MINING AND METALLURGY INSTITUTE BOR
UDK: 622

ISSN: 2334-8836 (Štampano izdanje)
ISSN: 2406-1395 (Online)

UDK: 622.236.2/.73(045)=111
DOI: 10.5937/mmeb2501041S

Received: 06.05.2025.
Revised: 28.05.2025.
Accepted: 30.05.2025.

Original Scientific Paper
Mining Engineering

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# SELECTION OF THE OPTIMAL FEEDING VARIANT FOR HAMMER CRUSHERS IN ORDER TO ACHIEVE THE DESIGNED PARAMETERS OF CRUSHED COAL[***]

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***Abstract***

*The process of coal crushing for the Kostolac "B" Thermal Power Plant is carried out at the "Drmno" crushing plant using two hammer crushers of Czechoslovak production (PSP Engineering a.s. Prerov), type KDV 1137, with a nominal capacity of 1350 t/h, an electric motor power of 1000 kW, and a rotational speed of n = 593 min* $^{-1}$ *(the circumferential-peripheral speed of the hammers is approximately 49 m/s).*

*This type of crusher requires a specific feeding regime, meaning that the material must be delivered to a designated space between the impact rollers and the rotor. Additionally, the height from which the material falls into the crusher is limited to 2.2 times the rotor diameter. It is crucial that the feeding speed of the crusher remains below 2 m/s and that the material falls precisely into the designated crushing zone.*

*This study examines the selection of the optimal variant for uniform crusher feeding to reduce the uneven wear of the hammers.*

***Keywords:*** *Coal, hammer crushers, crushing, thermal power plant*

## 1 INTRODUCTION

The capacity of the "Drmno" open-pit mine is 9,000,000 tons per year of raw coal, and the distribution of this coal to the thermal power plants "A" and "B" is shown in Table 1.

From the data presented in Table 1, it can be concluded that achieving the annual capacity of 6,300,000 tons of raw coal for the needs of Thermal Power Plant Kostolac "B" is enabled by operating two crushers with a capacity of 1,200 t/h, which corresponds to approximately 2,625 hours per year of effective operation of the Drmno crushing plant. [1]

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[***] *The authors would like to thank Electric Power Industry of Serbia A.D. – Branch "Thermal Power Plants and Mines Kostolac", Open–Pit Mine "Drmno". This work was financially supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, Contract No. 451-03-136/2025-03/200052.*

**Table 1** *Capacities of crushers and thermal power plants Kostolac A and B*

| Parameter | Thermal Power Plant „Kostolac B” | Thermal Power Plant „Kostolac A” |
|---|---|---|
| Annual Capacity (tons / year) | 6.300.000 | 2.700.000 |
| Working time | 300 days x 3 shifts / day = 900 shifts / year | |
| Tons per day | 21000 | 9000 |
| Tons per shift | 7000 | 3000 |
| Average hourly capacity (tons/hour) | 2400 | 1000 |
| Effective working time | 2625 h/y | 2700 h/y |
| Maximum capacity (tons/hour) | 2700 t/h | 1200 t/h |

This means that the crushers can occasionally operate with a capacity lower than the average, which is 1,200 t/h per crusher, and even as low as 1,000 t/h. With a combined capacity of 2,000 t/h (2 x 1,000 t/h), the required annual operating time for the Drmno crushing plant is 3,150 hours.

The increase in the capacity of the "Drmno" open-pit mine to 12,000,000 tons per year will be achieved through a new crushing line that is currently under construction. The bulk density of raw coal varies, depending on particle size and quality, within the range of 0.65 to 0.9 t/m³. [2] For calculation purposes, a value of 0.76 t/m³ has been adopted. For raw coal from the "Drmno" open-pit mine, a natural angle of repose of 38º has been adopted.

The operation of the crushing plant can be evaluated based on the fulfillment of requirements for the desired granulometric composition, i.e., the appropriate particle size of crushed coal. There are two primary requirements regarding the granulometric composition of the crushed product:

*Crushed coal 100% –50 mm, with the content of the –30+0 mm size class in the crushed coal being at least 85%, and the content of the –50+30 mm size class being a maximum of 15%.

*Requirement by A. Mazurkiewicz (Furnace and Boiler Designer from Poland): Crushed coal should have a particle size of 100% –60 mm, with the content of the –40+0 mm size class being at least 95%, and the content of the –60+40 mm size class being a maximum of 5%. [3]

To achieve the designed granulometric composition, according to the equipment manufacturer's requirements [4,5] and the technical manual for this crusher, the following conditions must be met:

- According to the manufacturer's specifications, the maximum input coal size must be 800 mm, or the volume of individual pieces must be less than 0.1 m³. However, the technical manual for this crusher specifies a maximum input coal size of –450 mm.
- Feeding must be continuous, with a coal flow speed of a maximum of 2 m/s, distributed evenly across the entire rotor width, entering the feeding zone which ranges from 20 to 40º (45º) in the direction of rotor rotation with hammers.
- The feeding capacity should range between 1250 and 1450 t/h. Within this capacity range, the electric motor current drawn by the crusher should be between 90 and 110 A.
- During crusher operation, the gap, which is adjusted by moving the third impact roller, should be regulated according to the degree of hammer wear.

## 2 COAL CRUSHING PROCESS FOR THERMAL POWER PLANT "KOSTOLAC B"

All the coal arriving at the Drmno crushing plant is directed for crushing via chute S1. In the case of separating large coal pieces, only the oversize from the cylindrical sizing screens R3 and R4, installed above the belt feeders, is processed.

If all the coal arriving at the Drmno crushing plant is to be crushed, then after chute S1, the coal gravitationally falls onto chute S2, which evenly splits the coal stream into two halves and directs it onto belt feeders TR6 and TR7. Belt TR6 feeds coal into hammer crusher D1, while belt TR7 feeds coal into hammer crusher D3.

The original design planned for the installation of three hammer crushers: D1, D2, and D3. The function of the belt feeders TR6 and TR7 was to supply all three crushers, which was made possible through the reversible operation of the conveyors. The expected particle size after crushing was approximately 85% –30 mm.

Hammer crusher D2 was dismantled due to problems that occurred with feeding the crushers, as the installed feeders TR6 and TR7 did not provide an optimal material entry trajectory into the crushers.

**Table 2** *Technical characteristics of crushers D1 and D3*

| Crushers D1 and D3 | |
|---|---|
| Number of crushers | N = 2 |
| Rotor diameter | D = 1600 mm |
| Rotor width | B = 2200 mm |
| Rotor speed | n = 600 o/min |
| Maximum input size | Umax = 800 mm |
| Output particle size | I = 0 – 40 mm |
| Motor power | P = 1000 kW |
| Capacity | Q = 1350 t/h |

The total number of hammers on the crusher is 104 (Figure 1), which are arranged in 8 rows with 13 hammers each. The crusher housing does not have a grate, and the particle size of the output product is regulated by adjusting the distance between the hammers and the impact rollers.

**Figure 1** *Arrangement of hammers on the crusher shaft [1]*

The crushed coal is collected on conveyor belt TR10 and then, via a system of belt conveyors, it is deposited onto one of the crushed coal stockpiles (A, B, C, and D) located in front of Thermal Power Plant Kostolac “B”, or it is directly transported to the bunkers of blocks B1 and B2 of the power plant, without intermediate storage.

Figure 2 shows the feeding zone of crushers KDV1137.

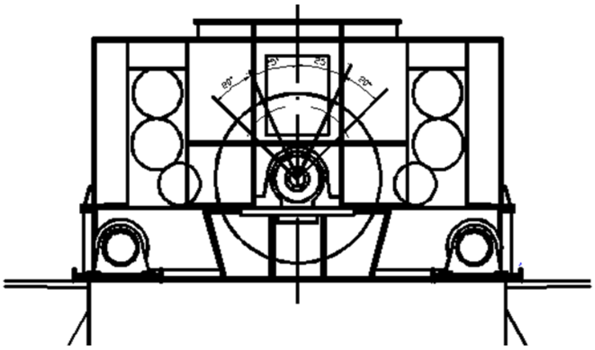

**Figure 2** *Hammer crusher KDV1137*

The crushers are mounted on appropriate reinforced concrete foundations. Feeding of the crushers is performed using belt feeders TR6 and TR7, which handle raw coal with a particle size of –400 (1000)+0 mm directly from conveyor belt TR0 (via chutes S1 and S2, or from the oversize of screens R3 and R4, with a particle size of –150+0 mm).

The adjustment of the gap between the lower impact roller and the hammers on the rotor is performed depending on the degree of hammer wear. The method of hammer attachment allows them to be rotated after wear, which enables better utilization of the hammers.

Figures 3 and 4 show photographs of the shaft with hammers and the lower impact roller, where the side walls of the discharge opening are visible. These walls are inclined inward, which is contrary to the manufacturer's recommendations.

The discharge opening of the crusher must have vertical side walls, perpendicular to the rotor axis, while the walls parallel to the rotor must be angled at 30º (inverted funnel).

**Figure 3 and Figure 4** *Shaft with hammers and lower impact roller [1]*

Figure 5 shows the granulometric composition (% – mm) of raw coal and figure 6 shows granulometric composition (% – mm) of crushed coal from open–pit mine "Drmno".

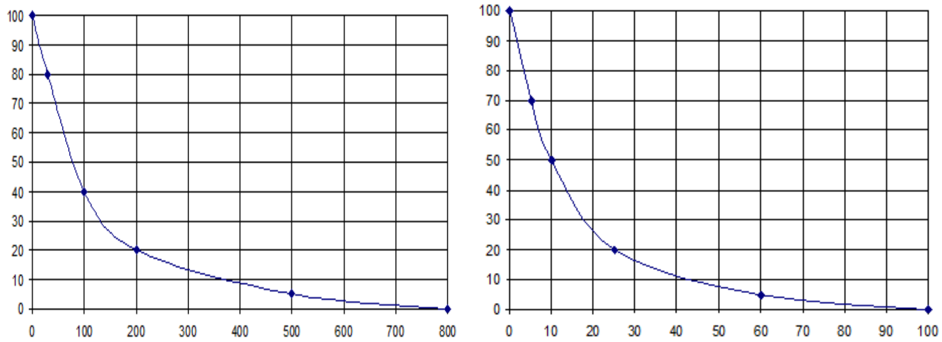


**Figure 5 and Figure 6** *Granulometric composition (% - mm) of coal from open-pit mine "Drmno" [2]*

Periodic monitoring of the condition and operation of the crushing plant revealed the following:

- Feeding of the crushing plant is continuous, with capacity control in place.
- Coal pieces up to approximately 1000 mm in size are entering the crushers.
- Coal moisture content remained within a consistent range of about 40% ± 2.3%.
- The speed of the belt feeder feeding the crusher is below 2 m/s, thus satisfying the requirement for continuous feeding.
- The width of the belt feeder, B = 2000 mm, is slightly larger than the crusher's inlet opening, which is B = 1900 mm.
- The belt feeder has a trough-shaped cross-section, which means the material is unevenly distributed, with the thickness of the coal layer being greatest at the center of the cross-section.
- The impact plate, which is designed to direct material into the crushing zone, is positioned so that its center, where the material from the conveyor belt primarily strikes, is located approximately 0.5 m from the vertical axis of the rotor and is installed at a height of over 2 m.
- The hammers wear unevenly and irregularly, with faster and more significant wear occurring at the center, which prevents proper adjustment of the lower impact roller. The particle size of the crushed coal depends on the degree of hammer wear, although this dependency cannot be clearly identified from the analysis of granulometric composition. A greater impact on the particle size of the crushed coal comes from the uneven hammer wear across the width of the shaft and the inability to properly adjust the gap between the hammers and the lower impact roller.

The general conclusion, considering both crushers in the Drmno crushing plant (D1 and D3), is that the hammers wear unevenly, specifically, they wear much faster in the middle of the shaft than at the ends. This results in difficulty adjusting the gap of the crusher's discharge opening.

The manner in which the hammers are mounted on the shaft attached on one side to a disc and on the other side to a sleeve also contributes to greater wear on the side facing the disc. After a certain period, the discharge opening can no longer be properly adjusted, which leads to a particle size that is larger than the designed specification.

This uneven hammer wear is primarily due to:

Uneven feeding of the crusher across the width of the rotor, and the type of material used for manufacturing the hammers.

The gap between the rotor and the lower impact roller is adjusted in steps, specifically in four steps of 20 mm each. In an ideal case, with uniform hammer wear, the gap would, through natural wear of the crushing bodies, range between 40 and 60 mm. After this, a new adjustment would reduce the gap to 40 mm. However, the mere increase of the gap over time indicates that it is impossible to continuously maintain the desired particle size of the crushed coal. Due to uneven hammer wear, the gap adjustment is made according to the longest hammers, i.e., the least worn hammers, which are located at the ends of the shaft. As a result, in the central crushing zone, the gaps cannot be adjusted to the appropriate size.

In that area, the hammers have reduced mass, which decreases their crushing potential. The larger gap and reduced hammer mass result in coarser crushed coal.

## 3 ALTERNATIVE SOLUTIONS FOR CRUSHER FEEDING

After analyzing the current state of coal crushing and the feeding of hammer crushers in the Drmno crushing plant, three main new feeding solutions are proposed for consideration to achieve the designed particle size parameters of crushed coal, i.e., 15% –60+30 mm and 85% –30 mm:

1. Reconstruction of existing belt feeders, by reducing speed and increasing the coal layer height on the feeder, with adjustment of the entry trajectory into the crusher.
2. Replacement of existing belt feeders with chain scrapers.
3. Replacement of existing belt feeders TR6 and TR7 with plate feeders.

All three proposed solutions are feasible, each with its own advantages and disadvantages. This paper presents the basics of all three proposed solutions and the selection of the most optimal variant, which will be further developed by the equipment supplier in collaboration with the investor.

### 3.1. Reconstruction of existing belt feeders by reducing speed and increasing coal layer height on the feeder with adjustment of entry trajectory into the crusher

This solution involves replacing the existing belt feeders and acquiring new ones, with a flat profile rather than a trough profile, using more durable rubber and closely spaced rollers beneath the belt. The drive motor would be equipped with a frequency regulator to control the rotation speed, thus adjusting the belt speed. The belt speed would be significantly reduced, thereby increasing the coal layer height on the belt.

Figure 7 shows the appearance and capacity calculation of a belt feeder with a width of 2000 mm.

| SELECTION AND CALCULATION OF BELT FEEDER | | | | | |
|---|---|---|---|---|---|
|  | | | | | |
| Type of feeder | | | Belt feeder | | |
| Feeder manufacturer | | | As per investor's choice | | |
| Feeder width | | | B = 2000 mm | | |
| Effective feeder width | | | Bef = 1850 mm | | |
| Coal layer height | | | H = 1200 mm | | |
| Bulk density of coal | | | 0,85 t/m3 | | |
| Coal particle size | | | from + 0 to – 400 mm | | |
| Feeder speed | | | 12 m/min | | |
| Feeder capacity | | Q = 60 x 1,85 x 1,2 x 12 x 0,85 x 0,8 = 1086,9 t/h | | | |
| V [m/min] | 5 | 10 | 12 | 14 | 15 |
| V [m/s] | 0,083 | 0,167 | 0,200 | 0,233 | 0,250 |
| Q [t/h] | 453 | 905,8 | 1086,9 | 1268,1 | 1358,6 |

**Figure 7** *Appearance and capacity calculation of a belt feeder*

This requires reconstruction of the chute and checking the load-bearing capacity of the structural construction, due to the increased load, mainly caused by the coal layer on the feeders.

The belt feeder would be equipped with scrapers for the return side of the feeder belt.

By installing these feeders, the mass would increase due to the volume of coal above the belt by approximately 10 tons per feeder, plus an increase due to the expanded volume of the chute above the belt feeder. As seen from the calculations, a range of belt speeds has been adopted for a capacity of up to 1350 t/h, but the optimal capacity is set at 1000 t/h per crusher. This is done to ensure that the particle size of the crushed coal is as close as possible to the designed specifications. The adopted capacity allows the processing of 6,300,000 tons per year over approximately 3150 hours of effective operation per year, which can be considered a very acceptable load for the equipment in the crushing plant.

### 3.2. Replacement of belt feeders with chain scrapers

Chain scrapers are of similar construction to the scrapers used in the reserve reception bunkers. They are characterized by a high material layer and low coal feeding speed. This solution involves the complete replacement of the existing belt feeders with chain feeders.

Figure 8 shows the appearance of the chain feeder and an approximate calculation of feeding capacity, which demonstrates that with a chain speed of 11 m/s and a coal layer height of approximately 1.6 m, the desired capacity of around 1000 t/h is achieved.

SELECTION AND CALCULATION OF CHAIN FEEDER

| | | | | | |
|---|---|---|---|---|---|
| Type of feeder | | | Chain feeder | | |
| Feeder manufacturer | | | As per investor's choice | | |
| Feeder width | | | B = 2000 mm | | |
| Effective feeder width | | | Bef = 1850 mm | | |
| Coal layer height | | | H = 1600 mm | | |
| Bulk density of coal | | | 0,85 t/m3 | | |
| Coal particle size | | | od + 0 do – 400 mm | | |
| Feeder speed | | | 12 m/min | | |
| Feeder capacity | | Q = 60 x 1,85 x 1,6 x 12 x 0,85 x 0,6 = 1086,9 t/h | | | |
| V [m/min] | 8 | 9 | 10 | 11 | 12 |
| V [m/s] | 0,133 | 0,150 | 0,167 | 0,183 | 0,200 |
| Q [t/h] | 724,6 | 815,2 | 905,8 | 996,3 | 1086,9 |

**Figure 8** *Appearance and capacity calculation of chain scraper*

In this variant, in addition to the mass of the chain feeders, the mass of coal on the feeder also increases, which amounts to approximately 15 tons, plus an increase in the mass of the chute, whose side walls must correspond to the increased height of coal being fed into the crushers.

### 3.3. Replacement of belt feeders with apron feeders

As the third solution, the replacement of the existing belt feeders with plate feeders was considered. The reason for this solution is the significant drop height of coal from chute S1 onto the feeders, and in this regard, the plates of the feeder provide the highest level of safety for operation. This machine also has disadvantages, including its significant weight and the necessity of installing cleaning devices beneath the return side of the feeder plates. Figure 9 shows the calculation of the apron feeder for the required capacity of 1000 t/h.

| SELECTION AND CALCULATION OF PLATE FEEDER | | | | | |
|---|---|---|---|---|---|
|  | | | | | |
| Type of feeder | | | Apron feeder | | |
| Feeder manufacturer | | | As per investor's choice | | |
| Feeder width | | | B = 2100 mm | | |
| Effective feeder width | | | Bef = 2000 mm | | |
| Coal layer height | | | H = 1100 mm | | |
| Bulk density of coal | | | 0,85 t/m3 | | |
| Coal particle size | | | od + 0 do – 1000 mm | | |
| Feeder speed | | | 12 m/min | | |
| Feeder capacity | | Q = 60 x 2 x 1,1 x 12 x 0,85 x 0,8 = 1077,1 t/h | | | |
| V [m/min] | 6 | 9 | 10 | 12 | 15 |
| V [m/s] | 0,100 | 0,150 | 0,167 | 0,200 | 0,250 |
| Q [t/h] | 538,6 | 807,8 | 897,6 | 1077,1 | 1346,4 |

**Figure 9** *Appearance and capacity calculation of plate feeder*

## 4 SELECTION OF A NEW CRUSHER FEEDING SOLUTION

A brief comparative analysis of the proposed solutions revealed the following:

1. The proposed belt feeder has the disadvantage of receiving coal from a great height (chutes S1 and S2), which increases the risk of damage to the rubber belt. The return side of the belt is cleaned using scrapers.
2. The proposed chain feeder has an inconsistent coal height and requires a large height of about 1.6 m. There is not enough space for that height, and the discontinuity of the coal height entering the crusher is not favorable. The return side of the feeder is cleaned by an additional scraper with a single plate on the underside.
3. 
4. The proposed plate feeders, despite having increased weight compared to the previous two solutions, offer an advantage due to the robustness of the machine. They maintain a continuous height that is adjusted and regulated by speed, allowing the feeding capacity to be kept constant. They have a low input speed of material into the central crushing zone, and they maintain a uniform height across their entire width, making

it realistic to expect uniform hammer wear in the crusher. The plate feeder requires the installation of a chain feeder for cleaning the return side of the plates.

After analyzing all three described proposals and consulting with the Investor, the decision was made to replace the existing belts TR6 and TR7 with appropriate plate feeders, which are robust and can meet the conditions for receiving coal through chutes S1 and S2, as well as enabling smooth feeding of the crushers into the center of the crushing area.

## 5 PRESENTATION OF THE NEW CRUSHER FEEDING SOLUTION

After replacing the existing belt feeders with new plate feeders, the designed parameters of the crushed coal were achieved. The new solution ensured even feeding of crushers D1 and D3, resulting in uniform hammer wear [3].

With uniform hammer wear, it became possible to adjust the gap using the impact roller, which increased the service life of the hammers and reduced the number of hammer replacements on an annual basis.

Before the reconstruction, hammers were replaced two or three times per year, depending on the quality of the material. After the reconstruction, hammer replacement is performed during the planned maintenance of the crushing plant.

In addition to uniform hammer wear and extended hammer life, proper material delivery to the crushing zone was achieved, fulfilling the required parameters of the crushed coal.

Figures 10 and 11 show the new apron feeders PD6 and PD7 installed at the Drmno crushing plant during the trial operation and capacity verification phase.

**Figure 10** *Apron feeder PD6 [3]*

**Figure 11** *Apron feeder PD7 [3]*

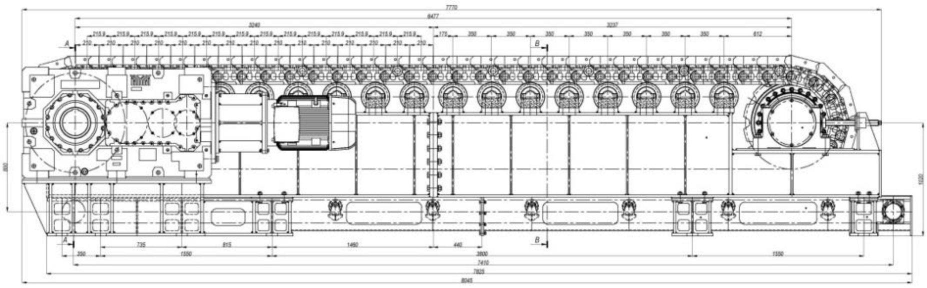

**Figure 12** *Apron feeder PD6/7 [3]*

## 6 CONCLUSION

This paper presents the selection of the crusher feeding method aimed at achieving uniform hammer wear and the designed parameters of crushed coal.

First, a description of the existing state was provided, highlighting the issue of uneven hammer wear, which results in the inability to adjust the gap in the crusher. As a consequence, it is impossible to achieve the designed parameters of the crushed coal.

The process of forming alternative solutions was presented, along with an analysis and evaluation of each variant.

Finally, the most optimal variant was selected, and a brief description of the state after installation was provided.

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