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SELECTION OF A PRACTICABLE SHEARER LOADER BASED ON MECHANICAL PROPERTIES OF COAL FOR PARVADEH 1 MINE

WYBÓR WRĘBIARKO-ŁADOWARKI W OPARCIU O WŁAŚCIWOŚCI MECHANICZNE WĘGLA W KOPALNI PARVADEH 1

Obtaining the maximum productivity with minimum energy consumption in coaling faces, directly depends on selection of the suitable shearer loader machine with the most effective and fitness picks for it and also their arrangement on cutter head. In order to select appropriate shearer loader machine, some in-situ tests have been carried out on C1 coal seam of Parvadeh1 long wall mine located in east of Iran. Studying of the mechanical properties of C1 coal seam demonstrates an extremely low strength of coal. Thus, it was concluded that a kind of two drums shearer (model EL600) with the conical picks can be effectively worked.

Keywords: Shearer loader, mechanical properties, C1 coal seam, long wall, Parvadeh1

Zapewnienie maksymalnej wydajności pracy w rejonie przodka połączonego z minimalnym zużyciem energii związane jest z wyborem odpowiedniego rodzaju urządzenia (wrębiarko-ładowarki), zapewniającego optymalną ilość i układ noży wrębowych. W celu wyboru optymalnej maszyny urabiającej, przeprowadzono badania *in situ* w złożu węgla C1 w kopalni Parvadeh 1 we wschodnim Iranie, gdzie wydobycie prowadzi się metodą ścianową. Badanie właściwości mechanicznych węgla C1 wykazało, że jest to węgiel o niskich parametrach wytrzymałościowych. Stwierdzono, że do urabiania tego typu węgla optymalnym rozwiązaniem będzie zastosowanie dwóch wrębiarek bębnowych (model EL600) wyposażonych w stożkowe noże wrębowe.

Słowa kluczowe: wrębiarko-ładowarka, właściwości mechaniczne, pokład węgla C1, wydobycie ścianowe, Parvadeh 1

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1. Introduction

Proper exploitation of coal is most significant not only for economical development but also for environmental, ecological and conservation viewpoints. Mechanized extraction of coal provides better production, productivity and safety (Singh, 1999). The coal producing target is being increased every year and, to achieve it, the coal mining industry is moving fast towards mechanization (Singh et al., 1995). Performance of the mechanical excavators like road headers, continuous miners, and shearer-loaders is one of the most crucial factors influencing the production rates in mining projects (Rostami et al., 1994). There have been done numerous works to imagine cutting features of coal seams, and therefore several testing methods have been proposed for the coaling machines selection (Singh et al., 1995).

Most of the studies on coal cutting process and the associated machines were done during last decades. Influence of the cutting tools and machine parameters, geo-mining conditions and physical-mechanical properties of coal over cutting force has been studied by many researchers.

Performance of a power loader machine mostly depends on the physical and mechanical characteristics of the coal (Evenden & Edwards, 1985). Then, Hekimoglu (1995) considered experimental results of interaction between cutting tool and rock for use of the cutting machines with high efficiency (Hekimoglu, 1995).

Kahraman et al. (2003) emphasized the use of specific energy values in estimating penetration rates of percussive drills. Specific energy, which is defined as an amount of energy imposed to a unit volume of rock to be cut, is a crucial parameter in selection of the most appropriate shearer loader (Balc et al., 2004).

Bilgin et al. (2006) studied machines cutter performance influencing by dominant rock properties. For this purpose, he realized a large amount of laboratory mechanical and cutting tests. During the tests different cutting depth and spacing were considered using one type of conical pick on large blocks of rock specimens.

Jaszczuk and Kania (2008) proposed a model incorporating the essential components of coal production costs together with coal price which play a major role in designation of coal output for longwall faces. This model includes theoretical capacity of shearer loader, degree of its utilization under mining conditions, parameters of the longwall face, actual work time of mining machinery on a face, and cutting sequence.

Dinescu and Andraş (2009) modeled the interaction between shearer cutter-head and coal seam, in order to study the influence of the haulage speed related parameters and the cutting system optimizing energy consumption.

Shahriar et al. (2009) studied various in-situ and laboratory tests outlined to investigate mechanical properties of C1 coal seam in Parvade1 mine, Iran.

Here, on the basis of mechanical properties of C1 coal seam achieving due to some in-situ tests the most appropriate shearer loader machine has been selected for Parvadeh1 long wall mine located in east of Iran. Furthermore, the laboratory and in-situ tests are summarily reviewed and their suitability to aid machine design and selection is discussed.

2. General site study

The main coal seams in Parvadeh1 region located in east of Iran are B1, B2 and C1. Other seams are C2, D and possibly E. the coal seams covered mostly by mudstone with prominent coarsening up siltstone and sandstone sequences in Parvadeh1 coalfield. The most thickness belongs to C1 seam which varies from 1.5 to 2.2 m (Shahriar et al., 2009). C1 coal seam of Tabas Parvadeh1 is considered in the class of Low Volatile Coking Coal or Low Volatile Bituminous Coal according to Russian classification. But, it is in class1 of Bituminous Coals according to American Society for Testing Materials (ASTM) classification (Shahriar et al., 2009).

During the design stage long wall underground method was selected as the most adequate one for mining C1 coal seam. For this purpose, the main production machine is shearer loader should be selected accordingly.

3. Mechanical properties of the coal seam

There are several tests procedure in the laboratory and the field to measure mechanical properties of coal. Often, there considerably are differences between obtained results from the laboratory tests of coal specimens and the in-situ coal characteristics. Recovery of core type samples of coal for the laboratory testing is also difficult. Therefore, in present study in-situ tests have been frequently done for assessment of the coal mechanical properties. Moisture of the coal samples in all mechanical tests was approximately 6 percent.

3.1. Uniaxial Compressive Strength (UCS)

In Parvadeh1 coalfield, because of high brittleness of the coal and the arrangement of cleat and coal bedding, providing the cubic and cylindrical specimens with large dimensions was not possible (Shahriar et al., 2009). Therefore, the small pieces of specimens are considered for uniaxial compressive strength (UCS) test. The results obtained from UCS test for C1 coal seam are summarized in Table 1.

TABLE 1

UCS test and the results for C1 coal seam (Shahriar et al., 2009)

Test number	F(N)	UCS (MPa)
1	4350	6.74
2	4050	6.28
3	4258	6.6
4	4570	7.08
5	3950	6.12
6	4558	7.06
7	3564	5.52
8	4252	6.59
9	4300	6.67
10	5050	7.83
Average	4290.2	6.655

According to Table 1 the average uniaxial compressive strength of C1 coal seam was approximately measured to be equal to 6.66 MPa, which implies a low strength.

3.2. Shear Strength

Shear strength is known to have an effect on the assessment of coal cuttability and the selection of the practicable cutting machines. In order to measure the shear strength of C1 coal seam, in-situ test was performed as described in Shahriar et al. (2009). All results due to the shear test are summarized in Table 2. Average shear strength for C1 coal seam is about 0.53 MPa.

TABLE 2

Results of Shear Strength in-situ test of C1 coal seam (Shahriar et al., 2009)

Test number	Imposed pressure (MPa)	Cutting surface area (m^2)	Cutting force (KN)	Shear strength (MPa)
1	2.5	0.0375	1766.25	0.471
2	3.3	0.0412	2331.45	0.566
3	3	0.0392	2119.5	0.540
5	2.6	0.0395	1836.9	0.465
6	3.1	0.04035	2190.15	0.5428
7	2.8	0.036	1978.2	0.5495
8	2.7	0.0348	1907.55	0.548
Average	2.86	0.038	2018.57	0.52615

3.3. Tensile Strength

Preparation of coal specimen for tensile strength test especially in C1 coal seam (with poor strength) is most difficult and not feasible. Therefore, a tensile strength of C1 is used which resulted from Impact Strength Index (ISI). ISI can be considered for characterizing tensile coal strength. It can be used for practical implementation in coal cutting and drilling. Evans (1966) proposed a graph indicating a relationship between tensile strength and ISI (Cited in Shahriar et al., 2009). All results of ISI test are listed in Table 3. The average amount of ISI is measured to be equal to 39.91 indicating a poor strength of the coal seam in Tabas region.

TABLE 3

Results obtaining from ISI test in C1 coal seam (Shahriar et al., 2009)

Test number	Place	Moisture (%)	ISI
1	Conveyer Drift	5.2	41
2	Conveyer Drift	5.5	46
3	Conveyer Drift	5.5	43
5	Conveyer Drift	5.4	42
6	Conveyer Drift	5.3	41
7	Conveyer Drift	5.4	41
8	Conveyer Drift	5.8	39
9	Material Drift	7.8	35
10	Material Drift	8	36
11	Material Drift	8.2	38
12	Material Drift	8	37
Average	-	6.375	39.91

4. Selection of the suitable shearer

4.1. Pick selection and the cutting force

In modern coal-winning machines, the extraction of coal results from the interaction between the pick and the coal substance (Goktan, 1992). It means that type of picks is a character plays an important role in selection process of the most practicable shearer loader. Selection of the most appropriate cutting tools is of at most critical in optimizing cutter head of shearer which has a considerable influence on machine performance.

Point-attack (conical) picks and wedge-shaped (chisel) picks are two main types of drag picks can be employed on underground mining machinery, such as continuous miners and shearers. In practice, cutting efficiency, dust generation, mechanical strength of coal, ignition potential, and pick wear are generally accepted as the main parameters influencing the selection process of the fitness pick.

More recent tests on the performance of a continuous miner in cutting South African coal have proved that the wedge-shaped pick is a more efficient tool only at shallower depths of cut. At greater depths of cut (generally beyond about 50 mm), the point-attack pick was found to be the more efficient (Goktan, 1992).

The compressive strength of C1 coal seam is low as given in Table 1, and also there are three joint sets in Tabas Parvadeh 1 long wall mine. Therefore, the most fitness type of drag pick is selected for the practical use among the point-attack or conical picks. As shown in Figure 1 optimal picks spacing considering minimum specific energy is decided in $s/d = 2$; where, s is picks spacing and d is cutting depth (Roxborough et al., 1981). In this case, the picks spacing on blade of shearer drum equals 105 mm in cutting depth of 52.5 mm.

Knowing the magnitude of the cutting forces is an important aspect of machine design, since it allows the engineers to estimate the cutter head torque and machine power requirements for a particular application.

Evans's rock cutting theory for point-attack picks is one of the most practical formulas offered for calculation of peak cutting force (Evans, 1984). Goktan (1997) modified and im-

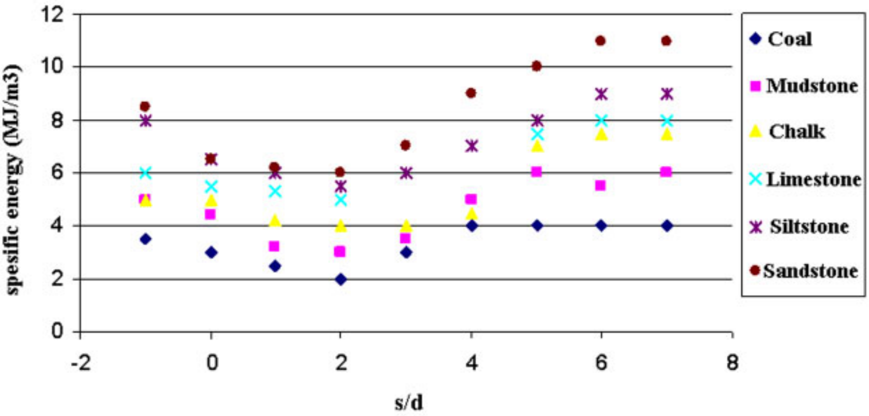

Fig. 1. Specific energy in relation to (*s*/*d*) ratio (Roxborough et al., 1981)

proved that in order to remove its deficiencies. Despite the improvement brought to the original Evans's theory, an attempt was also made to take account of asymmetrical attack by introducing the parameter "rake angle" of pick. This attempt caused to establishing a new procedure named semi-empirical technique for cutting force predictions of point-attack picks under asymmetrical attack (Goktan & Gunes, 2005).

According to the semi-empirical technique as given in Equations 1 and 2 with considering the mechanical properties of C1 coal seam and characteristics of the selected point-attack pick as in Table 4, peak and mean cutting forces are measured to be equal to 31.36 KN and 10.45 KN, respectively (Figure 2).

TABLE 4

Mechanical properties of C1 with characteristics of the selected conical pick

Description	Parameter	Meaning of parameter (unit)	Value
Mechanical properties of C1	σ_c	Uniaxial compressive strength (MPa)	6.66
	σ_t	Tensile strength (MPa)	0.39
	δ	Shear strength (MPa)	0.53
Characteristics of the selected conical pick	s	Picks spacing (cm)	10.414
	B	Curvature radius of pick head (cm)	0.1524
	D	Cutting depth (mm)	52.07
	α	Rake angle of pick (deg)	-15
	β	Clearance angles (deg)	5
	ψ	Friction angle between the pick and rock (deg)	10
	2θ	Pick angle or cone angle (deg)	80
	m	Curvature coefficient of pick head	0.5
	n	Stress distribution coefficient	8.5

$$F_C = \frac{12\pi \cdot \sigma_t \cdot d^2 \cdot \sin^2\left[\frac{(90)-\alpha}{2} + \psi\right]}{\cos\left[\frac{(90)-\alpha}{2} + \psi\right]} \tag{1}$$

$$\frac{F_C}{F_C{}'} \cong 3 \tag{2}$$

where

F_C — Pick cutting force (N),
F_C' — Mean cutting force (N),
σ_t — Tensile strength of rock (MPa),
d — Cutting depth (mm),
α — Rake angle of pick (deg),
ψ — Friction angle between the pick and rock (deg).

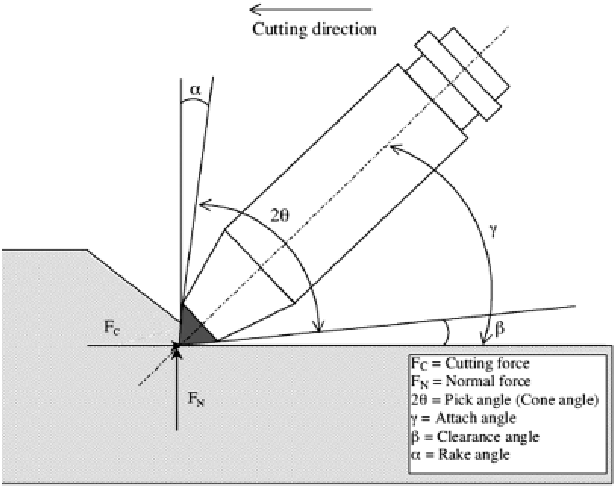

Fig. 2. Cutting geometry of point-attack picks (Goktan and Gunes, 2005)

4.2. Design of shearer drum

Shearer drum is an important component for cutting and especially for conveying coal (Liu et al., 2009b). It totally consumes 80 to 90 percent of the entire shearer power. A drum structure and characteristics directly influence productivity, energy consumption and service life of shearer. Hence, designing the most appropriate drum with smooth working performance and high productivity is of at most crucial. The major parameters in the shearer drum design which influence the shearer output and performance are considered here.

4.2.1. Drum structure parameters or dimensions

Drum diameter of the shearer can be calculated using Equation 3 (Chadwick, 1995). Average and maximum thickness of C1 coal seam in the long wall mine region are 1.83 and 2.59 m, respectively. Therefore, drum diameter of the shearer is calculated to be almost 1.5 m.

$$\left\{ \begin{array}{l} 2D_{on} \succ H_{\max} \\ D_{on} = (0.7 - 0.8) \cdot H_a \end{array} \right\} \tag{3}$$

where

D_{on} — external diameter of drum (m),
$H_{\max}$ — maximum mineable thickness of seam (m),
H_a — average mineable thickness of seam (m).

Drum width of the shearer is considered between 0.6 to 0.9 m with considering the coal seam strength and hardness and also drum diameter. Consequently, drum width of the shearer is found to be equal to 0.8 m on the basis of the low strength of C1 coal and drum diameter of 1.5 m.

4.2.2. Number of loader vanes

Du et al. (2008) presented a mathematical relation between pick arrangements and drum fluctuation loads, drum rotary speeds and haulage speeds according to coal cutting theory. Pick arrangements and number of loader vanes influence drum rotary and haulage speed (Du et al., 2008).

During coal cutting operation using shearer some difficulties may occur such as: dissipation of energy, dust generation, slime creation, and ore lose on the floor of working face. In order to prevent these difficulties, it is necessary to be equal "volume of space between vanes" and "volume of extracted coal by the vanes". For this purpose, data for drum and the related vanes as summarized in Table 5 are used in Equations 4 to 7 proposed by Chironis (1978) for the long wall coal mine.

TABLE 5

Input data required for determining number of loader vanes

D_{on} (m)	D_{on1} (m)	D_i (m)	w (m)	d (m)	d_p (m)	$\sin\gamma$	f_t	f_c
1.5	1.25	0.746	0.8	0.05	0.035	0.422	0.74	0.6

$$V_p = \frac{1}{n} \cdot \left[\frac{(D_{on1}^2 \times \pi \times w) - (D_i^{\,2} \times \pi \times w)}{4} - V_{pl} \right] \tag{4}$$

$$V_{pl} = \frac{n \times (D_{on} - D_i) \times d_p \times w}{2 \sin\gamma} \tag{5}$$

$$V_{pr} = \frac{n \times d \times D_{on} \times w}{f_t} \tag{6}$$

$$V_{lsp} = \frac{V_{pr}}{f_c \times n} \tag{7}$$

where

V_p — volume of space between vanes (m^3),
D_{on1} — external diameter of drum without picks (m),
D_i — internal diameter of drum (m),
w — drum width (m),
V_{pl} — volume of vanes (m^3),
n — number of vanes,
d_p — vane thickness (m),
γ — vane slope angle (deg),
V_{pr} — volume of extracted coal (m^3),
d — average depth of cut for each picks (m),
f_t — swelling factor,
V_{lsp} — coal loading volume by a vane (m^3),
f_c — crushing factor.

Results due to the calculations using Equations 4 to 7 as summarized in Table 6 indicate that the optimal loading operation in the investigated coal region can be obtained by a drum with three vanes ($n = 3$). It is concluded on the basis of the above mentioned rule that volume of space between vanes (V_p) should equal to or has the lowest discrepancy with the volume of extracted coal by the vanes (V_{pr}). Therefore, the lowest discrepancy belongs to a number of 3 vanes drum.

TABLE 6

Results to find the optimal number of loader vanes for the case study

N	V_p	V_{pl}	V_{pr}	V_{lsp}
1	0.607	0.025	0.081	0.135
2	0.291	0.05	0.162	0.135
3	0.186	0.075	0.243	0.135
4	0.133	0.1	0.324	0.135

4.3. Shearer selection results and discussion

Determination of total power of shearer loader, which requires for “cutting”, “haulage” and “loading” operation, is most important issue in selection of the most practical shearer. Equations 8 to 14 are employed in order to calculate total power of shearer as a sum of the power for cutting, haulage and loading sections using the data summarized in Table 7. According to the results listed in Table 8, it is evident that the major portion about 93% of the total power of the shearer consumes for the cutting operation. It is notable that average drum speed is assumed to be 45 r.p.m.

TABLE 7

Input data for determination of total shearer power as a sum of the power for three sections

N_{rpm} (rpm)	N	F_c' (KN)	R (m)	W_{sh} (ton)	F_n (KN)	ρ (gr/cm^3)
45	12	10.45	0.75	0.05	1.918	1.4

$$P_C = \frac{2 \times \pi \times N_{rpm} \times T_{td}}{60} \tag{8}$$

$$T_{td} = 2 \times N \times F_c' \times R \tag{9}$$

$$P_h = \left[(W_{sh} \times g \times \sin\gamma) + (2 \times N \times F_n)\right] \cdot V_{p\,\mathrm{sec}} \tag{10}$$

$$V_{p\,\mathrm{sec}} = n \times d \times \left(\frac{N_{rpm}}{60}\right) \tag{11}$$

$$P_l = W_c \times D_{on} \tag{12}$$

$$W_c = V_{cp} \times \rho \times g \tag{13}$$

$$V_{cp} = \frac{d \times n \times w \times H_{\max} \times N_{rpm}}{60} \tag{14}$$

where

P_c — required power for cutting section (KW),
N_{rpm} — shearer drum speed (rpm),
T_{td} — shearer drum moment (KN · m),
N — number of exposure picks,
F_c — cutting force of each picks (KN),
R — drum radius (m),
P_h — required power for haulage section (KW),
W_{sh} — shearer weight (ton),
F_n — normal force of each picks (KN),
V_{psec} — advance speed (m/sec),
n — number of vane on drum,
P_l — required power for loading section (KW),
W_c — weight of loaded materials (KN/sec),
V_{cp} — volume of extracted coal (m^3/sec),
ρ — specific weight of coal (gr/cm^3),
d — average depth of cut for each picks (m),
$H_{\max}$ — maximum mineable thickness (m).

TABLE 8

Required power of shearer for the sections

Section	Power (KW)	Percentage of required power
Cutting	886.4	92.6%
Haulage	$2.7\,F_n + 0.207$	6.33%
Loading	4.8	1.07%
Total	$2.7\,F_n + 891.407$	100%

In this study, there are four kinds of shearer loaders to be considered for the selection. Their characteristics are summarized in Table 9. According to the results obtaining during the previous sections of this study especially with emphasis on the required cutting power of 886.4 KW almost 93%, a "double ended ranging drum shearer (DERDS)" model EL600 is selected as the most applicable and fitness one for the long wall mine.

TABLE 9

Four shearer alternatives with their characteristics made by DBT Company

Electra Range	EL3000	EL2000	EL1000	EL600
1	2	3	4	5
Seam range (m)	2.2-6.0	1.5-3.5	1.8-5.0	1.0-3.5
Typical machine length (m)	14.6	12.2	11.8	11.9
Available cutting power (KW)	2×850; 2×650	2×500	2×600	2×450; 2×375; 2×285
Cutting drum diameter (m)	1.9-3.0	1.2-2.2	1.4-2.5	1.1-2.2

1	2	3	4	5
Haulage system	AC	AC	DC	AC
Haulage motors (KW) – up to	2*125	2*100	2*70	2*50
Haulage speed (m/min) – up to	60	45	25	20
Haulage pull (KN) – up to	1000	750	900	600
Pump motor (KW) – up to	40	50	40	40
Machine weight (tons)	100	55	75	50

Specific cutting energy can be calculated by Equations 15 and 16 (Roxborough & Phillips, 1981). The relationship between specific cutting energy and average cutting depth of each picks (*d*) for the investigated long wall mine is considered as shown in Figure 3. According to $d = 0.05$ m, specific cutting energy is 5.66 (MJ/m^3).

$$S.E = \frac{2 \times \pi \times N_{rpm} \times T_{td}}{60 \times AR} \tag{15}$$

$$AR = \frac{n \times d \times w \times H_a \times N_{rpm} \times f_e}{60} \tag{16}$$

where

$S.E$ — specific cutting energy (KJ/m^3),
AR — volume of produced coal (m^3/sec),
f_e — operational lose coefficient (equals 0.95).

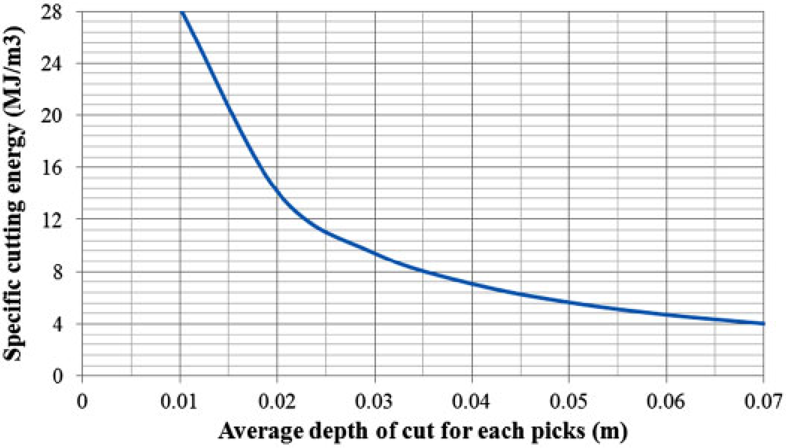

Fig. 3. Relation between Specific Energy and cutting depth for Parvadeh 1 long wall mine

5. Conclusion

Coal samples assembled throughout C1 coal seam characterized by a thickness of 1.5-2.2 m located in Tabas Parvadeh1 coalfield of Iran. It has been considered for mining by long wall method requiring the most fitness shearer loader according to physical and mechanical properties of the seam. C1 coal seam includes a low compressive strength and there are three joint sets in Parvadeh1 long wall coal mine. In order to select the most appropriate shearer, characteristics of its components should adjust to the mechanical properties of the coal seam. For this purpose, the most crucial physical parameters of the shearer such as pick, drum and vanes have been studied and designed. Therefore, the most practical type of drag pick is selected among all types of the point-attack or conical picks. Drum diameter of the shearer has been estimated approximately 1.5 m on the basis of the average and maximum thickness of C1 seam. Drum width is also determined to be equal to 0.8 m with considering the coal seam strength and hardness as well as the drum diameter. A number of 3 vanes drum causes the lowest discrepancy between the volumes of space between vanes and extracted coal by the vanes. Total power of the shearer has been determined as a sum of the powers required for cutting, haulage and loading operation. As a result, the major portion almost 93% (886.4 KW) of the total power of the shearer belongs to the cutting operation. In order to achieve high productivity and avoiding dust generation, coal cutting should be performed with low speed and high penetration depth. Finally, it was concluded that "double ended ranging drum shearer" model EL600 is the most practical one for Parvadeh1 long wall coal mine conditions especially from technical viewpoint.

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