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**DETERMINATION THE LIMIT CAPACITY OF
PRODUCTION THE ROOF COAL SERIES AT THE OPEN PIT
GACKO-CENTRAL FIELD IN A FUNCTION OF USE A
DISCONTINUOUS-COMBINED EXPLOITATION SYSTEM*****

Abstract

This paper presents the methodology of determining and analysis results of the limit production capacity of coal in the roof exploitation zone of the open pit Gacko-Central Field in a function of configuration and parameters of the combined system. The coal exploitation system at the open pit Gacko-Central Field mine is a system of exploitation characterized by the complex conditions under which it operates, with the use of continuous, combined and discontinuous coal and waste exploitation systems. It is also characterized by the existence of two spatially dislocated sites, in which the exploitation is carried out under significantly different conditions. A complex solution for coal exploitation is the result of optimization a large number of mutually determined technological processes and systems, both in terms of the possibility of applying a certain complex of mechanization, as well as in terms of individual capacities at the site of excavation. As a criterion for success the exploitation system, a unit cost of exploitation was adopted including the capital and operational costs of a variable part of combined system.

Keywords: *combined system of exploitation, selective exploitation, transport by belt conveyors, truck transport, coal*

**BASIC CONDITIONS AND
CHARACTERISTICS OF THE
SURFACE COAL EXPLOITATION
AT THE OPEN PIT GACKO –
CENTRAL FIELD**

Intensive coal exploitation in the Gacko Coal Basin began with opening the Open Pit Gračanica in the western part of the basin in 1977, in order to open the open pit in 1982. In mid 1983, the Thermal Power Plant Gacko has started its operation with the installed power of 300 kW. From then onwards, the coal exploitation is developed

with the almost exclusive intention of providing the corresponding amount of fuel for the thermal power plant, that is, in a function of electricity generation.

In the previous exploitation period, the coal production is developed in different parts of the deposit, in various structural, geomechanical, hydrogeological, qualitative

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and other working conditions, as well as various legislative, social, infrastructural, market and economic conditions. All of this has resulted in the necessary adjustment of the exploitation system in order to ensure the required capacity and quality of coal, and the elements and parameters of the system were most often conditioned by numerous limiting factors [1].

Also, numerous project solutions have been formed on the basis of previous research results that have not been of sufficient reliability. The lack of knowledge about the characteristics of the working environment resulted in the fact that the applied exploitation systems worked with lower efficiency than the designed ones. Within the factors that particularly influence the efficiency of production, the geomechanical characteristics of detection (occurrence of layers with extremely high excavation resistance above the guaranteed excavation force of the rotary excavators) and the structural characteristics of a coal seam (stratification of a coal seam with a frequent change of coal and waste interbeds) can be distinguished.

This should include the added variability of parameters of the working environment and structural and qualitative characteristics of coal. In order to fulfill the basic goal of exploitation, i.e. to provide the corresponding quantity of coal of the given quality, it was necessary to adapt to concrete conditions in the field. Initially conceived as an open pit with a continuous exploitation system, the open pit Gračanica, formed in the west part of the deposit, has undergone a series of transformations by introduction a discontinuous equipment. Discontinuous equipment was introduced first of all on coal within the combined system (hydraulic bucket excavator - trucks - crusher – belt conveyors - landfill) and then on overburden within the discontinuous system. With the completion of works in the western part of the deposit, the

extension of the open pit Gračanica was also done in a part of the Field C, that is, in the central part of deposit.

This relocation of works was accompanied by the introduction of a combined system on overburden with retention also on a combined system on coal, continuous systems on overburden as well as a discontinuous system, primarily designed for exploitation the interbed and layered tailings. Problems related to the implementation of production plans, mainly related to the inability to provide the designed structures of the basic and auxiliary mechanization, led to a need of providing a part of coal from the roof coal series which is characterized by a lower quality of coal, distinct stratification and favorable relationship between waste/coal. The coal exploitation from the roof coal series is spatially dislocated in relation to the rest part of the open pit (Figure 1).

Also, the beginning of work realization, according to the Main Mining Design of the open pit Central Field for capacity of 2.3×10^6 t/year of the run-of-mine coal, has started the coal exploitation on a new open pit. This project has continued the exploitation of main and footwall coal seams in the area of the Central field of the Gacko deposit, but also the coal exploitation is planned in a part of the roof coal series [2]. In addition to being spatially dislocated, the site in the roof coal series is characterized by the specific exploitation conditions (structural and qualitative coal characteristics) and resources that, besides the natural limits of expansion the coal seams, are limited by the administrative boundary of concession. All these factors represent limitations in determining the production capacity of coal from the roof coal series. On the other hand, the production capacity is an important factor for defining the most favorable system of exploitation and techno-economic parameters of the applied system.

Figure 1 Location of the open pit site Gacko-Central field ■ - site of the roof coal series, ■ - site of the Central exploitation zone

Currently, the coal exploitation in the roof coal series is carried out by selective excavation of coal and waste with hydraulic bucket excavators. Transport of waste is discontinuous to the external landfill, and transport of coal is combined, discontinuous to the crusher, positioned in the northern part of the central exploitation zone. Position of the crusher is conditioned by the available belt conveyors and position for coal transport in the northern part of the central exploitation zone.

The existing design solution has taken into account the analysis results of application the combined system in the existing form and conditions of increasing the length of continuous transport to the site in the roof exploitation zone. In order to select a more favorable combined system in terms of length of continuous and discounted transport, the number of belt conveyors, number of trucks in discontinuous transport, the existing system configuration was analyzed as well as the combined system with extension of continuous transport in a length of about 1400 m

with two additional belt conveyors [3]. A new position of the existing coal crusher is determined on the edge of the roof coal series at the shortest distance from the center of works for the next five-year period. The conveyor lines are such that they do not interfere with development the front of works or have a stationary character. The adopted belt conveyors have a width of 1200 mm and speed of 4.5 m/s meet the needs in terms of capacity, grain-size distribution of crushed

In calculation the capital and operating costs, they are not deducted to the present value, since their relative absolute value is not important for comparison the variants, but the relative value.

Considering that the open pit has already has the certain elements of the system (crusher, part of the conveyor belt and excavation - loading equipment), and that these elements are common to the considered variants, the techno-economic parameters of the combined system are compared only in the areas in which they differ.

CALCULATION THE TRANSPORT PARAMETERS WITHIN THE COMBINED SYSTEM OF THE ROOF COAL ZONE

Figure 2 presents the coal transportation routes in the Variant 1 and Variant 2. The Variant 1, the case where there is a crusher in the old location and the transport is discontinuous (line of purple color) by trucks

with capacity of 55 t. The Variant 2, a crusher on a new location, continuous transport (red line), two belt conveyors and discontinuous transport inside the open pit (green line) by trucks with capacity of 55 t.

Figure 2 Coal transportation routes in the Variant 1 and Variant 2

Table 1 lists the transport lengths that have been included in the budget of the transport capacity.

Table 1 Quantities of materials that need to be excavated for a ramp construction

	Length of discontinuous transport	Length of continuous transport
Variant 1	2100	0
Variant 2	700	1400

The Talpac computer program was used to calculate the system of excavator - truck. On the basis of the input parameters, the time capacities of trucks for the Variant 1 and Variant 2 are calculated.

The Talpak software package is a simulation model of loading and transport process at the open pits. Software enables the optimization of transport fleet, calculation the technical-economic parameters of the

equipment operation, such as a cycle length, capacity, etc. [4]. In this particular case, this program was used to determine the parameters for coal transport from the roof zone in the Variant 1, when there is only a truck transport and, in Variant 2, when there is a truck transport just inside the open pit. Figure presents the calculation results for the Variant 1. Figure 4 presents the calculation results for the Variant 2.

Production Summary - Full Simulation				
Haulage System: Haulage System-1		Haul Cycle: [PRJ] Trava		
Material: [PRJ] Ugal		Route: [PRJ] Route-1		
Loader:		[PRJ] KOM-15.5% 100-G		
Availability	%	100.00		
Bucket Fill Factor		0.92		
Average Bucket Load Volume	cu.metres	5.46		
Average Payload	bcm	4.55		
Operating Hours per Year	OpHr/Year	3,500.00		Op. hrs factored by availability
Average Operating Shifts per Year	shifts/Year	500.00		Shifts factored by availability
Average Bucket Cycle Time	min	0.50		
Production per Operating Hour	bcm	354.91		Max. prod. based on 100% avail.
Production per Loader Operating Shift	bcm	2,484		Avg. production factored by avail.
Production per Year	bcm	1,242,171		
Wait Time per Operating Hour	min	6.47		
Truck:		[PRJ] BEL-42 7533 (22.33-T Gear Ratio)		
Availability	%	100.00		
Payload in Template	bcm	27.56		
Operating Hours per Year	OpHr/Year	3,500.00		
Average Payload	bcm	27.59		
Production per Operating Hour	bcm	177.45		
Production per Loader Operating Shift	bcm	1,242		
Production per Year	bcm	621,086		
Queue Time at Loader	min/ Cycle	0.35		
Spot Time at loader	min/ Cycle	0.40		
Average Loading Time	min/ Cycle	2.53		
Travel Time	min/ Cycle	3.53		
Spot Time at Dump	min/ Cycle	0.30		
Average Dump Time	min/ Cycle	0.20		
Average Cycle Time	min/ Cycle	7.31		
Fleet Size		2		
Average No. of Bucket Passes		6.06		
Haulage System				
Production per Year	bcm/Year	1,242,171		
Discounted Capital Cost	\$bcm	0.00		Loading Methodology
Discounted Operating Cost	\$bcm	0.00		Single Sided
Discounted Average Cost	\$bcm	0.00		Full Truck
Excavation Target	bcm	1,077,000.00		Average for 150 Shifts
Time to move Excavation Target	Days	316.68		
Loader Hrs to move Target	Op. Hours	3,035		
Total Truck Hrs to move Target	Op. Hours	6,069		
Total cost to move Target	\$	0		

Figure 3 Calculation results of the truck transport for the Variant 1

Production Summary - Full Simulation				
Haulage System: Haulage System-1		Haul Cycle: [PRJ] Trava 2		
Material: [PRJ] Ugal		Route: [PRJ] Route-1		
Loader:		[PRJ] KOMATSU PC 800-G		
Availability	%	100.00		
Bucket Fill Factor		0.92		
Average Bucket Load Volume	cu.metres	5.46		
Average Payload	bcm	4.55		
Operating Hours per Year	OpHr/Year	3,500.00		Op. hrs factored by availability
Average Operating Shifts per Year	shifts/Year	500.00		Shifts factored by availability
Average Bucket Cycle Time	min	0.50		
Production per Operating Hour	bcm	396.76		Max. prod. based on 100% avail.
Production per Loader Operating Shift	bcm	2,777		Avg. production factored by avail.
Production per Year	bcm	1,388,672		
Wait Time per Operating Hour	min	1.04		
Truck:		[PRJ] BEL-42 7533 (22.33-T Gear Ratio)		
Availability	%	100.00		
Payload in Template	bcm	27.56		
Operating Hours per Year	OpHr/Year	3,500.00		
Average Payload	bcm	27.58		
Production per Operating Hour	bcm	79.35		
Production per Loader Operating Shift	bcm	555		
Production per Year	bcm	277,734		
Queue Time at Loader	min/ Cycle	2.24		
Spot Time at loader	min/ Cycle	0.40		
Average Loading Time	min/ Cycle	2.53		
Travel Time	min/ Cycle	10.59		
Spot Time at Dump	min/ Cycle	0.30		
Average Dump Time	min/ Cycle	0.20		
Average Cycle Time	min/ Cycle	16.26		
Fleet Size		5		
Average No. of Bucket Passes		6.06		
Haulage System				
Production per Year	bcm/Year	1,388,672		
Discounted Capital Cost	\$bcm	0.00		Loading Methodology
Discounted Operating Cost	\$bcm	0.00		Single Sided
Discounted Average Cost	\$bcm	0.00		Full Truck
Excavation Target	bcm	1,077,000.00		Average for 150 Shifts
Time to move Excavation Target	Days	283.27		
Loader Hrs to move Target	Op. Hours	2,714		
Total Truck Hrs to move Target	Op. Hours	13,572		
Total cost to move Target	\$	0		

Figure 4 Calculation results of the truck transport for the Variant 2

Calculation of the transport parameters for belt conveyors was done using the appropriate software solution according to the method prescribed by the technical

standards [5]. In Figures 5 and 6, the output form of the program is shown, and a part of the output listing for the T1 and T2 belt conveyors is given.

Transportne trake

OZNAKA TRANSPORTERA t 928-944

Sirina trake (mm) 1200 Brzina trake (m/s) 4.5 Dužina trake (m) 450 Vrsta uložaka EP-500 Zahtevani kapacitet (t/h) 480

Gornja gumena obloga (mm) 4 Donja gumena obloga (mm) 2 BROJ ULOŽAKA 1 Broj valjaka u slogu 3 Ugao nagiba bocnih valjaka 30

Precnik valjaka Proracun 133 133

Zapreminska masa (t/m³) 1.3 Nasipni ugao materijala (o) 20

Kota pogonske stanice 928 Kota povratne stanice 944 Koeficijent trenja 0.025

K1 - koeficijent smanjenja kapaciteta u funkciji načina nasipanja materijala 0.95

Koeficijent sigurnosti na kidanje	Potrebna snaga motora (kW)	Instalisana snaga motora (kW)
26.25	47.04	55.34
18.33	67.35	79.24

Za maksimalni kapacitet

Za zahtevani kapacitet

Otpor kretanju trake (daN) 1526.7

Vucna sila na obodu bubnja (daN) 3272.6

Zatezna sila (daN) 3491.7

PRORAČUN

Transporter: T1

Length of conveyor (m): 450

Level of drive station (m): 944

Level of return stations (m): 940

Altitude difference (m): 4.

Slope of conveyor (%): .89

Track width (m): 1200

Bandwidth (m): 4.5

Velocity resistance (daN): 2297.1

Tensile force on the rim of drum (daN): 4923.9

Tensile force (daN): 5253.7

Maximum capacity (t/h-m³/h): 2882.96 - 2217.66

Required capacity (t/h-m³/h): 480. - 369.23

Installed engine power (kW): 119.22

Figure 5 Program form and a part of the output listing for the T1 conveyor

Transportne trake

OZNAKA TRANSPORTERA t 944-940

Sirina trake (mm) 1200 Brzina trake (m/s) 4.5 Dužina trake (m) 1020 Vrsta uložaka EP-500 Zahtevani kapacitet (t/h) 480

Gornja gumena obloga (mm) 4 Donja gumena obloga (mm) 2 BROJ ULOŽAKA 1 Broj valjaka u slogu 3 Ugao nagiba bocnih valjaka 30

Precnik valjaka Proracun 133 133

Zapreminska masa (t/m³) 1.3 Nasipni ugao materijala (o) 20

Kota pogonske stanice 944 Kota povratne stanice 940 Koeficijent trenja 0.025

K1 - koeficijent smanjenja kapaciteta u funkciji načina nasipanja materijala 0.95

Koeficijent sigurnosti na kidanje	Potrebna snaga motora (kW)	Instalisana snaga motora (kW)
2.62	472.03	555.33
6.18	199.72	234.96

Za maksimalni kapacitet

Za zahtevani kapacitet

Otpor kretanju trake (daN) 4527.

Vucna sila na obodu bubnja (daN) 9703.9

Zatezna sila (daN) 10353.8

PRORAČUN

Transporter: T2

Length of conveyor (m): 1020

Level of drive station (m): 944

Level of return stations (m): 940

Altitude difference (m): 4.

Slope of conveyor (%): .39

Track width (m): 1200

Bandwidth (m): 4.5

Resistance to movement of the band (daN): 4527.

Tensile force on the rim of the drum (daN): 9703.9

Tensile force (daN): 10353.8

Maximum capacity (t/h-m³/h): 2882.96 - 2217.66

Required capacity (t/h-m³/h): 480. - 369.23

Installed engine power (kW): 234.96

Figure 6 Program form and a part of the output listing for the T2 conveyor

Based on the results obtained in calculation for truck transport and transport by belt conveyors, the unit normative costs for the Variant 1 and Variant 2 have been

determined and shown in Table 2. In Table 3, the unit costs for transport by belt conveyors are given.

Table 2 Unit costs for truck transport according to the variant solutions

	Variant 1		Variant 2	
	Quantity	Unit costs (€/t)	Quantity	Unit costs (€/t)
Fuel norms (l/cm³)	0.66998	0.26571	0.29993	0.11895
Lubricant norms (kg/cm³)	0.06700	0.07592	0.02999	0.03399
Oil norms (l/cm³)	0.07370	0.14614	0.03299	0.06542
Tire norms (pcs.)	0.00002	0.00685	0.00001	0.00307
Spare parts norms (kg/cm³)	0.00500	0.02833	0.00500	0.02833
TOTAL (€)		0.52296		0.24976

Table 3 Unit costs for transport by belt conveyors for the Variant 2

Type	Norm (unit/m ³)	Unit costs (€/t)
Electric power (kWh/t)	0.0000	0.01729
Oil (kg/ t)	0.0000	0.00851
Lubricant (kg/t)	0.0000	0.00208
Sets of rollers (pcs./m³)	20%	0.02682
Sets of lower rollers (pcs./m³)	20%	0.00670
Sets of shock absorber rollers (pcs./m³)	50%	0.00102
Drums (pcs.m³)	20%	0.00653
Rubber belt B=1200 mm (m/m³)	15%	0.02857
Wipers (pcs.)	100%	0.00004
Buffer plates (pcs./m³)	100%	0.00076
Sealing rubber (pcs.)	100%	0.00229
TOTAL		0.10062

Table 4 gives the annual labor costs for the variant solutions. Labor costs are taken as the total operating costs. In addition

to the operational costs, the capital costs are calculated per year, and for the variant solutions are shown in Table 5.

Table 4 Yearly labor costs for the variant solutions

Yearly labor costs	€/year
Variant 1	204,000
Variant 2	148,800

Table 5 Capital costs per year for the variant solutions

Capital costs per year	€/year
Variant 1	340,000

Based on the previously calculated values in Table 6, the capacities of a variable part of combined systems are shown

and calculated for the unit costs of the standardized material and energy are calculated for them.

Table 6 Capacities of a variable part of combined systems and their unit costs of standardized material and energy

	Hourly capacity of truck (hm ³)	Hourly capacity of belt (hm ³)	Unit normative costs (€/t)
Variant 1	79.35	0	0.523
Variant 2	177.25	369.23	0.350

DISCUSSION

Capacity of the exploitation system is the basic techno-economic parameter, which, in addition to defining the type, number and individual capacities within the individual technological processes that make it, is also a key factor in the system efficiency [6]. The principle of system optimization in terms of capacities in the surface exploitation is based on comparison of several variants, and the techno-economic

indicators have the abrupt passes in a function of capacity, type of application the basic equipment, transport lengths, automation possibility, etc. [7,8]. In the concrete case, based on the calculated parameters of a variable part of the combined systems, a diagram of change in total costs (capital and operational) was defined, depending on the production capacity of coal, and as such shown in Figure 7.

Figure 7 Diagram of the total cost changes in a function of production capacity

The illustrated diagram shows that the introduction of new conveyors and extension the continual part of transport is a more favorable solution in the production of over 2 000 000 t. This is applied only to a specific case involving a specific type of unloading loading and transport equipment, pre-defined routes and transport conditions, and specific working environment parameters.

The obtained result is in a domain of a number of applicability analyses of combined system, which were carried out in our country and in the world. Factors that can be further analyzed, and which can significantly influence the analysis result are: the possibility of system automation, application of modern materials and more energy efficient equipment, application of mobile crushers and optimization the transport routes in terms of their elements (length, inclination, radii of curves, etc.).

Within the Strategy of mining and technology opening, development, optimization and maintenance the continuity of coal production with introduction the process of coal enrichment by dry separation at the open pit Gacko, several cases of coal production from roof coal series were considered, with a maximum capacity of 3 000 000 tons per year. In the current development stage of the open pit, the production capacity of the roof coal series is around 1 000 000 t per year. This is due to the optimization of available resources, which are, inter alia, limited by the artificial boundary of the concession. The carried out also analysis took into account the specific natural conditions of the working environment and artificial limitations, which in this case are both administrative and economic. In order to optimize the exploitation system at the open pit Gacko Central Field, it is necessary to consider the other elements that are not a part of this analysis, but which influence the overall efficiency of the open pit (production in the Central Exploitation Zone, pro-

gress the front of continuous work systems, transport length to the landfill site, seam and interbed waste, etc.).

CONCLUSION

The limit of use a discontinuous, that is, a combined system is in a function of a number of factors, among which the system capacity is the most significant. Depending on the specific exploitation conditions, available or designed basic equipment, level of labor engagement, available resources and other factors, a change in the total production costs by a particular exploitation system is not unified in terms of capacity. In addition to the costs that have a relative character, that is, directly dependent on capacity, there are also costs that have a relatively fixed character and which belong to a group of capital expenditures. In particular, these relatively fixed costs relate to the procurement of necessary equipment for achieving the target capacity. The cost comparison methodology, used in the two capacity exploitation systems, can be applied to the other similar facilities, given the increasing standardization of coal production capacities for the needs of thermal power plants.

The obtained result is within the values stated in many other analyzes of the use of discontinuous-combined systems in the world. These analyzes are usually done for the needs of the equipment manufacturer and the need to dimension the elements of exploitation system (basic equipment) and only in a small part analyze the impact of work environment characteristics as they are performed for a specific object and unique conditions. The presented analysis was carried out precisely on this principle, but the variation in influence of natural factors would certainly contribute to a more precise determination the efficiency limit of a particular discontinuous-combined system.

REFERENCES

- [1] N. Stanić, A. Doderović, S. Stepanović, M. Gomilanović, Dynamics of Development the Works of Roof Coal Series of the Open Pit Gacko By The Software Gemcom Gems - Module Cut Evaluation
- [2] S. Stepanović, R. Rajković, N. Stanić, D. Bugarin, Selection the Most Favorable Pump Type and Configuration of Pump Systems at the Open Pit Gračanica – Gacko, Mining and Metallurgy Engineering Bor br.3-4 2017.
- [3] S. Stepanović, N. Stanić, A. Doderović, M. Gomilanović, Ž. Sekulić Analysis of Losses in a Function of Selection the Level of Roof Coal Series - Coal Deposit Gacko, 50th International October Conference on Mining and Metallurgy, October 2018
- [4] N. Stanić, S. Stepanović, D. Bugarin, M. Gomilanović, Selection The Rational Model of Transport Truck by the Selective Coal Mining at the Open Pit Gacko, Mining and Metallurgy Engineering Bor, br. 1-2 2017.
- [5] N. Stanić, S. Stepanović, D. Govedarica, A. Doderović, Application the Software Solution for Calculation the Capacity of Bucket Wheel Excavators in the Complex Conditions from the Aspect of Resistance to Excavation, Mining and Metallurgy Engineering Bor, br. 3-4 2017.
- [6] S. Stepanović, N. Stanić, D. Bugarin, M. Gomilanović, Selection the Optimal Development Options of Mining Operations in the Gacko Coal Basin, Mining and Metallurgy Engineering Bor, br.3-4 2017.
- [7] V. Pavlović, D. Ignjatović, Selektivna površinska eksploatacija uglja kontinualnim sistemima, Monografija, Rudarsko-Geološki Fakultet, ISBN 978-86-7352-217-3, Beograd, 2012.
- [8] A. Lazić, S. Bošković, R. Klačar, Selektivno otkopavanje uglja na površinskim kopovima, monografija, Rudarsko-geološki fakultet, ISBN: 86-7352-078-9, Beograd, 2004.
- [9] Nehring, M. & Knights, P. & Kizil, M. & Hay, Edward, A Comparison of Strategic Mine Planning Approaches for In-Pit Crushing and Conveying, And Truck/Shovel Systems, Article, International Journal of Mining Science and Technology, 10.1016/j.ijmst.2017.12.026., 2018.