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Load Characteristics of Pick Cutting Coal Seams with Coal and Rock Interface

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Abstract

A series of experiments of a pick cutting coal seam in different forms were conducted on a cutting testbed of coal and rock. Rotational speeds of the pick and initial velocities of the coal seam in the experiments are uniformly set to be 60 r/min and 0.6 m/min, respectively. Based on the amplitude domain analysis of the cutting force-time signals of the pick cutting rock with different Compressive Strength (CS), it is found that force increment between the pick cutting rock and uniform coal seam linearly increases with the increase of CS difference between fault and coal, and the larger the CS is, the larger the load fluctuation is. Amplitude domain analysis of the signals of the pick cutting coal seam with coal and rock interface at different locations shows that the force increment of the pick cutting the coal seam with coal-rock interface at the center of the coal seam is the largest, compared with those of the pick cutting the coal seam with coal-rock interface at the top and at the bottom, but smaller than the sum of them.

Keywords*: helical vane drum, coal-rock interface, pick, coal seam, cutting load.*

1. Introduction

With the increasing development of the coal industry and continual improvement of coal science and technology, mining of the special seams, which were difficult to be excavated previously, has been put on the agenda. Especially, excavation of coal seams consisting of coal seam with coal-rock interface, formed from the change of geological structures, has become an important direction of coal mining. Drum shearer, as one of the most important tools in coal mining, has attracted many attentions from researchers both in China and foreign countries. A lot of research work has been done onpick of shearerbased on theoretical, experimental and numerical simulation methods. The first model for prediction of the peak cutting force of conical pick was established by Evans based on the maximal tension stress theory [1], then Roxborough*et al*. [2] andGoktan [3] both modified the Evans mathematical model appropriately. According to experimental data from various experiments of cutting different structure rock by conical picks, regression expressions of the relationship between peak cutting force of conical picks and rockCS, tensile strength, dynamic and static modulus of elasticity and brittle index were established. The conclusion was drawn that the cutting performance of the pick is affected mainly by the rock compressive strength, and basic rules governing the relationships between specific energy and chip sizes were explained [4-7]. Numerical methods were also applied to simulate the rock cutting processes for predicting the peak cutting force in the literature [8, 9]. However, there are some differences between theoretical results of the existing models and the experimental data [10], because the accuracy of the empirical models usually cannot be counted upon due to insufficient experimental data. So a considerable amount of related experiments are necessary and significant. The relationship between Cutting Specific Energy Consumption (CSEC) of the pick and pick geometric parameters was further studied in the present work, on the basis of coal cutting experiments of five drums with different types of picks [11, 12]. Xia *et al*. [13, 14] studied the load characteristics of picks and load distribution using simulation methods. They pointed out that the maximum load of picks followsa normal distribution, which provided a theoretical guidance for the study of stress distribution of picks. Ayhan*et al*. [15] studied the relationship among the CSEC, the respirable dust and the relevant parameters of a pick. Results demonstrated that the CSEC and the respirable dust are correlated with the pick geometry, the pick arrangement, the shearer haulage speed and the drum rotary speed. Mishra [16]studied the influence of pick types on the cutting effect and built the relationship between the heat produced by pick during rock cutting and the cutting parameters.

Du*et al*. [17] established a drum load fluctuation model to obtain relationships between pick arrangements and drum fluctuating loads, drum rotary speeds and haulage

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speeds and pointed out that the pick with a punnett square arrangement has a smaller cutting load fluctuation than that of other pick arrangement forms. Li *et al*. [18] analyzed the optimization principle for the pick arrangement, and described the optimized arrangement of checkerboard pick, which as a result laid the foundation for the drum's pick arrangement optimization. Liu *et al*. [19-21] studied the influence of motion parameters and structure parameters of pick on its cutting efficiency, CSEC, vibration characteristics, etc.

A lot of the above-mentioned studies on the load characteristics or cutting performance of pick aimed at uniform coal seams. Under realistic conditions, however, coal seams usually have complicated formation and consist of coal seam with coal-rock interface of different patterns. Relatively, there are few studies on the load characteristics of pick cutting complex-structure coal seams. Liu *et al*. [22] studied experimentally the cutting load characteristics of pick cutting rock of three different structures which are hard-soft-hard rock, soft-hard rock and soft-hard-soft rock, respectively; Ma *et al*. [23] established simulation models of pick cutting complex coal seams, which could predict the influence of different kinds of loads on the pick stress status under different conditions. In the present paper, therefore, three artificialcoal seam each of which containsa rock of different CS and three artificialcoal seam each of which consists of one or twocoal seam with coal-rock interface at different locations were made and experiments of a pick cutting those coal seam were carried out to obtain corresponding cutting force data, then the analysiswere conducted to master the cutting load characteristics.

2. Introduction of a TestSystem for Cutting Coal-Rock Seams

Experiments were conducted on a Cutting Testbedof Coal and Rock (CTCR) (shown as Fig. 1), which was described in [19]. The rotary speed *n* (r/min) of the pick is within the range of [0, 120]; the velocity of the coal seam v_1 (m/min), which is moving close to the drum along its axial direction, is within [0, 2]; the velocity of thecoal seam v_2 (m/min), which is moving along the direction perpendicular to the drum axis, is within [0, 1]. The pick used in the experiment is shown in Fig. (2a) and its motion mode is shown in Fig. (2b),from which it can be seen that half the picks on the pick are cutting coal simultaneously during the pick rotating and going deep into the coal seam. The structural parameters of the pick are listed in Table 1.

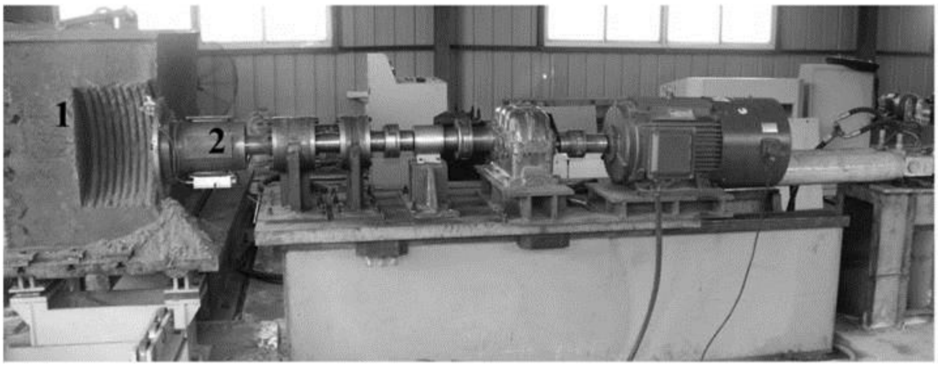
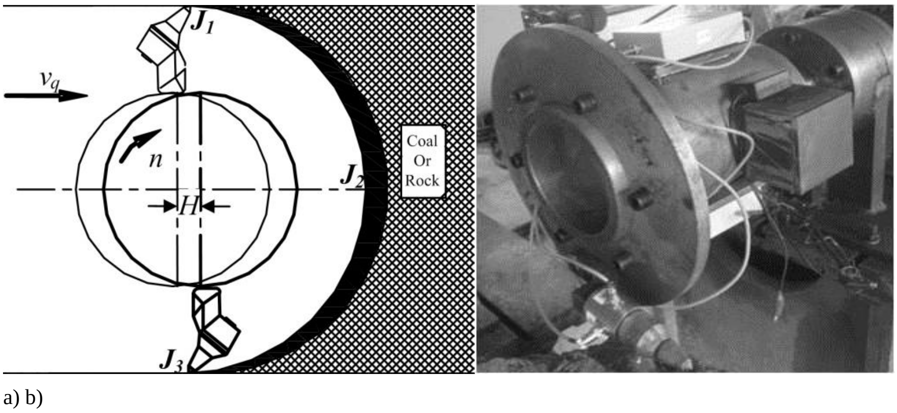


Figure 1.A cutting testbed of coal and rock: 1and 2 indicate a coal seam and a helical vanedrum, respectively.



a) b)

Figure2.A pick used in the experiments:

(a) a photograph of the pick and (b) a schematic of the pick cutting coal seam process

Table 1. Structure parameters of the pick

Parameter	Diameter *D* (mm)	Vane number *n* (-)	Helical angle *e*(°)	Pick impact angle *a*(°)	Cutting line space *t* (mm)
Value	560	2	75	25	30

The process of a shearer pick cutting seams containing coal and coal seam with coal-rock interface is very complicated, especially when the pick is encountering the coal-minor fault interface.At that moment, the pick will transit its status from only cutting coal to cutting rock suddenly. Due to the fact that coal and rock are different in physical properties, such as hardness and CS, large load fluctuations of the pick will occur in this situation, which can affect the cutting performance and reliability of the shearer. So, in order to study the load characteristics of pick cutting complex coal seams, in the experiments, coal seam in different forms (see Fig. 3) were made. Fig. (3a) shows a coal-fault seam, which means that the pick will pass through the coal seam, the coal-fault interface and finally the minor fault. Fig. (3b) shows coal seams consisting of coal seam with coal-rock interface at top and bottom, respectively. In this case, pick will cut coal and coal seam with coal-rock interface simultaneously. Homogeneous coal seams and coal seam with coal-rock interface with different CS are made with different ratios of coal and cement, according to the method of manufacturing artificial rock seams in [19].

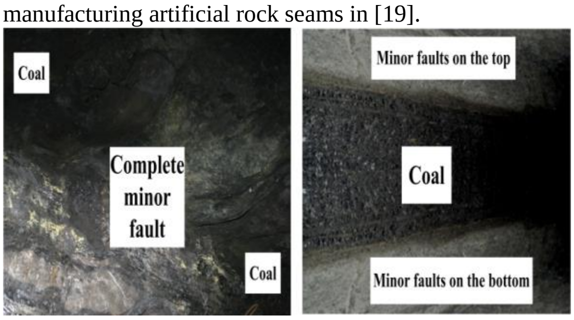


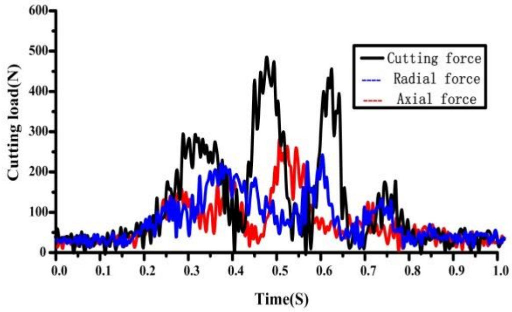
Figure3. Coal seams consisting of different coal seam with coal-rock interface: (a) complete minor fault; (b)coal seam with coal-rock interface on the top and bottom.

3. Experimental Study on Pick Cutting Coal-Fault Seams

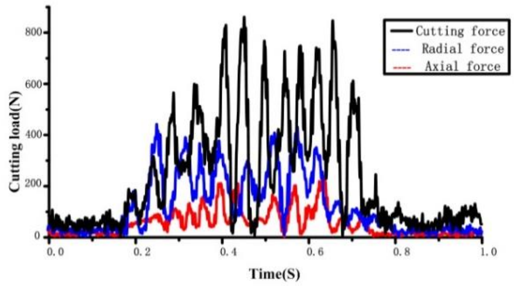
3.1. Cutting tests of coal seams and rock seams with different CS

To study the cutting force characteristics of the pick when cutting the homogeneous coal seams and rock seams, five experiments were conducted for the three types of homogeneous coal seam with different CS, which are 0.69 Mpa, 1.58 MPa,2.73 Mpa.and two type of homogeneousrock seam with different CS, which are 4.55Mpa and 8.71Mpa,respectively. The rotational speeds of the pick in the five experiments are uniformly set to 60 r/min and the initial velocities of the coal seam are all set to 0.6 m/min.

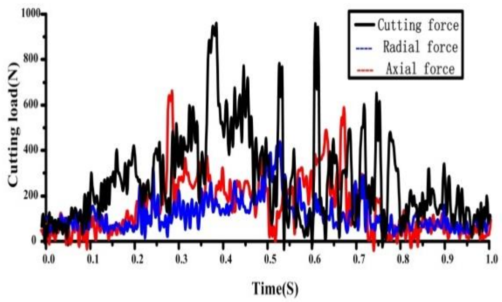
The cutting force-time signals for the five different conditions are shown in Fig. 4. The data are analyzed statistically and the results are listed in Table 2. It can be seen that all the curves show a trend of fluctuation around zero at Stage 1(J_3~J_1), then as the *h* rising , the cutting force rising continuously at Stage 2(J_1~J_2) and finally fluctuating around a higher level at J_2,then reduceing continuously at Stage 3(J_2~J_3). As the CS of rock is higher than that of the homogeneous coal seam, the force value waves around 800 N. The relationship between force increment and CS increment is shown in Table 2. It can be seen from the experimental value and the expression for the fitting value that the force increment linearly increases with the increase of CS difference between rock and coal seam.



a) coal seam



b) rock seam



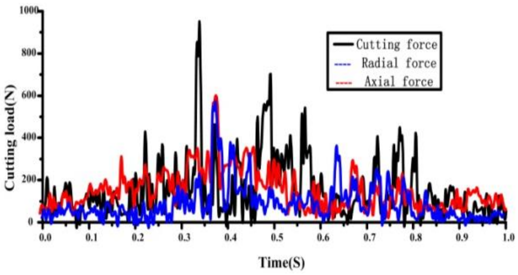
c) rock seam

Figure 4. Cutting force v.s. time curves for pick cutting coal or rock seam of the form in Fig. 4 with different CS: (a)coal seam2.73 MPa, (b) rock seam 4.55 MPa, (c) rock seam 8.71 MPa

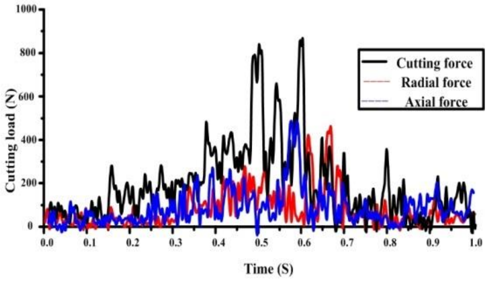
Table 2. Cutting load statistics for different compressive strength coal and rock

	Mean cutting force	Mean peakcutting force	Standard deviation	Mean radial force	Mean peakradial force	Standard deviation	Mean axialforce	Mean peakaxial force	Standard deviation
Coal0.69 MPa	194.55	475	16.80	51.44	247	16.55	61.2356	235.3821	11.41
Coal1.58 MPa	217.34	490	17.83	57.50	257.8	15.28	74.8175	253.6794	13.64
Coal2.73 MPa	229.01	515	17.13	65.83	269.2	16.98	88.2838	281.1141	14.15
Rock 4.55 MPa	324.55	855	19.84	151.24	537.08	16.53	158.059	509.693	15.76
Rock8.71 MPa	367.34	890	15.59	187.31	557	18.66	212.3393	549.928	14.55

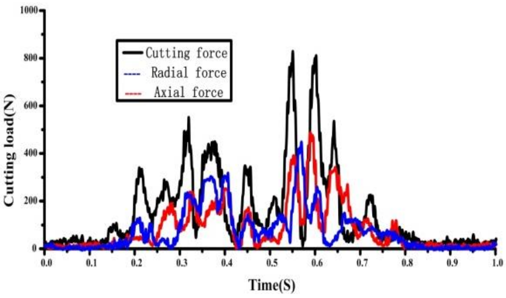
3.2. Cutting tests of minor fault at different location of coal seam with coal-rock interface



(a)



(b)



(c)

Fig. 5. Cutting force v.s. time curves for pick cutting coal seam of the form in Fig. (3a) with coal-rock interface of different location: (a) top, (b) center, (c) bottom

Fig. 5 shows the cutting force for the pick cutting coal seam containing rock of different CS. Obviously, cutting force for Stage 1 and 3 approximately follow normal distributions. In Fig. 5, Stage 2 has two peaks, force values are in a larger fluctuation range. Fig. 5 shows cutting force for pick cutting coal seam containing coal seam with coal and rock interface at different locations. It is not hard to be seen that cutting force for the Stage 1 and 3 follow approximate normal distributions; probability density distribution in Stage 2 is scattered, that is, force values for Stage 2 are in larger fluctuation range, which means that the pick will suffer a more serious problem. The force value corresponding to cutting force peak of Stage 3 in Fig. 5 is the largest.

As shown in the load above in the cutting process of coal and coal seam with coal-rock interface cutting load,cutting load is gradually increasing with the time, this process is the corresponding cut pick cut into the seam, due to the cutting thickness increaseing with time until the cutting pick rotation at the horizontal position with rotary center (maximum cutting thickness), so the pick load will slowly increase in this stage, the cutting load variation is consistent with cutting load variation in homogeneous coal seam.Aspick cutting into the cutting rock of coal seam, the load suddenly drops, produce the process, load reduction is due to the cutting pick cut into the rock of coal seam, the compressive strength of coal seam is less than the rock, cutting pick to crush coal load is small, but the rock strata are not affected by the cutting pick cutting coal seam.As pick cutting from the phase transition to the coal rock, the process due to the compressive strength of coal seam is less than the rock, in the process of rock broken, coal seam have been damaged, so load is lower than before. As pick cutting once again return to coal cutting stage, but because of this stage pick rotation direction and the direction of feed for the obtuse Angle, cutting thickness is reduced, so the load evenly reduceing. the axial and radial forece change trend are similar with the cutting force.

The cutting force-time signals under three different conditions are shown in Fig. 5. The data were analysed statistically and the results are listed in Table 3. It can be seen in terms of mean and standard deviation that the cutting force and its fluctuation of the pick cutting the minor fault at its top are lower than those of the pick cutting minor fault at its bottom. Due to the existence of the haulage speed v_2, the line speed of a pick at the top of the pick is larger than that at the bottom when the pick is rotating, so the transient cutting thickness at the top is smaller. As a result, the cutting force of the pick cutting the minor fault at its top is smaller. It can also be foundin Table 3 that the cutting force of the pick cutting coal seam with coal-rock interface at its center simultaneously is the largest, but the force increment in this case is larger than the sum of the force increments in the other two cases. Seen from the Table 3,we can see that the cutting force changes as the different location of coal seam with coal-rock interface.And the cutting load of the center location is larger than the other locations,as the center has the biggest thick of coal-rock interface.

Table 3. Cutting load statistics for different location of coal seam with coal-rock interface

Coal seam form	Mean force (N·m)	Mean peak force(N·m)	Standard deviation	Mean force (N·m)	Mean peak Force (N·m)	Standard deviation
Top	326.41	779.126	16.92	182.27	490.45	16.92
Center	437.1	865.267	15.37	219.04	522.79	15.37
bottom	414.18	788.127	14.32	191.08	510.84	14.32

3.3. Cutting tests of different compressive strength coal seam with coal-rock interface

To study the cutting force characteristics of the pick when cutting the complete coal-minor fault seams, three experiments were conducted for the twotypes of coal seam in Fig. (3a), consisting of coal seam with coal-rock interface with different CS, which are 4.55Mpa and 8.71Mpa,respectively. The homogeneous coal seams have aCS of 0.69 MPa. The rotational speeds of the pick in the five experiments are uniformly set to 60 r/min. The initial velocities of the coal seam are all set to 0.6 m/min.

The cutting force-time signals for the three different compressive strength are shown in Fig. (5b).The data are analyzed statistically and the results are listed in Table 4. It can be seen that all the curves show a trend of fluctuation around a lower level at Stage 1, then rising continuously at Stage 2 and finally fluctuating around a higher level at Stage 3. As the CS of minor fault is higher than that of the homogeneous coal seam, the force value waves around 200N when half the picks on the pick are cutting the uniform coal seam simultaneously.The force will not begin to rise until the pick comes across the coal seam with coal-rock interface.The force value is increasing as the pick going deep into the fault when the number of picks cutting the minor fault at the same time is from one to half the total pick number. After that, The resistance soars when picks turn to cut the minor fault. With the proceeding of the pick cutting the minor fault, the force value keeps rising until the pick completely enters it, and the force value stays fluctuating around the high level. The higher the difference of CS between coal seam with coal-rock interface and coal seam is, the longer it takes the force to come to the high level, which indicates that haulage speed v_2 gets smaller when pick cutting harder rock. Combined with Table 4, it can be observed that the higher the CS of the coal seam with coal-rock interface is than that of the uniform coal seam, and the larger the fluctuation of the force at Stage 3 is, and the larger the increments of cutting forces at Stage 3 and at Stage 1 are.

The relationship between force increment and CS increment is shown in Table 4. It can be seen from the experimental curve and the expression for the fitting curve that the force increment linearly increases with the increase of CS difference between minor fault and coal seam. So when designing pick used for cutting coal seams consisting of coal seam with coal-rock interface, not only the cutting power should be increased, but the impact on the pick caused by a sudden rise of the cutting force should also be taken into consideration. Based on the relationship between the cutting force increment and the CS increment, strength of transmissiongears in the rocker arm could be enhanced appropriately to improve both stability and reliability.

So when designing pick used for cutting coal seams consisting of coal seam with coal-rock interface, not only the cutting power should be increased, but the impact on the pick caused by a sudden rise of the cutting force should also be taken into consideration. Based on the relationship between the cutting force increment and the CS increment, strength of transmissiongears in the rocker arm could be enhanced appropriately to improve both stability and reliability.

4. Conclusions

Experiments of a pick cutting coal seam of different forms were conducted on a cuttingtestbed of coal and rock. The rotational speeds of the pick inthe experiments are uniformly set to 100r/min and the initial velocities of the coal seam are all set to 1.5 m/min. Analysis on the cutting force-time signals of the pick cutting rock of different CS shows that force increment between the pick cutting rock and uniform coal linearly increases with the increment of CS difference betweencoal seam with coal and rock interface. Analysis on the signals of the pick cutting coal seam with coal and rock interface at different locations shows that the force increment of the pick cutting the coal seam with coal-rock interface at the top and bottom simultaneously of the coal seam is larger than the respectively top and bottom case, but smaller than the sum of the two. All the force-time curves show a trend of fluctuation around a lower level when the pick only cuts uniform coal-seam, rising continuously when cutting coal seam with coal-rock interface and finally fluctuating around a higher level when cutting coal seam with coal-rock interface steadily.

Acknowledgements

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Table 4. Cutting load statistics for different compressive strength coal seam with coal-rock interface

	Mean cutting force(Coal)	Mean cutting force(Rock)	force increment	Mean radial force(Coal)	Mean radial force(Rock)	force increment
Coal 1- Rock 1	194.55	375	180.45	51.44	160.2	108.76
Coal 2- Rock 1	229.01	390	160.99	57.5	157.8	100.3
Coal 3- Rock 1	244.55	415	170.45	65.83	147	81.17
Coal 1- Rock 2	207.34	485	277.66	54.24	281.11	226.87
Coal 2- Rock 2	224.81	496	271.19	56.31	257	200.69
Coal 3- Rock 2	267.34	513.67	246.33	68.28	237.08	168.8

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