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Embedded Wireless Testing System Applied in Coal Cutting Experiment

Chenxu Luo*, Shuangxi Jing ,Yu LIU, xiaoming HAN

School of Mechanical and Power Engineering, Henan Polytechnic University, Jiaozuo454000,China

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Abstract

The Study aims at finding solutions to the existing condition that is difficult to achieve the operation of the wire data transmission in the process of shearer cutting, which demands putting forward an embedded wireless testing system that meets 3D mechanical signal collection and transmission. Embedded signal acquisition and wireless data transmission are included by the test system. Signal acquisition device is used to get the three-dimensional force of shearer pick cutting coal and rock, the wireless data transmission was built based on the zigbee wireless technology and labview virtual technology. This system is utilized in the coal cutting test-bed (CTBCR), two sequential cylinder head with different cutting parameters were used in the cutting experiment. The results show that The relationship between the cutting force and the coal compressive strength, pick-tip cone angle, drum rotate speed ,traction speed. Fluctuation in the cutting force has a linear relationship to coal compressive strength and traction speed. A plot of cutting force fluctuations versus the cutting thickness follows a sigmoidal curve. Based on the analysis of these test results a theoretical basis is supplied for design and effective use of shearer drums.

Keywords: *Wireless transmission, embedded system, shearer pick, cutting force, cutting thickness.*

1. Introduction

When cutting the coal seam , the cutting pick of the shearer drum suffers a great impact and friction, which is a disadvantage for the shearer normal operation. The cutting load has a Significant influence on the shearer drum cutting specific consumption, cutting efficiency, dust quantity, stability and reliability [1~2]. So the study on pick cutting force can provide relevant basis for the design of shearer drum. Scholars at home and abroad have done a large number of experiments on pick cutting force. Foreign representative is Nishimatsu who came from UK and Evans who came from Japan. They respectively established the pick cutting force formula according to the maximum tensile stress and maximum shear stress type [3~4] But the formula design suits to coal cutting, and it has certain gap with the drum of shearer picks cutting[5-7]. Xia Yimin etc.[7-8] studied the dynamics of spiral cutting method based rock breaking, pointing out its load fractal in 2005. Li Xiaohuo etc.[5-6] established different kinds of dynamic model: the cutting unit for continuous miner and drum type shearer, which provides the basis for the research, that numerical methods for solving continuous miner cutting unit vibration state differential equation, under different working conditions and loading conditions of various mass, stiffness and damping factor of each part of the cutting unit vibration impact on the continuous miner in 2009. Domestic scholars researched on the pick not only the mechanical model was established ,but also points out the influence parameters of the pick cutting force and its change rule [8~9].And that they all carried out in a straight line cutting conditions, it is different in terms of the actual working condition[10~11]. Given the disadvantage of current test system based on the cable connection, it is hard to avoid cable layout complex, high cost, poor maintainability and system flexibility[12~13], therefore, the solution is to use the wireless network test mode to build embedded wireless testing system, the cutting force signal is collected, then the wireless data was transferred to the PC, and carry on related research about dynamic performance[14~16]. Related experiments were made based on the actual cutting condition. On the coal cutting test-bed, the embedded wireless testing system was used to study the influence on cutting load of cutting material parameters and the pick parameters. It can provide theoretical basis for designing a better pick cutting performance type cutting pick[17~18].

* Corresponding author e-mail: xzhqingting@163.com.

2. Cutting test-bed based on coal

According to the theory of coal minning machine cutting coal and the similarity theory, the coal cutting force test-bed(Fig.1)and different types picks(Fig. 2) were developed, and the simulation of cutting coal seam was made [19].

In order to meet with the actual condition in conformity with the drum shearer cutting coal and rock, propulsion cylinder working mesa translation as a cylinder along the axial movement was used, also using the pinion with rack drives the coal seam along with the radial feed movement to meet the drum cutting coal and rock movement. Cutting power of coal cutting test-bed is 15 kw, drum speed range is 0~200 r/min, the coal seam translational velocity is 0 ~ 10 m/min, translation range is 0 ~ 2.5 m,Cylinder of the hydraulic cylinder speed is 0~2 m/min, use the coal cutting test-bed to studying the related experiment[20~21].

2.1. The embedded wireless testing system

The function of the launcher based on wireless data transmission is acquisition, processing, and then making the electromagnetic wave signals emitted by wireless transmission. As shown in figure 3 embedded wireless testing system hardware block diagram. The wireless acquisition circuit design mainly includes the transformation of launcher amplifier circuit, filter circuit, A/D conversion circuit, single chip acquisition circuit and peripheral circuit, such as wireless transmitting and receiving modules. Single-chip microcomputer control A/D converter for the power supply voltage and the sensor signal acquisition and conversion, and the transformed signal digital should be processed and coded and then passed on to the wireless transmitting module for launching out.

Figure 1: Coal cutting experiment and test system

Figure 2: Test picks

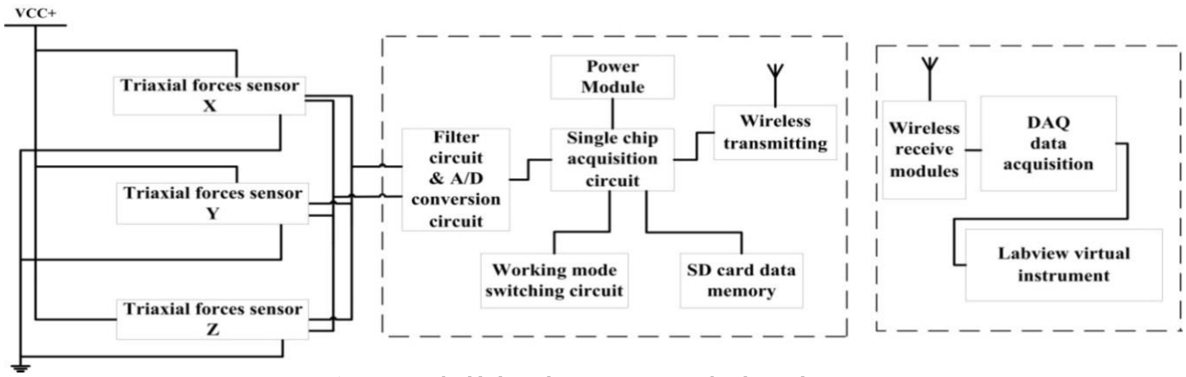

Figure 3: Embedded wireless testing system hardware diagram

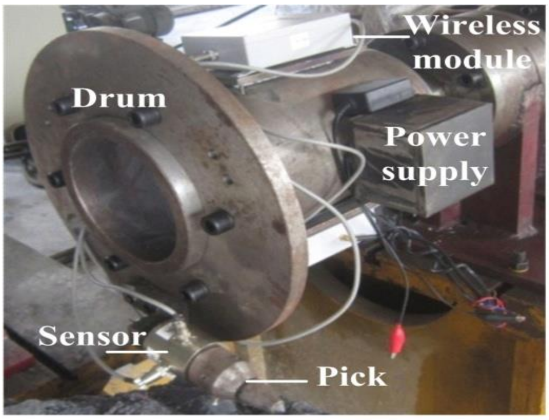

Figure 4: Pick sensor and wireless data transmission module

Figure 5: The Labview virtual acquisition signal display

PC is designed and produced based on the acquisition signal displayer of labview virtual instrument. As shown in Figure 5 , the user interface is the visual display screen of the collected signals by this system, in this you can learn the shearer drum speed test facility, you can learn kinematics parameters such as feed speed of coal seam, you can also get the parameters under the condition of pick cutting three force.

3. 3 Experimental study

3.1. The influence of coal compressive strength on the cutting force

According to the compressive strength of coal seam simulation similar standards, three kind of coal seams was made as shown in table 1. These single pick cutting experiments was carried out to research the influence of pick cutting load under different compressive strength of coal seam. Material parameters shown in table 1.And the drum cylinder speed is 60 r/min, the coal seam traction speed is 0.6m/min, drum diameter of 480mm, pick impact angle is 50°, inclination angle is 0°,pick carbidetip diameter is 10mm, pick-tip cone angle 75 °,pick-body cone angle 25°, pick body material is 40Cr, test time is 5 s .(corresponding to the five rotating cycle).

To get the cut load and volatility of pick in cutting different materials of coal seam conditions, three groups of test results about single cutting pick rotating 5 circumference cutting three types coal seam were analyzed as results listed in table 2. Among the load average is in the process of cutting pick cut coal seam (excluding no-load phase). Peak averages load is 5 cutting cycle of the average of the peak load, which indicates the impact of the cutting pick. Standard deviation represents the load fluctuation in the process of pick cutting coal seam; the greater the value shows, the more severe the load fluctuation is, it is not conducive to the stability of the whole machine. According to the results of statistical analysis, under the condition of the coal and rock material cutting, cutting pick cutting force and radial resistance all shown increasing trend with the increase of coal and rock compressive strength. Obviously the cutting material of cutting pick produce a great impact on the cutting force, the following have the specific analysis.

Table 1: Property parameters of experimental coal materials

Coal seam	Compressive strength	Friction coefficient	Poisson ratio	Density(kg/m^3)
Coal seam Ⅰ	0.69	0.36	0.27	1414.64
Coal seam Ⅱ	1.58	0.36	0.26	1563.53
Coal seam Ⅲ	2.73	0.36	0.29	1608.56

Table 2: Statistics of cutting loads for different compressive strength coal

Compressive strength （MPa）	Mean cutting force （N）	Peak average cutting force （N）	Standard deviation	Mean radial resistance （N）	Peak average radial resistance （N）	Standard deviation
0.69	109.01	201.41	16.80	31.44	147.38	16.55
1.58	154.55	265.56	17.83	32.50	177.8	15.28
2.73	176.21	323.75	17.13	45.77	209.2	16.98

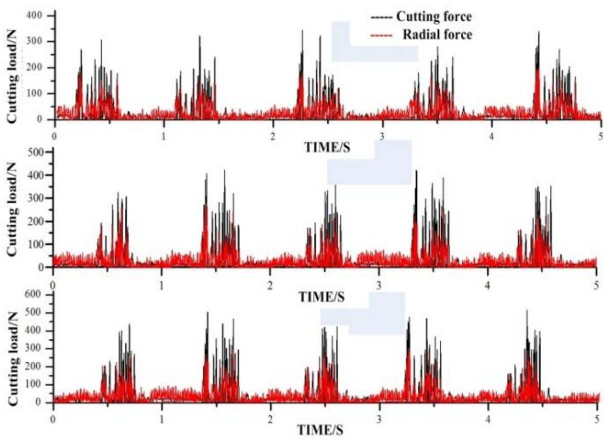

Figure 6: Mean cutting force of different compressive strength

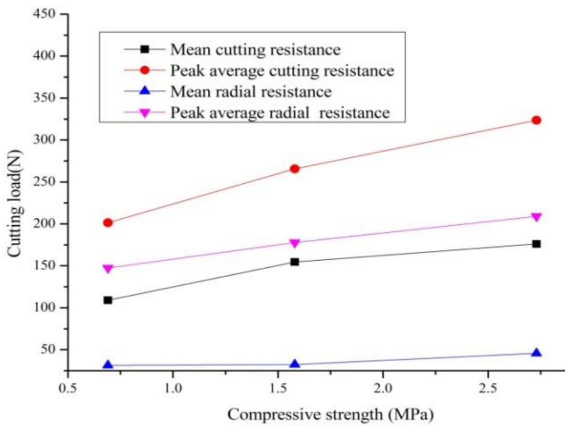

Figure 7: Relations of compressive strength and cutting force

Draw the curve of cutting load and compressive strength (fig.7). Seen from the results, with the increase of compressive strength, cutting force changes in the average peak average cutting force changes gently.Because the cutting average describes the average value of the load in the process of the interaction between cutting pick and coal seam. Cutting force peak means that in the process of cutting coal collapse fall down before cutting force rapid growth at the upper end of the maximum point of critical load. So the single peak load is difficult to fully describe the cutting broken rule, average analysis more accurate. Radial resistance changes with the compressive strength of trend is basically consistent with the cutting force, but the radial resistance on the amplitude is less than the cutting force. On the one hand ,the traction speed in cutting process is far less than the linear velocity of top cutting gear pick,so in the process of rotary cutting, cutting load of the cutting pick instantaneous direction along the direction of cutting force component. On the other hand, on the direction of cutting force pick extrusion and impact crushing coal seam at the same time, but on the radial resistance direction is pure of extrusion, and the broken area is smaller.Combined with figure 6 and 7, it indicates that cutting load along with the change tendency of the compressive strength. There is a linear relationship between the coal strength and cutting force. However, the cutting force fluctuation which is coefficient of different coal and rock strength did not show the same distribution.

3.2. The influence of pick-tip cone angle on the cutting force

The size of the gear pick-tip cone angle determines the cut pick degree of the sharp knives, sharp cutting pick are more likely to pressure into the coal. Theory research results [22] have confirmed that the performance of sharp knives cutting coal is higher than a blunt tool, but it is not enough, so this section experimental study was carried on about the effect of different pick-tip cone angle on the cutting performance of coal seam. In order to study the influence of pick-tip cone angle on cutting force, respectively use 75 °, 85 ° and 100 ° three types of pick-tip cone angle (as shown in figure 8. Cutting seam Ⅲ, the drum cylinder speed is 60 r/min, the coal seam traction speed is 0.6m/min, drum diameter of 480mm, pick impact angle is 50°, inclination angle is 0°,pick carbidetip diameter is 10mm, pick-body cone angle 25°, pick body material is 40Cr, test time is 5 s .The pick cutting force domain curve as shown in figure 6, cutting force statistics as shown in table 3.

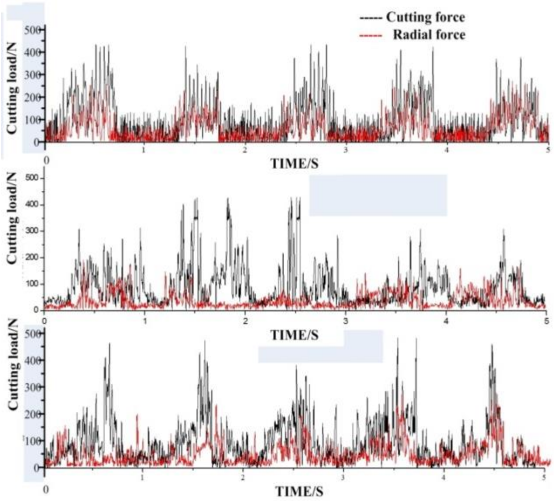

Figure 8: Cutting force graph of differentt pick-tip cone angles

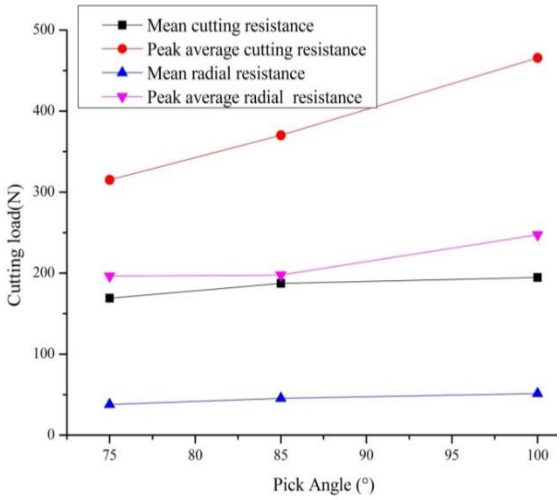

Figure 9: Relationship between pick-tip cone angle and cutting load

Table 3: Statistics of cutting loads for picks with different pick-tip cone angles

Pick-tip cone angle (°)	Mean cutting force (N)	Peak average cutting force (N)	Standard deviation	Mean radial resistance (N)	Peak average radial resistance (N)	Standard deviation
75°	169.01	315.11	17.13	37.83	196.21	16.98
85°	187.34	370.23	17.83	45.50	197.82	15.28
100°	194.55	465.64	16.80	51.44	247.4	17.55

Seen from table 3and figure 9, the experimental study of the pick-tip cone angle, cutting load increases with the increase of pick-tip cone angle, but the change trend of volatility have no obvious regularity. So the size of the gear pick-tip cone angle has a great influence on the cutting pick cutting load, the specific analysis as following.Seen from the figure 9, with the increase of pick-tip cone angle, the cutting load peak average change obviously, the mean cutting load change quite gentle, This shows that the size of the pick-tip cone angle greatly influenced the cutting load peak and the the coal spallation situation that appear in the process of cutting coal seam.The more smaller the pick-tip cone angle is ,the more sharper the pick are , the more easier coal avalanche fall , the cutting load smaller .

In addition, when the pick-tip cone angle is greater, the probability of interference between pick body and the coal body of coal is also greater, and the friction resistance be greater too. As a result the cutting load is bigger. Therefore, when designing pick, when the shearer drum rotating speed, traction speed and pick impact angle established, in order to reduce the wear of pick quantity and improve the stress of the pick, we can design pick-tip cone angle according to this part of the test results coincide with the simulation results.

3.3. The influence of cutting movement parameters on cutting force

When the pick cutting pick rotary cutting, the motion parameters include: The rotation of the drum n and the coal seam movement speed v_q (traction speed). But, these two parameters can be represented by the maximum cutting thickness h_{max} ,the conversion formula is:

$$h_{\max} = 1000 v_q / (nm) \quad (3)$$

In the formulam 3 is the number of cutting pick on each cutting line, When change the drum rotating speed or pulling speed, single pick chip thickness changes.

3.3.1. The influence of the drum rotate speed on pick cutting force

In order to study pick cutting load changes under different drum speed conditions, test condition is the drum diameter of 480mm, pick impact angle is 50°, inclination angle is 0°,pick carbidetip diameter is 10mm, pick-tip cone angle 75 °,pick-body cone angle 25°, pick body material is 40Cr, test time is 5 s .drum speed respectively 40 r/min, 60 r/min and 80 r/min. In order to ensure maximum cutting thickness is 10 mm, respectively the corresponding coal seam traction speed is 0.4 m/min, 0.6 m/min, 0.8 m/min.

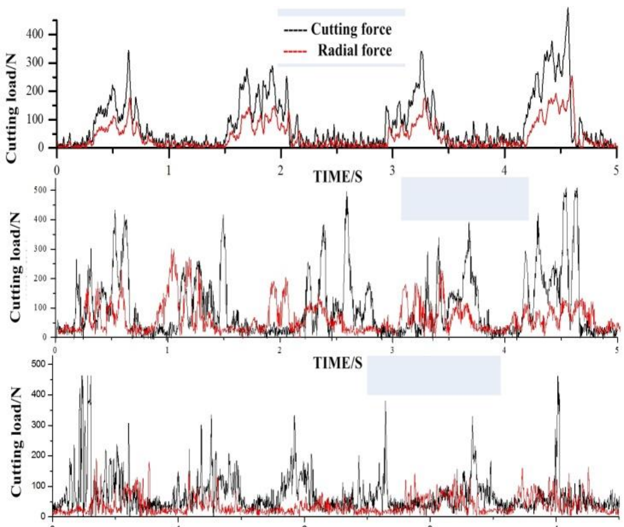

Figure 10: Time domain graph of cutting load with the drum rotating being 60r/min

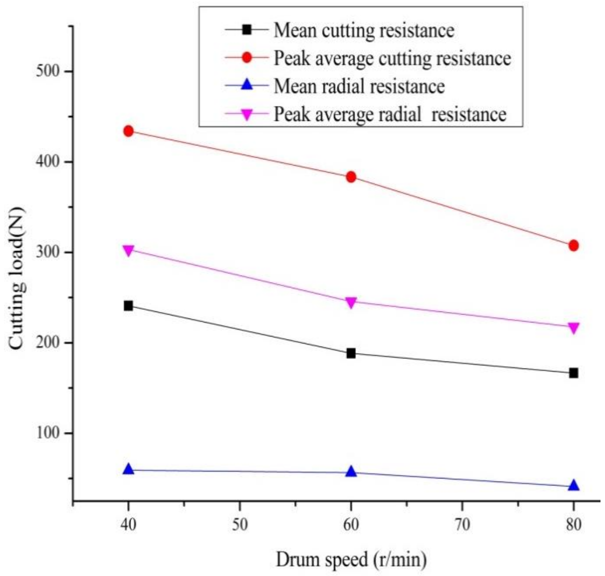

Figure 11: Relationship between drum rotating speed and cutting load

Table 4: Statistics of cutting load with different drum rotating speeds

Drum speed (r/min)	Mean cutting force (N)	Peak average cutting force (N)	Standard deviation	Mean radial resistance (N)	Peak average radial resistance (N)	Standard deviation
40	240.93	434	10.54	59.25	303	10.64
60	188.29	383.5	26.18	56.62	245.6	12.05
80	166.62	307.5	13.83	41.34	217.6	16.52

The domain waveform of the cutting load under different drum speeds in five cutting cycle time as shown in figure 10. Statistical analysis is carried on for the cutting load of three types single pick under different drum rotation speed condition and list in table 4.Draw the relation curve between cutting load and drum rotational speed (Fig.11),The above two type of fitting residual error are within the confidence region, fitting residual error within the confidence region, therefore, within the scope of the study the fitting change law correctly. As observed from the table 4 and figure11, the cutting load is reduced with the increase of drum speed and it coincides with this formula obtained according to the theory of simulation results. The reasons for this situation is along with the rising of the drum rotating speed, instantaneous velocity of cutting pick increase when impact the coal and rock. Due to the requied energy of coal and rock crushing is certain, so the cutting load reduce.

3.3.2. The influence of traction speed on pick cutting force

Shearer in the process of practical work, general drum rotating speed is constant, only by changing the traction speed change cutting thickness, as the cutting thickness raises, coal cutting force raises.So shearer should reduce the traction speed when cutting hard coal, avoid machine overworked. When cutting soft coal can increase the traction speed in order to improve the productivity. In order to study pick cutting load under the condition of different traction speed and carry out three cutting test under the different traction speed. Test conditions shown as table 5.

The experimental study of this paper is aimed at single pick cutting, the cutting form is plane cutting when single pick cutting the smooth surface of coal seam. Plane cutting generated the coal debris in break toward two sides[7,19-21]. In the condition of laboratory is easier to realize cutting coal seam, So often use the cutting load of single pick and energy consumption under the condition of laboratory as the standard of cutting performance.The time domain waveform of cutting load under different traction speed in five cutting cycle is shown in figure 13. Under the condition of three different traction speed, carried on statistical analysis, the results listed in Table 6.

Table 5: Cutting parameters of different experimental conditions

Traction speeds（m/min）	Drum speed（r/min）	Pick-body cone angle（°）	Impact angles（°）	Cutting thicknesses（mm）	inclination angles（°）	Pick-tip cone angles（°）
0.3	60	25°	50°	5	0	75°
0.6	60	25°	50°	10	0	75°
0.9	60	25°	50°	15	0	75°

5mm 10mm 15mm

Figure 12: Presentation of different cutting thicknesses tests

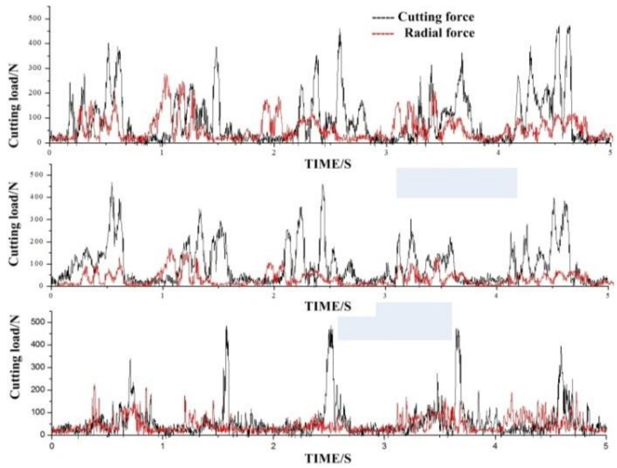

Figure 13: Time domain graph of cutting load with the traction speed being 0.6m/min

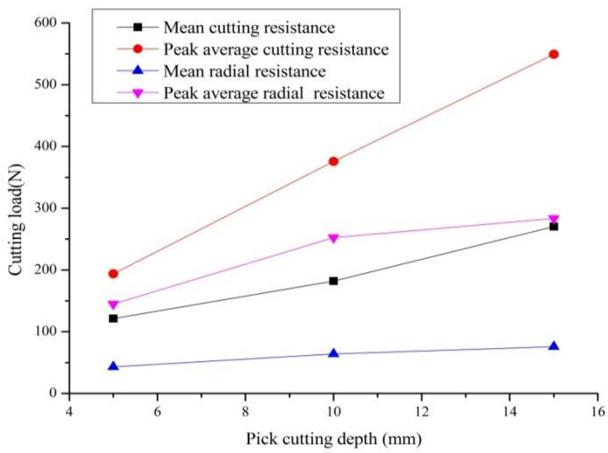

Figure 14: Relationship between cutting thickness and cutting load

Table 6: Statistics of cutting load with different drum traction speeds

Pick cutting thickness (mm)	Mean cutting force (N)	Peak average cutting force (N)	Standard deviation	Mean radial resistance (N)	Peak average radial resistance (N)	Standard deviation
5	121.49	193.9	13.29	43.15	145	18.63
10	182.03	375.7	12.65	64. 13	252.5	13.21
15	270.48	549.5	14.71	75. 96	283.5	16.23

Draw the relationship curve between the cutting load and cutting thickness (fig.14), According to the test results can be seen, cutting load increase with the traction speed increase, which coincide with the simulation results. Because this section drum rotating speed is constant, So the traction speed lead to cutting thickness increase, cutting thickness increases, the cutting load increase obviously. In addition, cutting the peak load is bigger than the average increase of cutting load average growth. The phenomenon generated by the following reason ,the increase of the pulling speed cause the increase of the cutting thickness, so the chip blocks of the corresponding caving are bigger , so from dense cores in the process of cutting to the coal caving the required cutting pick forces is bigger, so the peak load increase obvious.

4. Conclusion

1. Under the working conditions, coal and rock cutting experiment is difficult to achieve cable data transmission. This device is designed to provide a scheme that can meet the data signal transmission. Experiment test system includes the design of the power supply circuit, signal amplification circuit, filter circuit, A/D conversion circuit, SCM (single chip micyoco) acquisition circuit, the design of the wireless communication module transmission circuit, and the design of the wireless receiver circuit.
2. (2) In the scope of this experimental study, when cutting coal seam uses the larger alloy head, cutting pick can reduce the fluctuation of cutting load, and it can guarantee that the drum should run smoothly. With the increase of cutting thickness, the cutting energy consumption increases. As observed from maximum of cutting load and average cutting load, the cutting load increases with the increase of compressive strength.
3. In the scope of this experimental study, with the increase of pick-tip cone angle cutting load showed a trend of increase, the cutting peak mean load change obviously. When pick-tip cone angle is smaller, coal avalanche fall is relatively easy, so cutting peak load is relatively smaller. The big pick-tip cone angle is good for pick cuts into the coal seam.
4. When the drum at constant drum speed, the cutting load increases with the traction speed. The traction speed leads to the cutting thickness increase while the cutting thickness also increases, and consequently, the cutting force obviously increases. Along with the rising of the drum rotating speed, the rotary cutting pick has a large movement inertia according to the law of conservation of momentum, with the increase of kinetic energy transformation, as the coal seam is prone to be broken easier, so the cutting load reduces with the increase of drum rotation speed.

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