 Drawing of the tooth TZ-G-087

Width and length of tooth's cutting part, with optimal geometry and casting material, are the reasons for significant lower consumption, lower specific energy and increased economical results:

- tooth is not breaking,
- longitudinal wedge and safety pin are additionally protected by safety pin ∅6,
- falling-out of the tooth was reduced to minimum,
- tooth is not deforming and remains sharp as wearing progress,
- consumption was 85 pcs/10^6 t of excavated material.

Reconstruction of tooth holder was performed due to inappropriate replacement of pockets (remaining large clearance), requirement for installation of numerous insertion tins, falling-out of the tooth and complicated installation. Holder with longitudinal kiln was replaced by tooth holder TZ-G3-002. New construction of tooth for G-1 has marking TZ-G-087/R (Figure 11).

Fig. 11 Opencast mine Tamnava-West Field, excavator 1, bucket TZ-G-146, tooth TZ-G-087/R

Specific consumption of TZ-G-087 teeth for 1,000,000 t of excavated coal is from 65.3 to 115.9. Diagram of teeth consumption is presented on Figure 12.

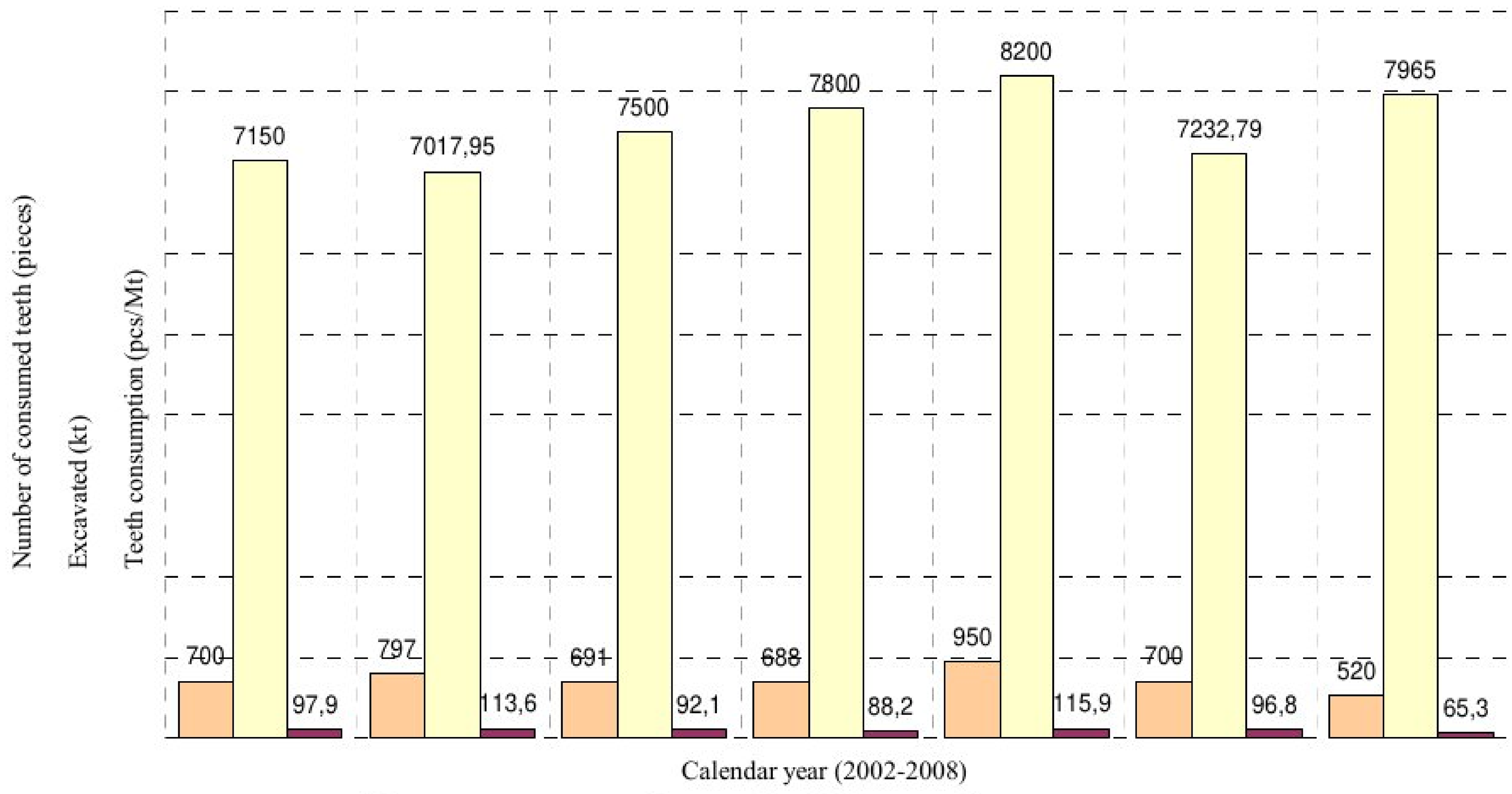


Fig. 12 Diagram of TZ-G-087 teeth consumption

- ***Bucket of excavator SchRs 630 (drawing no. TZ-G-146)***

Bucket wheel excavator SchRs 630 (factory number 1397, operational number G-1), started coal production on 16th November 1995, with buckets as supplied from the manufacturer. Problems with bucket failure (fracturing) occurred in 1996. During year 2000 a prototype of chain mesh bucket for coal production was made in mechanical workshop for excavator maintenance at Tamnava-West Field opencast mine (Figure 13). This bucket was installed on the wheel on 14th November 2000. Since June 2004 excavator G-1 operates with complete set of chain mesh buckets on its wheel. Original bucket was reconstructed according to the drawing TZ-G-146. Solution retained the tooth with pockets and front hooking eyes. Structure was strengthen because of frequent failures. Also, bucket was equipped with chain mesh since excavator frequently operates in interburden seams, thus enabling good discharge. After installation of refurbished buckets no failures were recorded. Level of material sticking within the buckets with chain mesh is just 5 to 10 litres, while the buckets with closed bottom sticking material occupied more than 70% of the bucket volume. Chain mesh is noticeably efficient, long-term and because of the solution for fixing the chains it is easy to replace. Bucket has semicircular (arched) tooth, three supports (two in front and one at the back) and 7 optimally distributed teeth.

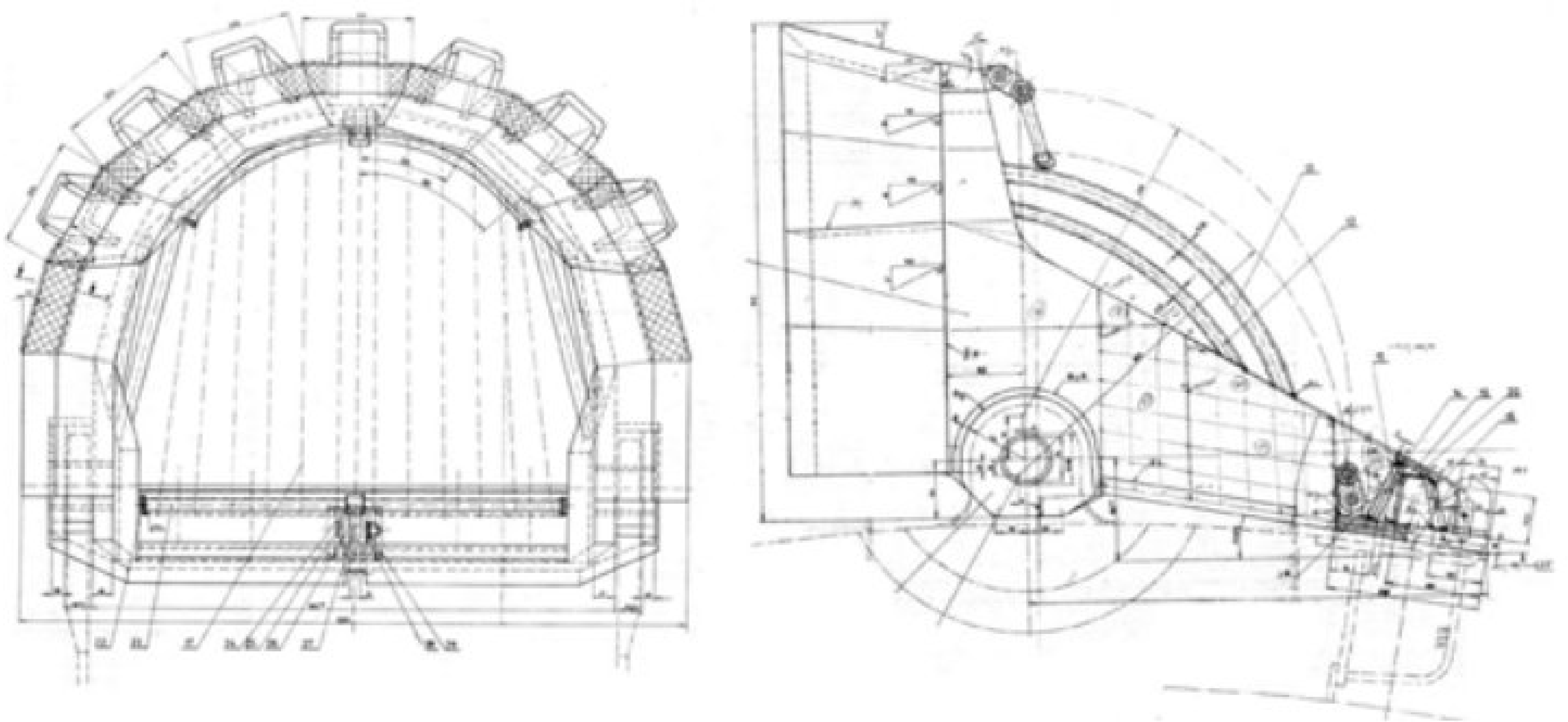


Fig. 13 Drawing of the bucket TZ-G-146

Diagram on Figure 14 indicated that number of broken buckets was 99 in year 2002. After introduction of refurbished buckets in 2003 and 2004, number of failed buckets was reduced to 63 and 28 respectively. During 2006 newly refurbished buckets were repaired which resulted in no failure. On the same year 8,200,000 t of coal was produced with effective operational time of 4,677 hours.

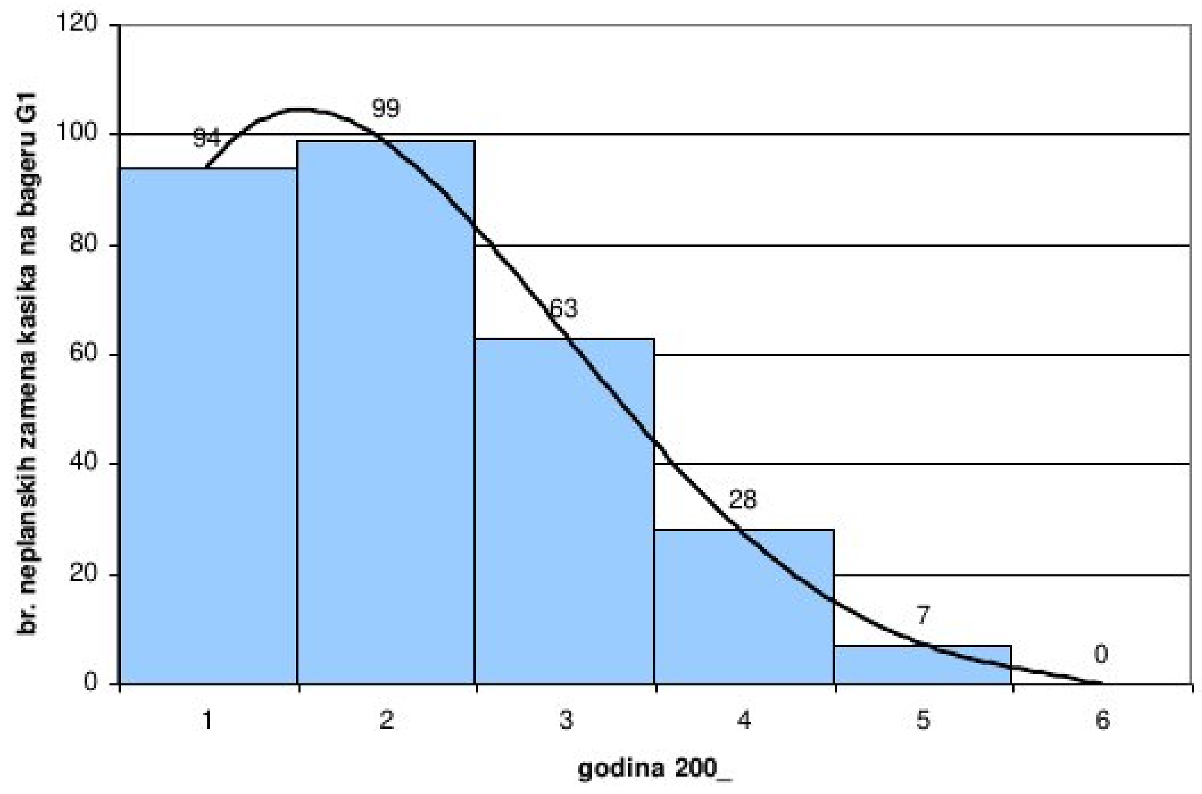


Fig. 14 Diagram of declining trend on non-planed replacements of buckets on excavator G-1

Bucket successfully operated on excavator G-4 in combined regime (interchangeable operation, i.e. excavation of coal and excavation of interburden).

According to the findings of case study "Optimization of excavator's bucket construction for the purpose of increasing production rate", developed by the FMG, workshop for excavator maintenance at Tamnava-West Field opencast coal mine manufactured a bucket with 4 supports in period from July to September 2003. Bucket from the excavator G-2 (drawing no. 881992) from the Tamnava-East Field opencast mine was used as a model for new bucket (Figure 15). Bucket from this excavator has good solution of tooth, tooth carrier and front hooking eyes, since these were cast in the single mold with good transitions between them.

Fig. 15 Prototype of bucket with 4 supports for bucket wheel excavator SchRs 630

- ***Bucket wheel excavator SchRs 740 (operational number G-5)***

Teeth TZ-G-087 was accepted for the installation on excavator SchRs 740 during its base engineering.

Design of the bucket resulted in angle toward the block of 8 degrees.

During operation with new teeth, excavator experienced high oscillation of bucket wheel and very low production rate.

Running-in of the teeth was done at the recommendation of the manufacturer, and new teeth can't be used on central positions.

After warranty period for the excavator this problem will be addressed.

New bucket wheel excavator SchRs 740 at Tamnava-West Field mine is shown on Figure 16. Tooth with increased wedge angle is shown on Figure 17, during excavation of coal.

Fig. 16 Bucket wheel excavator SchRs 740

Fig. 17 Increased wedge angle during exploitation

• ***Development of two-parted tooth***

a) Bucket wheel excavator SRs 2000

Prototype of two-parted tooth was manufactured in the workshop of Tamnava-West Field opencast mine (Figure 18), which is tested in operation (Figure 19). Optimized solution of two-parted tooth for excavator SRs 2000 is shown on Figure 20.

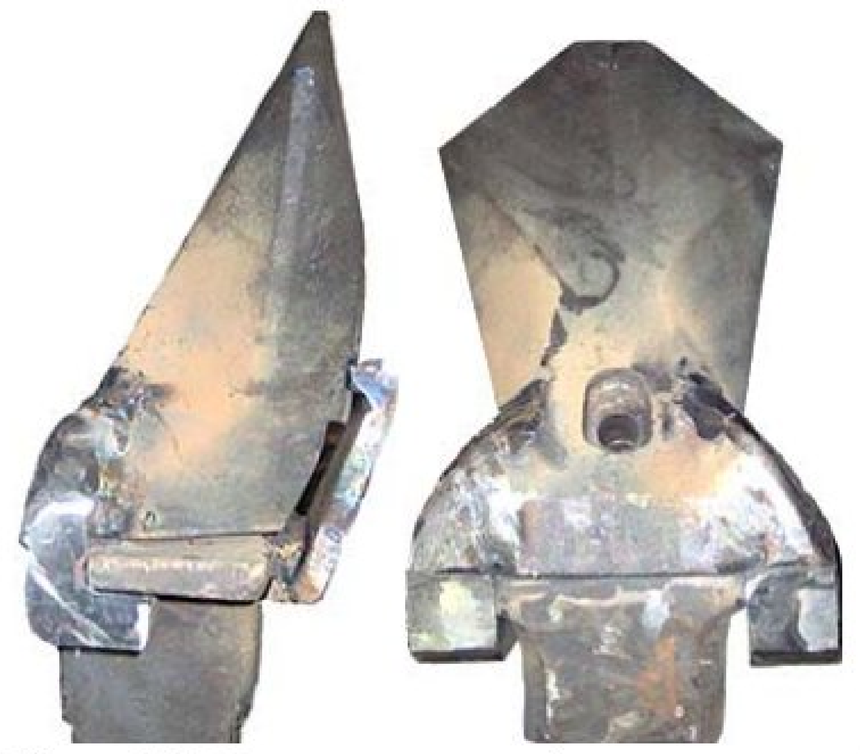


Fig. 18 Prototype of two-parted tooth TFGTZ-1M

Fig. 19 Two-parted tooth TFGTZ-1M after 70 hrs of overburden excavation

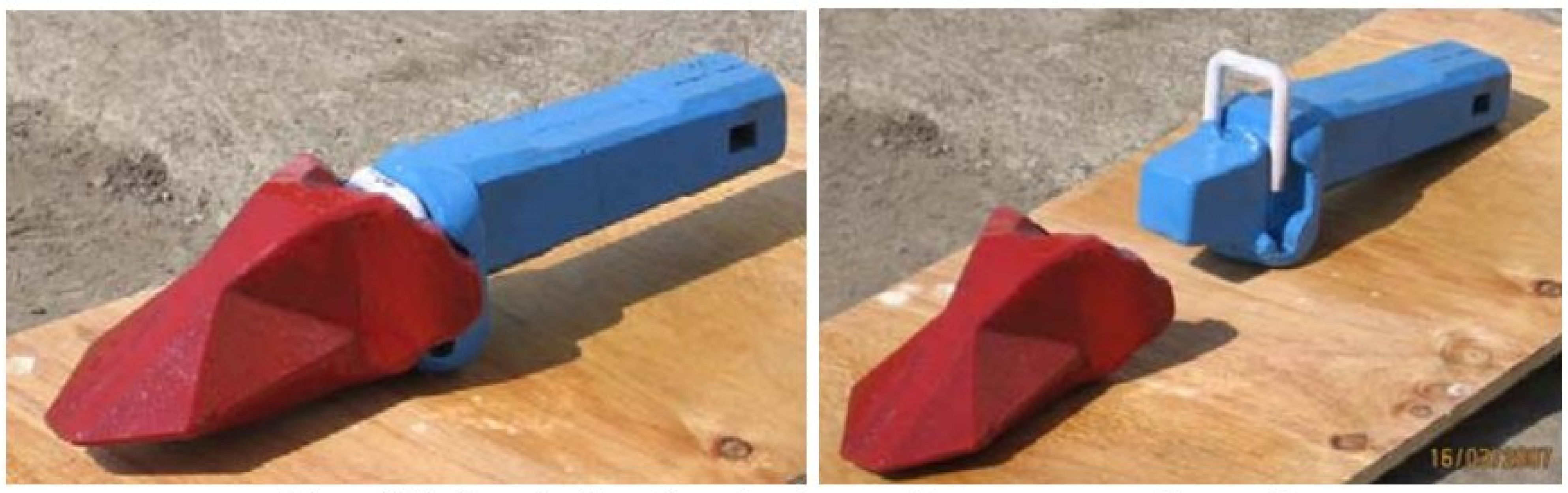


Fig. 20 Optimized solution of two-parted tooth

b) Bucket chain excavator ERs 1000/20

Prototype and worn-out two-parted tooth for bucket chain excavator ERs 1000/20 is shown on Figure 21.

Fig. 21 Prototype and worn-out two-parted tooth for bucket chain excavator ERs 1000/20

- ***Teeth for coal and overburden on excavators SRs 400 and SRs 470***

This tooth has larger wedge angle i.e. larger cutting angle, reduced width of cutting part and larger cross-sections at critical locations. Excavation process of these excavators is at the boundary of cutting and ripping, hence the massive tooth but in the range necessary for proper geometry. Basic components of tooth geometry are (drawing of the tooth and prototype are shown on figure 22): wedge angle 28^o; cutting angle (wedge angle and free angle) $36\text{-}37^o$; width of the cutting part 100 mm; length of the cutting part 180 mm; forming of frontal and rear surface with smaller friction surface (especially the rear surface); proper cutting angle must result in self-sharpening of the tooth, to the moment of increased consumption of electricity during excavation.

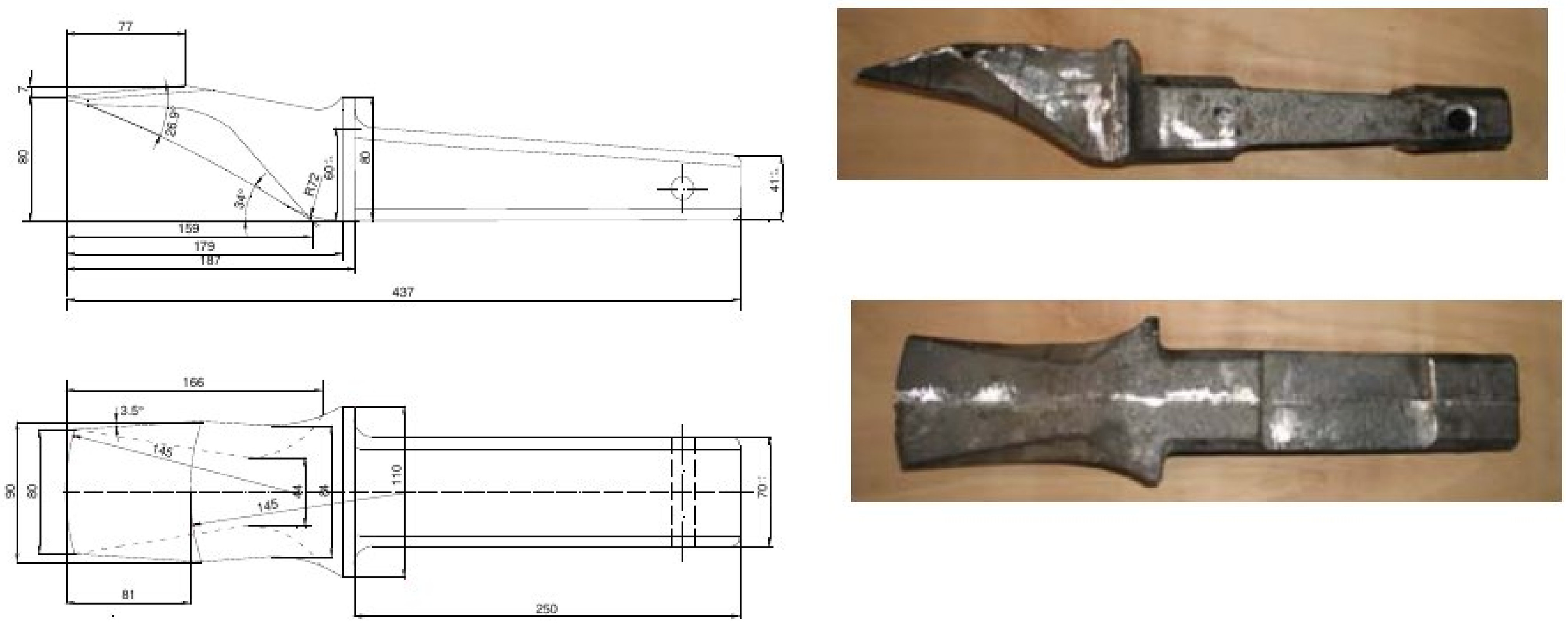


Fig. 22 Basic parameters and prototype of tooth for excavators SRs 400 and SRs 470

- ***Optimized bucket and tooth*** - recommendation for open cast mines in Kolubara basin:
- Bucket with edge of circular shape.
- Number of supports is 4.
- Tooth and extension in conical shape with angle of 15^o, should be casted together with front hooking eyes in one or two pieces, or as welded part of one or two bended arched parts.
- Tooth locking in pocket with 1:10 cone and tooth fixing with transversal wedge (cone 1:20).
- Length of cutting edge is 150 mm and wedge angle of 25^o.
- Optimal number of teeth is 7.
- Spacing between tips of the teeth should be between 120 and 150 mm.
- Central tooth (position 4) is installed without turning. Turning angle at positions 3 and 5 is 13^o, while on other positions this angle is approximately 5.5^o. Teeth axis must have joint crossing point.

- It is recommended that rear angle should be $\gamma = 3 \div 5°$ for teeth working in soft rocks, and $\gamma \geq 8°$ for teeth working in overburden.

The bucket and teeth on the Kolubara and Kostolac surface mines are given in Table 2.

Table 2 Bucket and teeth on the Kolubara and Kostolac opencast mines

Opencast mine	**Excavator**	**Material**	**Bucket**	**Tooth**
Tamnava-West Field	SchRs630 (G1 and G4)	Coal/overburden	TZ-G-146	TZ-G-087/R
Tamnava-East Field	SchRs 630 (G2)	Coal	TZ-G-146	T-G-083-4/1 and TZ-G-087
Field D	SchRs 630 (G7)	Coal	881922	881888C and TZ-G3-002/U
Field D	SRs 1300 (G8)	Coal	G8-3418036	881888C and TZ-G3-002/U
Tamnava-West Field	SchRs 740 (G5)	Coal		TZ-G-087
Field D	SRs 1201.24/4 (G2) SRs 1301(G10)	Coal/overburden	510452-2000	TZ-G3-002/JA
Field B	SRs 350.12/5 (G4M)	Coal	G4-111a	881888
Tamnava-West Field	SchRs630 (G4)	Coal/overburden	TZ-G-146	TZ-G3-002/u
Field C	C 700s	Coal/overburden	1623303	TZ-G3-002/J
Tamnava-East Field	SchRs 900 (G1)	Overburden	T-G-007	T-G-113/1, T-G-115/1, T-G-116/1
Tamnava-West Field	SRs 2000 (G2)	Overburden	TZ-G2-152	TZ-G2-187
Field D	SRs 1200 (G5, G6)	Overburden	G-355	G-456 and G4-356
Field C	SRs 1200 (G3, G4)	Overburden	G-355	G-456 and TZ-G3-002/U
Drmno	SRs 400	Coal		40-008-3
Drmno	SRs 470	Coal/overburden		40-008-3

4 Conclusion

Optimization means defining of the optimal teeth geometry, the optimum arrangement of the teeth on the bucket, and the manner of its fixing. The first step in carrying out the optimization of the bucket and teeth is a good knowledge of the physical and mechanical properties of excavated material, then the knowledge of the specific resistance of material planned for excavation and its compliance with the available digging force. The second step in the bucket and teeth optimization is the knowledge of the mining parameters impact, i.e. cutting parameters on the excavation process. The third step is to know the excavator design parameters. Knowing of these parameters and analysing the geometry of cutting can lead to the optimal geometry of the cutting edges. After many years of expert work to optimize cutting elements of bucket wheel excavators and chain excavators, came to the following conclusion: coal tooth TZ-G-146 is suitable for operation on excavators SchRs 630 and SchRs 740 (with correction bucket), tooth TZ-G3-002 on excavators SchRs 630 in combined operating mode (coal and overburden excavation), excavator C 700s, excavators SRs 1200, SRs 1300, SRs 1201 and SRs 1301. This indicates possible unification of the cutting elements in RB Kolubara, but more research is necessary in this direction.

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