Comparison of globoid and cylindrical shearer drums' loading performance

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Synopsis

Drums of a modern longwall shearer are manufactured to include various constructional features conveying extracted material onto the face conveyor as efficiently as possible. Designing a drum with a conical shell or with reduced vane length, consequently with a stepper vane angle, is the most widely employed method in an attempt to increase loading efficiency. This study compares loading performances of two such drums, one having a conical shell with modified loading vanes, the other with a cylindrical shell with reduced vane length. Firstly, the loading performances of drums are predicted and the maximum haulage rate attainable with the drums are calculated. Then the performances of drum are compared by long-term comprehensive underground trials with coal shearers under similar conditions during the production operation of Park Termik Cayirhan coalmine in Turkey. Although higher loading performance is predicted for cylindrical drums, the *in situ* trials point out that Globoid drums have a slightly higher loading performance than cylindrical drums. Furthermore, the relationship between operational variables, i.e. extraction height, sumping depth, haulage rate and *in situ* loading performance, were investigated statistically on the basis of data gathered during the underground trials.

Keywords: longwall mining, shearer drums, loading performance.

Introduction

Recent improvements in longwall mining and technology have led to a significant increase in production speed and capacities up to 4000–5000 tons/h and 4–5 million tons/annum from a single face. Although the high production speed and capacities require a combined high performance of all longwall equipment, the shearer drum plays a key role by cutting and loading the material onto the armoured face conveyor (AFC). Although, the cutting action of shearer drums has been improved by increasing the motor power and using enhanced drums equipped with heavy-duty picks and box, the loading action of shearers is still a problem, particularly in thin seams.

The loading action of shearer drums could be best compared with the short-length screw conveyor, as noted by previous researchers[1,2]. In this model, the screw conveyor has a large diameter shell and a relatively low height of vein. The veins are terminated by a circular end plate (called as face ring) that has the same overall diameter as the vanes. The material is excavated by picks located on the face ring and vanes, then conveyed and discharged onto the face conveyor with the help of veins. The face rings of the drums where 12–25% of material is excavated in the vicinity, are formed with a 30 degree cone angle to enable easy conveyance of excavated material towards the face conveyor[1]. The material conveyed between the vanes increases linearly from the face side to the back or to the conveyor side and reaches the maximum at the discharge point of the drum. Since the amount of conveyed material reaches the maximum, in order to protect the drum from excessive wear, some drum manufacturers weld special wear plates made of tungsten carbide to the sides of the vanes at the discharge point[3].

Previous researchers suggested that the vanes should be wrapped around the drum shell with a less than 360° and overlapped at least 20°[2,4]. The higher wrap angle causes recirculation of the excavated material inside the drum aperture. In contrast, the small wrap angle prevents regular discharging of material onto the AFC, increasing the number of vanes and material speed, consequently resulting in poor loading efficiency[5]. The variables that effect the loading efficiency of shearer drums are vane angle, number and depth of vane, drum diameter and rotational speed, haulage speed, seam thickness, face gradients, the distance between drum and AFC and ancillary loading device[2,4–6].

Extensive investigations were carried out on the loading performances of shearer drums by the Mining Research and Development

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Establishment of British Coal around 1980. A computer program was developed to predict loading performances of different drums that have various design properties in a variety of working conditions[7]. Recently, some firms have manufactured shearer drums having different constructional properties in order to increase the loading performance. One of the most important designs is known as the Globoid drum. As a result of *in situ* comparison, it was reported that the performance of the Globoid drum was better than the cylindrical one in terms of grain size, dust generation and haulage rate[8]. However, the loading performances of drums were not measured; it was observed visually that the performance of the Globoid drum was better than the cylindrical drum. On the other hand, some companies have been manufacturing cylindrical shearer drums with reduced vane length in an attempt to improve loading performance of shearer drums. Although these drums have been used widely in longwall shearer machines, detailed investigations have not yet been performed to compare the theoretical and practical loading performance of drums.

In this study, the loading performance of Globoid and cylindrical drums is predicted firstly, and then compared under the practical circumstances of use at Park Termik AS Cayirhan Coal Mine in Turkey. Since the loading performance of shearers is not satisfactory, a flitting run is necessarily performed after each cutting run, thus resulting in lost production and time, consequently decreasing production volume. Globoid and cylindrical drums designed in an attempt to increase the loading efficiency are compared under similar conditions. Furthermore, the effect of working parameters on *in situ* loading performance at constant rotation speed was investigated statistically.

Constructional specifications of the drums

The Globoid drum is manufactured with several design features in an effort to increase loading efficiency. The most distinctive feature of the drum is the conical shell shown in Figure 1. Due to the conical shell, the depth of vane being minimal at the face side increases linearly across the cross-section of the drum, reaching maximum at the discharge point. Since the conveyance capacity of the drum is related to the depth of the vein, it also increases across the cross-section. In practice, the amount of extracted material, hence the conveyed material inside the drum aperture, increases from the face side towards the discharge point. The Globoid drum is designed with a conical shell in an attempt to satisfy larger volume requirements at the rear part of the drum.

In addition to the drum shell, the vanes of the Globoid drum are also formed in such a way as to increase the conveyance capacity towards the discharge point. The vanes of the drum are formed in a half elliptical shape at the goaf side to increase the conveyance area, as shown in Figure 2. This arrangement enables a larger cross-sectional area at point B compared with point A; thus the conveyance capacity increases towards the discharge point. Furthermore, the surface of the drum aperture is shaped in a circular form in order to decrease the friction between conveyed material and the drum body, thus resulting in easy material flow.

The second type of shearer drum has a cylindrical shell, as shown in Figure 3. The wrap angle of the drum is kept at 200° in an effort to increase the loading performance. At a lower wrap angle, the length of the vane decreases while the vane angle increases. With this arrangement, it is possible to raise the speed of the material inside the drum aperture. Hence, the drum is designed to take advantage of high material speed to make the loading performance better. The drum has no additional design feature to improve loading performance other than the wrap angle.

Comparison of drums' loading performance

The loading performance of drums is predicted and then compared by long-term *in situ* underground tests.

Prediction of drums' loading performance

The drum of a shearer can be thought of as a short-length screw conveyor with a large diameter shell and vanes of relatively low height[2]. Loading efficiency depends on the constructional properties of the drum and operational parameters. The extraction and conveyance rate of a drum is mainly related to drum geometry, haulage rate and the rotational speed of drum. The notations used for predicting loading performance of drums are presented in Figure 4.

The loading performance of a drum can be calculated by the equations given below.

$$V_G = D_W T V_M S_{FL} \quad [1]$$

$$V_F = \pi / 4\left(D_L^{\,2} - D_T^{\,2}\right)\Psi V_Q \quad [2]$$

$$I_F = V_F / V_G > 1 \quad [3]$$

$$V_Q = S n_W \quad [4]$$

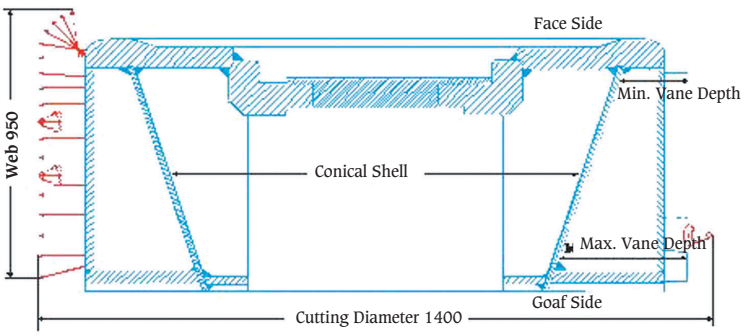


Figure 1—Cross-section of globoid drum (all dimensions are in mm)

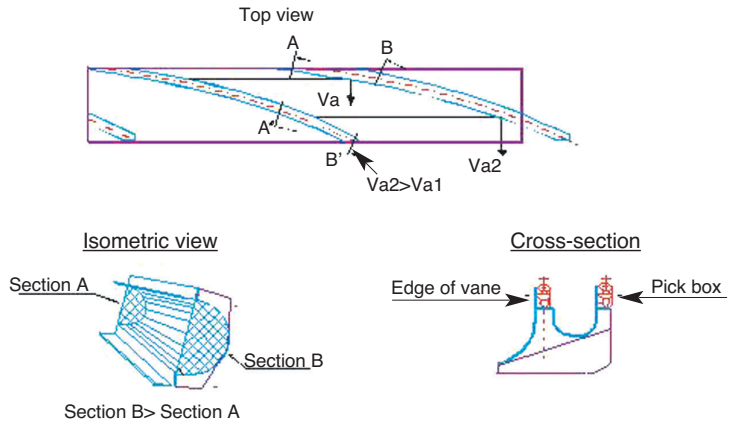


Figure 2—Arrangement of vanes in globoid drum

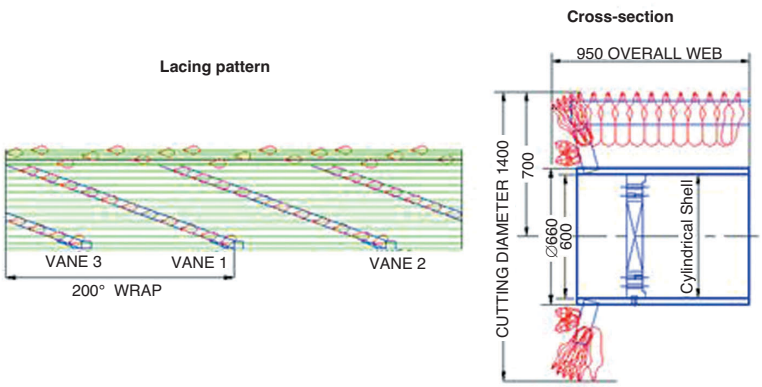
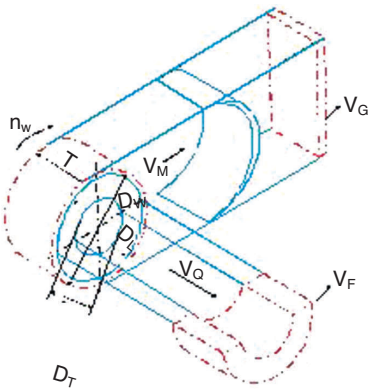


Figure 3—Lacing pattern and cross-section of cylindrical drum (all dimensions are in mm)



V_G : extraction rate (m^3/min)
V_F : conveyance rate (m^3/min)
V_M : haulage rate (m/min)
V_Q : transverse speed (m/sec)
T : drum width (m)
D_W : drum diameter over picks (m)
D_T : shell diameter (m)
D_L : drum diameter without pick (m)
n_W : drum rotational speed (rev/sec)

Figure 4—Notations used for prediction of loading performance of drums[1]

where;

S_{FL} : bulking factor of extracted material
Ψ : fill factor of drum aperture
I_F : conveyance ratio
S : pitch length of vane (m)

In order to operate the drum at constant rotational speed, the conveyance rate must be greater than the extraction rate, i.e. $I_F = V_F/V_G>1$. Otherwise the drum would become clogged.

The optimum transverse speed of the material inside the drum aperture, other than the number of vanes and geometry, depends on the drum diameter, sumping depth, haulage rate and rotational speed[1]. The construction specifications of Globoid and cylindrical drums such as diameters, the number of veins and widths are almost the same. This similarity between the drums' construction enables onto make a meaningful comparison of the drums. The constructional specifications of drums used to predict loading performance are presented in Table I. The transverse speeds of material are calculated 1.01 and 1.28 m/sec for Globoid and cylindrical drums, respectively. Since the transverse speed of the material is directly proportional to the pitch length of the vane (See Equation [3]), at constant revolution speed the cylindrical drum fitted with a stepper vane will convey material with a higher velocity than those of the Globoid drum.

The variation of the conveyance ratio with respect to haulage rate is provided in Figure 5 for both drums, assuming the bulking factor to be 1.5. From this figure, the haulage rates' limit for Globoid and cylindrical drums are calculated as 12 m/min and 17 m/min, respectively.

Considering a 15.4 m/min maximum haulage rate attainable with the shearer machine specified by the manufacturer, it can be stated that the Globoid drum would not be suitable at the maximum haulage rate of the machine. On the other hand, the high traversing speed of material enables one to operate the cylindrical drum up to 17 m/min haulage rate of the shearer. Furthermore, the conveyance ratio of the cylindrical drum is higher than those of cylindrical. Hence, on the basis of calculation results, it can be expected that the loading efficiency of the cylindrical drum will be better than the Globoid drum.

It is important to note that the conveyance volume of the Globoid drum is larger at full depth of the sump than the cylindrical drum due to its conical shell. The variation of conveyance volume and extraction rate depending on sumping depth is presented in Figure 6 for both drums. While the conveyance volume of the cylindrical drum is larger at smaller sumping depth compared with the Globoid drum, the conveyance volume of the Globoid drum is bigger above 0.7 m sumping depth.

In situ comparison of drums

The *in situ* loading performance of drums was investigated during the production operation of Park Termik Cayirhan underground coalmine in Turkey. The mine is the first fully mechanized underground mine in Turkey and is also the most modern one, with a 5 million tons/annum underground production capacity. Two coal-seams are mined separately by top and bottom retreating longwall faces in A, B and F fields with a height of 1.5 and 1.7 m respectively, whereas both seams and the intermediate layer are mined in a single operation with a height of 5 m in C field. Eickhoff EDW 200/230L and SL 300 type shearer machines are employed in the thin faces, while the Eickhoff SL 500 shearer machine is used in the thick face of C field. Since loading is not a problem in the thick seam, all trials were conducted at the thin face of B field, namely B06 bottom face, with an Eickhoff SL 300 type machine, where flitting run is necessarily employed after the cutting run due to poor loading efficiency. Five degrees raising gradients exist in line with the advance direction of the panel. Poor loading obstructs operation of the shearer drum at its full potential. Debris left in the track causes pushover of the AFC, and consequently the drum is partially sumped into new shear. Pushing of the AFC against debris left at the floor requires much more force, leading to breakdowns in pushing systems. Cleaning of the track can be achieved by a flitting run which results in loosing time and increasing respirable dust. Finally, poor loading efficiency causes both loss of production time and increases of respirable dust.

Table I

Specifications of drums

	Globoid	Cylindrical
Drum diameter over picks (D_W), mm	1400	1400
Drum diameter without pick (D_L), mm	1100	1000
Shell diameter (D_T), mm	910–640	660
Drum width (T), mm	950	950
Number of vanes	3	3
Vane length, mm	2760	2340
Angle of wrap, (degrees)	276	200
Vane angle, (degrees)	17	20
Drum rotational speed (n_W), rev/sec	0.833	0.833

Measurement method used in underground investigation

The performance of the drums was compared in terms of loading efficiency, particle size generated by drums and power consumption. These parameters were measured during a 180 m face advance, which corresponds to 120.000 t raw coal production.

Loading performances of drums were determined by measuring the depth of coal left in the track as proposed by Brooker[4]. The depth of coal between the face and AFC was measured at three points across the track to determine the profile of the coal left at the track. For any drum used in longwall operation, this profile is consistent and a limited

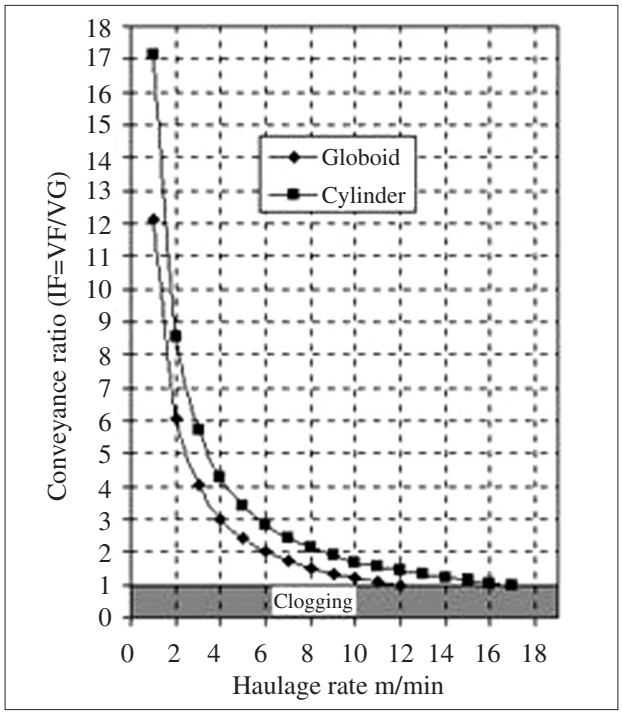


Figure 5—Variation of conveyance ratio of drums depending on haulage rate

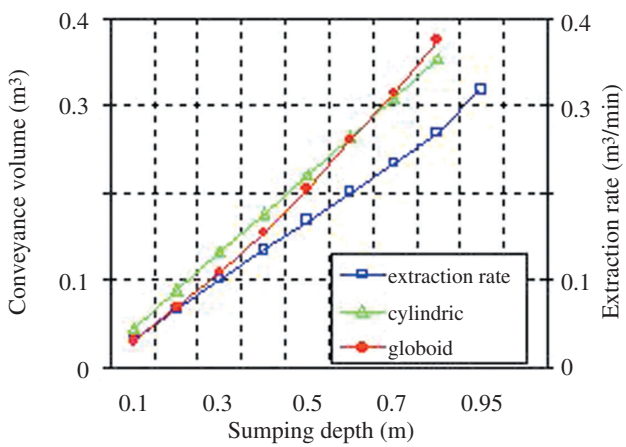


Figure 6—Variation of extraction rate and conveyance volume depending on sumpling depth

number of measurement locations along the face are necessary[4,9].The measurements were made after cutting and flitting runs. In addition, the depth of coal after the cutting run of the leading drum on the bottom bench was measured to determine the loading performance of leading and trailing drums separately. Two typical examples of measurement results obtained after cutting and flitting run are shown in Figure 7. From the measurement results, it is possible to calculate the profile of the mean depth of coal, shown with dotted lines in the figure. The proportion between the extracted material and the material left at the floor gives the loading performance of the drum. Five separate measurement locations were selected along the face to assess the loading performance of the drums.

In situ measurement results

The first set of trials was conducted with Globoid drums and then after replacing them, similar trails were carried out with cylindrical drums. The approximate production was 1160 tons/shift and 1260 tons/shift for Globoid and cylindrical drums, respectively. The mean haulage rate of the shearer, both in up-and down-gradient directions, was around 7 m/min and the mean sumping depth was 0.75 m during the measurements. The results of *in situ* measurements are listed in Table II and Table III. As shown in Table II, nearly half of the extracted material is conveyed onto the AFC by the leading drum, while the trailing drum conveys only between ten and fifteen per cent. The flitting run contributes a loading between twenty to twenty five per cent, of extracted material. The remaining material, which is less than twenty per cent, is loaded by means of pushing the AFC.

The performance of the leading drum running in both directions does not show a significant difference for Globoid and cylindrical drums. Furthermore, the performances of drums in the down-gradient direction is also nearly the same. However, in the up-gradient direction, the performance of the Globoid drum is 10.6 and 4.8 per cent better than the cylindrical drum after the cutting and flitting run, respectively. On the other hand the loading performances of the drums were found to be 8 per cent higher in the cutting run performed in a down-gradient direction compared to an up-gradient direction. Although the cylindrical drum consumes 3.5 per cent less energy according to measurement results, this result is insignificant considering the amount of difference and measurement sensitivity.

Excavated material samples collected after the cutting run were subjected to a series of sieve analyses to determine the degree of coarseness. The results presented in Table 3 indicate that the globoid drum generates coarser material and fewer fines than the cylindrical drum. The amount of material less than 2 mm grain size generated by the Globoid and cylindrical drums was 4.02% and 10.99%, respectively. Consequently, the Globoid drum became more advantageous than the cylindrical drum, considering the amount of generated fine parts. This result was confirmed by the respirable dust measurements, which were performed during the cutting run only.

Effects of operational parameters on in situ loading performance

The relationship between operational variables and drum loading performance at constant rotational speed was investigated statistically. Extraction height, haulage rate and sumping depth were determined as operational variables. A common model for both drums was developed with multiple

Table II

***In situ* measurement results**

Drum type	Cutting direction	Loading performance			Power consumption (MJ/m³)
		After leading drum	After cutting	After flitting	
Globoid	Up-gradient	46.1%	59.5%	82.7%	0.7764
	Down-gradient	52.4%	64.3%	84.7%	
Cylindrical	Up-gradient	45.1%	53.8%	78.9%	0.8031
	Down-gradient	53.3%	64.5%	83.4%	

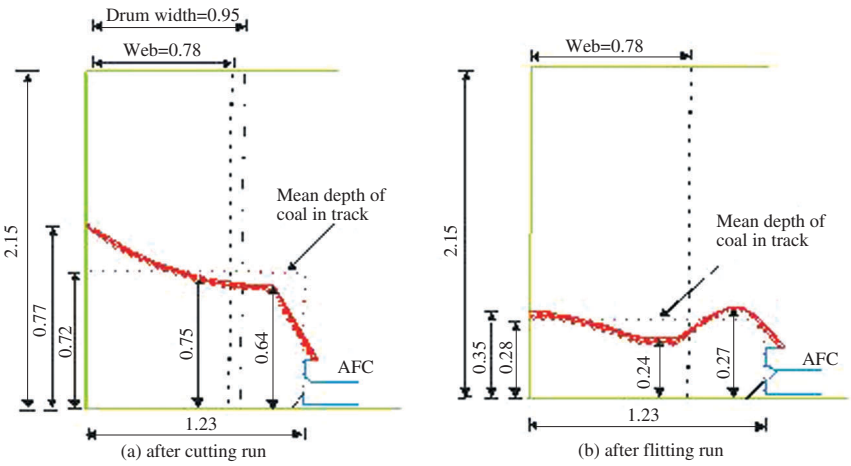


Figure 7—Profiles of coal left in the track (all dimensions are in metres)

Table III

Sieve analysis results

Grain size (mm)	Globoid drum		Cylindrical drum	
	wt.%	Σwt.%	wt.%	Σwt.%
Over 25	65.12	100	42.33	100
8 to 25	22.87	34.88	33.34	57.67
2 to 8	7.99	12.01	13.34	24.33
0.5 to 2	2.95	4.02	5.07	10.99
Under 0.5	1.07	1.07	5.92	5.92
Total	100		100	

regression analysis. Extraction height was considered to be the difference between seam height and drum diameter to obtain a more meaningful relationship with the model. The model is given below:

$$Y = 29.997 + 24.212X_1 + 21.050X_2 - 0.475X_3 \quad [5]$$

X_1 : extraction height (difference between seam height and drum diameter)

X_2 : sumping depth

X_3: haulage rate

Since the correlation coefficient equals 0.45, the relationship between loading performance (dependent variable) and extraction height, haulage rate and sumping depth (independent variables) is at the middle level according to the developed model. Furthermore, the model indicates a linear relationship between variables, since F equals 4.374 and the value of P is less than 0.05. On the basis of the Durbin-Watson analysis, it can be stated that the model is positive i.e. 0.95. As a result of statistical analysis, it is concluded that the loading performance of drums varies around 20 per cent, depending on operational variables.

Results and discussion

Although higher loading performance is predicted for the cylindrical drum by mathematical model, *in situ* comparison indicates that the performance of the Globoid drum is slightly higher than the cylindrical drum. The mathematical model developed by previous researchers was formulated assuming the drum to be like a short-length screw conveyor. Therefore, this mathematical model may be valid only for the drum formed with a cylindrical shell and ordinary vanes. In contrast, the Globoid drum has a conical shell and the drum aperture is modified in an attempt to increase loading efficiency. Probably these construction modifications result in a higher speed of the material inside the drum aperture. Since the model considers only the pitch length and rotational speed of the drum to calculate the transverse speed of material, it predicts a lower material speed for the Globoid drum than the actual speed. Therefore, to predict the loading performance of the Globoid drum or a drum with a more complex shape than the cylindrical one such as an exponential drum, the model must be modified according to structural properties. Otherwise, the prediction results may not be valid.

While the difference between the power consumption of drums is not significant, the Globoid drum generates coarser material and consequently less fines and respirable dust than the cylindrical drum. This result is confirmed by the previous investigation carried out by Hebel *et al.*[8].

Better loading performance experienced with the Globoid drum indicates the importance of construction properties on the improvement of loading performance. *In situ* measurement results prove that the loading performance of the Globoid drum increases considerably around full depth of sump compared with the cylindrical drum. Therefore, it can be concluded that the conical shell and modified vanes of Globoid drum raises loading performance.

In contrast to previous investigations, our *in situ* measurement results show that the loading performance of the trailing drum is very low compared with the leading drum[6]. Some of the coal extracted by the leading drum falls down onto the AFC with the help of gravity. Consequently, the loading performance of the leading drum is far better than the trailing drum. On the other hand, the small clearance between the ranging arm of the shearer and the AFC prevent the trailing drum from discharging material freely onto the AFC. This situation is confirmed by both the field observations of the authors during *in situ* measurements and the high wearing of the ranging arm cage. Since the clearance below the ranging arm and the AFC is not enough, the drum has to circulate material, thus trying to discharge above the ranging arm. Due to high wearing of the ranging arm cage, it is replaced very often. The high revolution speed of the shearer drum also degrades the loading performance of both drums. Finally, it may be concluded that the loading performance of the trailing drum in thin seams is lower than the leading drum due to lack of enough space between the ranging arm and the AFC.

The statistical analysis carried out at constant rotational speed shows that operational parameters, namely extraction height, haulage rate and sumping depth, affect the loading performance of drums only in the order of 20 per cent. This result confirms that the constructional parameters are more important than the operational parameters for improved loading performance. The high production speed of the shearer drum cannot be achieved only by the high cutting rate, but also by loading extracted material onto the AFC in accordance with the cutting rate. In this sense, utmost care must be exercised in designing the drums structural properties to achieve high loading performance and consequently production speed in longwall mining.

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