Study on the Charge of Pre-splitting Blasting Under the Condition of Composite Roof

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Abstract—**The pre-splitting blasting technology is the core of the roof-cutting pressure relief technology(RPRT), which is the key to achieve the transformation from the long beam to the short beam roof structure. And determining the reasonable charge is the key to the successful implementation of pre-splitting blasting. Under the condition of composite roof, the charge control is difficult due to the complexity of strata structure: too little charge will easily induce bed separation in the working face, and the deformation and instability of roadway surrounding. On the other hand, the roof strata in the roadway will be damaged by over-charging, which will result in roof caving potential. In order to ensure the stability of roadway surrounding rock, the roof rock properties were analyzed to determine the reasonable charge under different roof rock conditions. Combined with the field monitoring of a case study with optimized charge, the maximum roof-to-floor convergence and ribs convergence is 259 mm and 191 mm, by applying the reasonable charge, and the filed test showed good ground controlling effect.**

Keywords- Pre-splitting blasting; Charge control; Roadway stability; Rock pressure observation

I. Introduction

As the core of Academician Manchao He's theory of "short-arm beam with roof-cutting", RPRT's pre-splitting blasting is to use pre-splitting blasting method to cut off the mechanical connection between roofs while mastering the movement law of overlying strata under the guidance of Academician Zhenqi Song's "practical mine pressure theory", so as to maintain the stability of roadway[1]. The key to the success of pre-splitting blasting technology is the control of charge quantity[2]. Relevant scholars have done a lot of research on the relationship between charge quantity and the effect of blasting pressure relief. Zhang[3] et al. studied the stress optimization of surrounding rock of retained roadway to explore the relief mechanism of roof pre-splitting on the mining side. Yang[4] et al. studied the pre-splitting blasting of the shaped charge tube with uncoupled charge, and concluded that shaped charge tube has the function of guiding energy transmission and protecting side rock wall; Feng[3] et al. carried out the optimization of charge structure to determine the parameters of pre-splitting blasting and its the effect of shock absorption; Linlin Jiang[5] studied the directional fracture blasting mechanism of split charge and its application in pre-splitting blasting.

Under the condition of composite roof, the structure of roof is complex, and the selection of pre-splitting parameters has a great influence on the effect of roof pressure relief. Xiaoming Sun[6] and others studied the stress state of roof, and determined parameters such as the height of pre-splitting roof-cutting, the angle of pre-splitting roof-cutting and the spacing of pre-splitting blasting holes; Zhen Zhu[7] and others revealed that the roof subsidence of roadway formed by roof-cutting is composed of the basic roof "given deformation" subsidence and the roof strata separation; Yajun Wang[8] and others divided the deformation of surrounding rock into the influence period of pressure relief, the dynamic pressure deformation period and the compaction stability period. The analysis of roof movement and rock pressure manifestation characteristics in different stages; Chen[9] et al. carried out bidirectional tensile blasting to ensure the roof pressure relief of the return air roadway, effectively reducing the leading bearing pressure and floor heave of the roadway; Liu[10] et al. analyzed the deformation of the blasting pressure relief roadway, and found that the effect of borehole imaging, monitoring of roadway surface displacement and mine pressure was good.

The above studies are based on the determination of blasting parameters of RPRT, while the research on the effect of charge quantity on roof pressure-relief under composite roof conditions is less involved. The uncertainty of blasting charge has a great influence on the roof, so in order to explore the best relationship between them, this paper carries out a specific engineering test in Fuxing Coal Mine, determines the charge quantity amount according to the different rock properties of the roof of the coal mine, and formulates a charging scheme in line with the actual situation of the coal mine to ensure the effect of roof pressure relief. It provides a practical reference for the study on the effect of the pressure relief under the same roof conditions.

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Table I. COEFFICIENT TABLE OF THE ROCK FIRMNESS

Roof property	***Tender roof***			***Medium hard roof***		***Hard roof***				
Kinds of rock	Shal e	Mudston eMalm	Dunn bass	Arenaceous shale, hazel	Argillaceous sandstone,Sand y shale	siltsto ne	Medium sandston e	Fine sabdsto-ne	Limeston e	Tight sandstone,Conglo merate,Dense limestone
Roof stibility	instability			Moderate stability				stabilization		extremely stable
Firmness coefficient f	2	3	4	4-5	4-5	4-6	6	8-10	8-15	10-15

II. PRINCIPLE AND CHARACTERITICS OF PRE-SPLITTING MECHANISM OF PRE SPLITTING TECHNOLOGY FOR BIDIRECTIONAL TENSILE BLASTING

A. Pre-splitting mechanism of bidirectional shaped charge tube blasting

The presplitting of bidirectional shaped charge tube blasting refers to that the excavation contour is designed in advance and the blasting contour holes are blasted with specific specifications of explosives in devices with shaped charge effect in two set directions. After the explosive detonation, the detonation wave will form a concentrated tensile stress in two sets of directions[11], so that the pre-splitting boreholes will penetrate along the direction of energy-accumulating and form a pre-splitting surface; At the same time, due to the protection of energy-accumulating device to the surrounding rock, the damage to the rock mass around the borehole is also greatly reduced[12], which not only realizes pre-splitting, but also protects the roof of roadway. As shown in Figure 1.

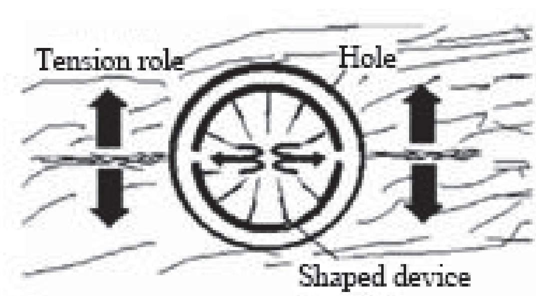

Figure 1. Chart of mechanism of tensile blasting

B. Pre-splitting characteristics of bidirectional shaped charge tube blasting

Reduce the damage of rock mass around the slit hole. The energy gathering tube device can reduce the damage of explosive energy to rock mass protection and effectively protect surrounding rock.

Enhancing the energy utilization rate of explosives. The guiding effect of the slit tube on the energy can make the energy propagate along the pre-splitting line and form a flat section.

Maintaining the stability of surrounding rock of roadway [13]. The mechanical connection between overburden is cut off by means of blasting, and gangue caving is used to fill the goaf to provide cushion for the rotary contact of the main roof with gangue.

III. CHARGE CALCULATION UNDER DIFFERENT ROOF CONDITIONS

According to the failure mechanism of Pre-splitting blasting, the hole is not damaged, which is mainly related to the charge quantity, which depends on the degree of rock solidity. Therefore, it is necessary to study the relationship between charge quantity and rock firmness.

A. Roof classification

According to the national classification standard of rock mass GB50500-2003, the rock firmness is qualitatively divided into the following Table I.

According to the rock mass classification standard of GB50218-94, the rock burst stability is evaluated. When the rock firmness coefficient f < 4, the roof can fall freely with the advancing of the working face, so no charge is needed.

B. Formula selection of charge quantity

In order to uniformly distribute the energy of cartridge and explosive, grade 3 emulsion for mining is used. The charge structure of shaped charge tube is divided into three sections, the length of borehole is L, including mud-sealing section l1, uniform charge section l_2 and section of borehole bottom with reinforcement l_3.

(1) Mud-sealing section. The function of mud sealing section is to prolong the action time of borehole implosion gas to ensure that only cracks are generated at the orifice [14]. The length of mud sealing section depends on the condition of roof. The mud sealing section of weak roof should be prolonged properly. The mud sealing section of deep hole blasting is determined by experience as follows: $l_1 = {}^{L}/_{5}$.

(2) Middle-charging section. The uniform charge section adopts decoupled charging and is evenly arranged along the borehole axis. The charge quantity is determined according to the hardness of the roof.

0.00－4.64 / 1.48	1139.31	5	The coal seam is black, massive and powdery, with strip structure. The gangue is usually 0-2 layers, with a maximum thickness of 0.68 meters.
5.92－33.10 / 14.46	1153.77		Ash to dark gray color siltstone, fine sandstone and silty mudstone are thin to medium-thick bedded. The upper part is often sandwiched with about two thin coal seams, which are unstable and recoverable at individual points. The middle and lower part is sandwiched with a layer of coal, which is about 0.56 m thick.
1.00－5.79 / 3.24	1157.01	9	Coal seam, black, massive and powdery, strip structure, endogenous fracture development, brittle, 0-3 layers of gangue, usually 1 layer, its lithology is dominated by mudstone, gangue thickness is generally 0.26 meters.
0.70－9.80 / 1.86	1158.87		Grayish to dark grayish siltstone, thin bedded, apparently horizontal bedded, containing pyrite nodules, locally transitioned to fine sandstone.
0.00－5.50 / 3.50	1162.37	B3	The upper part is dark gray argillaceous strongly silicified dolomite limestone with medium thick layer, silty structure, metasomatic residual structure and hard. See the loose crystals of pyrite,

Figure 2. Geological histogram

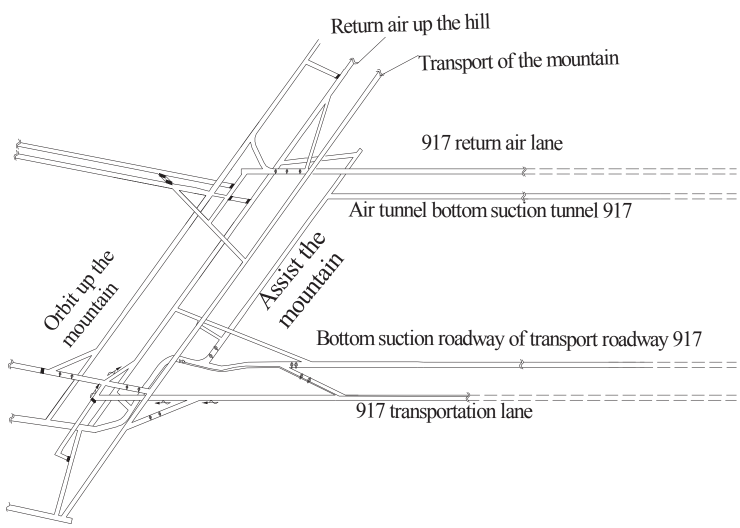

Figure 3. Mining plan

a) Empirical formula of line charge:

$$Q_L = 2.75\left(\frac{\sigma_y}{10^5}\right)^{0.53} \cdot r^{0.38} \quad (1)$$

Formula: σ_y is compressive strength of rock, Mpa; r is borehole radius, mm.

Formula (1) does not consider the relationship between resistance line W and decoupling coefficient D_e. The author reads a lot of research materials to determine the range of resistance line as shown in Table II.

Table II. RESISTANCE LINE RANGE TABLE

Rock consolidating coefficient f	***Roadway width***	***Minimum resistance line***
>10	<5	500-700
	>5	700-900
6-10	<5	600-800
	>5	800-1000
4-6	<5	700-900
	>5	800-1000

b) The resistance line W is inversely proportional to rock firmness; and the decoupling coefficient is the ratio of diameter of the borehole to the diameter of shaped charge tube.

Considering the action relationship between resistance line W and decoupling coefficient D_e, the formula of line charge is improved based on the experience of relevant engineering implementation.

$$q = \frac{2.75\left(f \cdot 10^{-4}\right)^{0.53} \cdot r^{0.38}}{D_e \cdot W} \quad (2)$$

where q is the linear charge density in the middle charge section; F is the rock firmness coefficient; R is the borehole

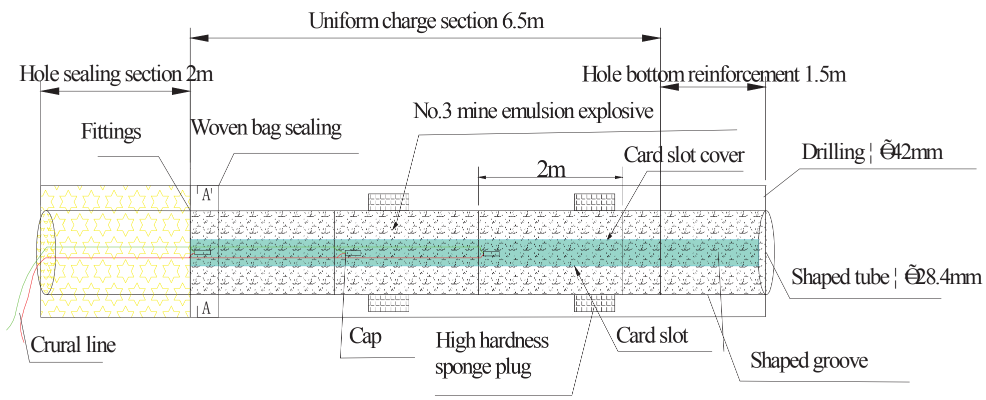

Figure 4. Internal charge diagram of the binding energy tube

radius;D_e is the decoupling coefficient (1.5-2); W is the resistance line, and the value is based on f.

$$Q_{l_2} = q_{l_2} \cdot l_2 = q_{l_{21}} \cdot l_{21} + \ldots + q_{l_{2n}} \cdot l_{2n} \quad (3)$$

where: Q_{l_2} is the charge in section l_2.

The equations are an exception to the prescribed specifications of this template. You will need to determine whether or not your equation should be typed using either the Times New Roman or the Symbol font (please no other font). To create multileveled equations, it may be necessary to treat the equation as a graphic and insert it into the text after your paper is styled.

(3) Section of borehole bottom with reinforcement. The purpose of reinforcing section is to overcome the clamping force of rock at the bottom of the borehole and ensure that the pre-cracking is in the end[15]. Based on the analysis of a large number of practical engineering applications, The hole bottom 1.5 m is taken as the reinforcement section. The increase of charge length and line charge quantity needs to be determined through the actual site. A great deal of practical experience shows that in the deep hole of 8-15 m, the charge quantity of section of borehole bottom with reinforcement is:

$$Q_{l_3} = \begin{cases} 2.5q_{l_3} \cdot l_3, f > 8 \\ 2q_{l_3} \cdot l_3, f < (6-8) \end{cases} \quad (4)$$

According to the above analysis, the formula of single-hole charge quantity is determined:

$$Q_L = Q_{l_2} + Q_{l_3} \quad (5)$$

IV. CASE STUDY

A. Geological and geotechnical Overview

M9 coal is mined in 917 working face of Fuxing Coal Mine, M9 coal seam belongs to Longtan Formation of coal measure strata with an average thickness of 3.5 m; The strike length is 853.5m, the roadway width is 4.2 m and the height is 3.8 m; M9 coal seam is the outburst coal seam, coal and rock dip angle is 8-12 degrees.

The absolute mine gas emission of the is $2.26m^3$/min; the coal seam is free of coal dust explosion danger; the coal seam spontaneous combustion tendency grade is class III spontaneous combustion coal seam. Geological histogram and mining plan are as shown in Figures 2 and 3.

B. Construction parameters

1) Drilling depth

According to the past engineering experience, the drilling angle is 15 degrees, the diameter of the borehole is 42 mm according to the roof condition of the working face, and the borehole construction is carried out at the angle between the goaf and the roadway. The borehole depth is determined according to the empirical formula of rock bulking:

$$H_F = {(H_{CF} - \Delta H_1 - \Delta H_2)} \big/ {(K-1)} \quad (6)$$

where: The average of H_{CF} is 3.5 m; ΔH_1 is the roof subsidence, m; ΔH_2 is the floor heave, m; K is expansion coefficient, which is 1.35; without considering floor heave and roof subsidence, the drilling depth of 917 working face is determined to be 10 m.

2) Charging structure

The situation of overlying strata on the 917 working face is complex. In order to accurately grasp the characteristics of the roof, portable geological drilling machine was used to drill and core the 10 m roof above the working face, The roof conditions were obtained as follows: 0.5 m carbonaceous mudstone, 1.5-2 m mudstone, 3-4 m argillaceous siltstone, 2-2.5 m fine sandstone and 1.5 m siltstone. Determine the structure of drilling charge as shown in the Figure 4.

3) Charge quantity

The diameter of drilling hole is 42 mm, the diameter of concentrator tube is 28 mm, the length is 2 m, and the decoupling index D_e is 1.5. Class 3 emulsion explosive for mines is used, model is 32 mm *200 mm, specifications are 150 g/roll. In order to reduce the damage to the roof strata of the retaining roadway, and to take into account the difficulties of distinct intervals and great bedding separations between strata under the composite roof, four 2-meter energy-accumulating tubes were used, with "3.5 volumes of explosives" in the 1.5-meter siltstone section at the bottom of the hole, "1 volumes of explosives" in the 0.5-meter fine sandstone section, "4 volumes of explosives + 1 detonator" in the 2-meter fine sandstone section in the middle, and "4 volumes of explosives + 2 detonators" in the muddy siltstone section at the bottom. As shown in the Figure 5.

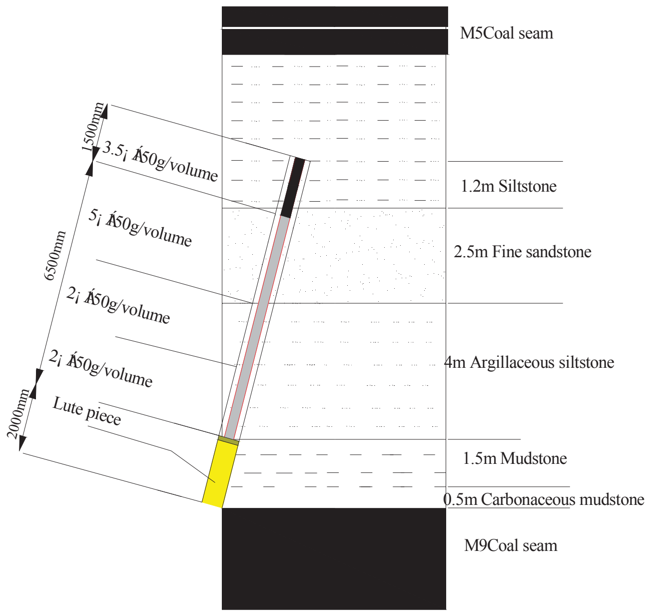

Figure 5. Structural chart of pre-charge

C. Construction technology

1) Construction tools:

1 cutter for cutting explosives; 1 plum screwdriver for fastening connector screw; 1 wipe cloth; several insulating tapes for fixing connectors and positioning blocks at the bottom of holes; air pipe changer, pneumatic injection gun input pipe Phi 10 mm, according to the size of downhole air pipe to make changers; fusion tube and its accessories.

2) Shaped charge:

Decoupling charge is used for roof slit hole after passing inspection. Using downhole pressure air, gas is supplied to the pneumatic injection gun with explosive through the air bag with pressure regulating device, and explosive is injected into the binding energy tube through the pneumatic injection gun; the blinding energy tube is capped, the high hardness sponge positioning block is tied up, and the section of the binding energy tube bottom with reinforcement is extended into the hole bottom; the two binding energy tubes are connected with connectors, and the binding energy tube is positively placed into a detonator, and the foot of the detonator is tightly tied to the binding energy tube. On the tube, detonation is initiated in series; the binding energy tube is placed in the borehole, and the concentrator grooves at both ends correspond to each other, showing a straight line along the roof of the roadway; the hole is sealed with gun mud, and the length is 2 m, as shown in Figure 6.

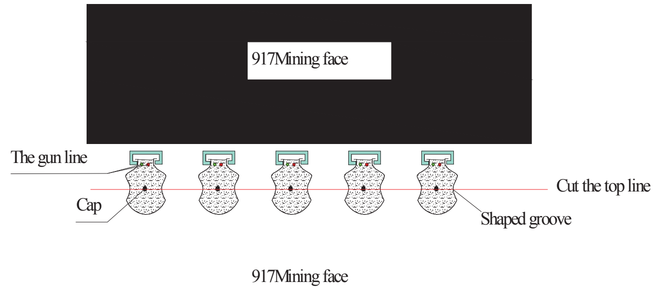

Figure 6. Schematic diagram for the installation of the binding energy tubes

3) Initiationa

According to the existing research results, the roof collapse is the best when the borehole spacing is 500 mm. In advance working face, 60 m detonation is initiated by using permissible emulsion in No. 3 coal mine. The detonation is initiated at intervals, that is, an empty hole is spaced between adjacent charge holes. The plan is as shown in Figure 7.

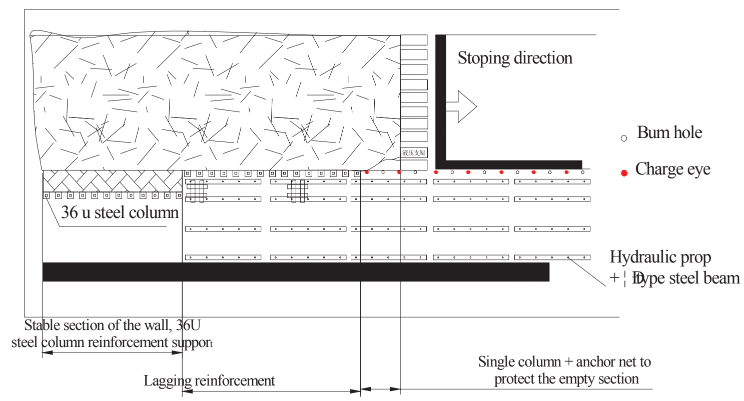

Figure 7. Blast hole layout

V. Effect Analysis

After the implementation of the above charging scheme, the effect of pressure relief in 917 air tunnel is shown in Figure 8. In order to further evaluate the effect of roadway formation, the displacement of roadway surface and the force of hydraulic roof lifting are monitored from the starting position of retaining roadway in working face[16]. There are 10 stations in 917 wind lane, 15 m apart. When the working face advances to the front of the first station, the observation results are shown in Figure 9. and Figure 10. The support force of the hydraulic lifting shed is recorded by the pressure indutor installed on it, and 10 stations are recorded, and the change curve is shown in Figure 11.

Figure 8. Pressure relief effect diagram of 917 air tunnel

Through the observation of rock pressure, the deformation law of surrounding rock of roadway is summarized: the first weighting step of roadway is 36.8 m, the periodic weighting step is 10-15 m, the maximum roof and floor of roadway is 259 mm, and the maximum two sides are 191 mm.

The pressure of hydraulic support in gob-side retaining roadway increases continuously with the advancing of working face. The maximum value of inductor No.10 at the tail of the machine reaches 44.1Mpa at 80 m behind the working face (where the fault develops), and then becomes stable.

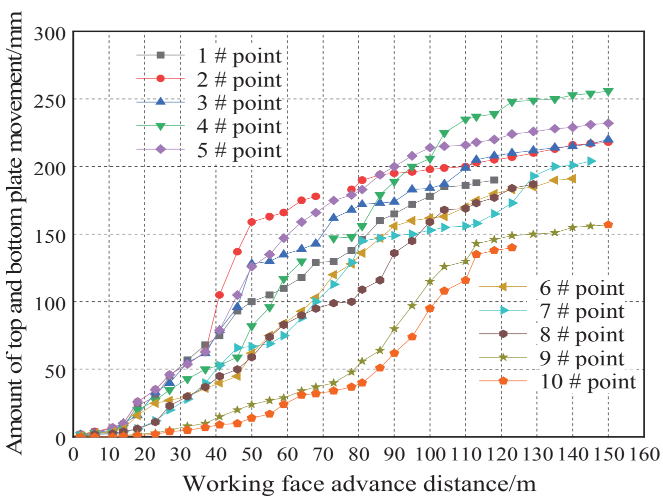

Figure 9. Roof to floor convergence map

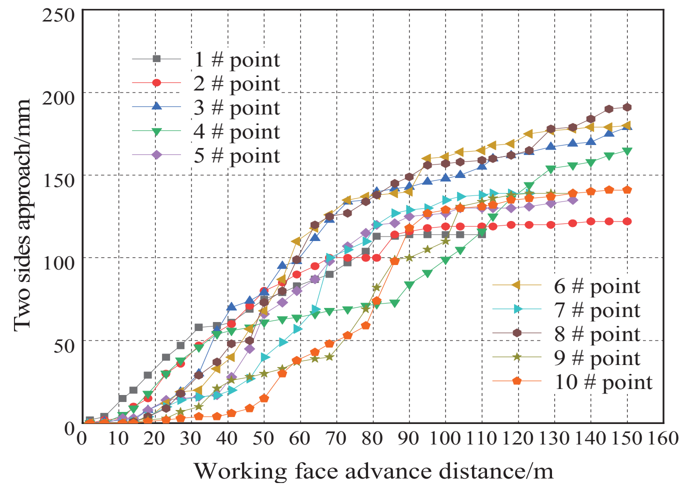

Figure 10. Two-sided convergence map

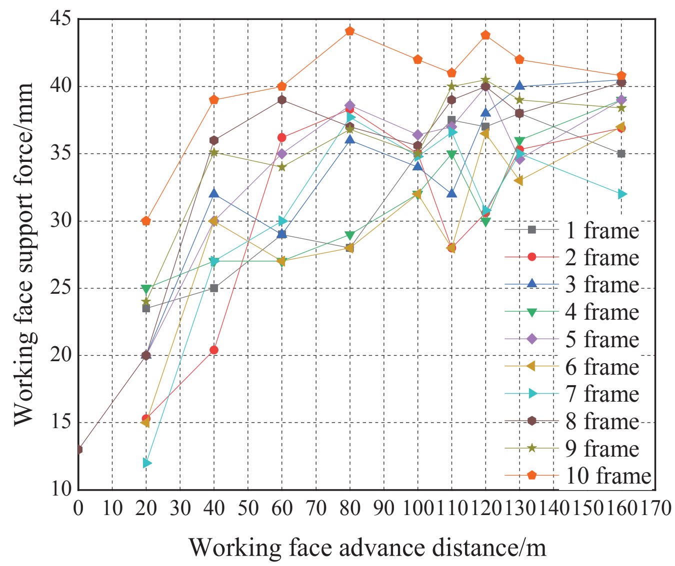

Figure 11. Holding power curve of bracket

From Figure VIII, it can be seen that the pressure relief effect of 917 air tunnel is good, and there is no obvious roof sag, bulging of two sides and other phenomena. Combining with the observation results of rock pressure, the charge quantity of 917 air tunnel is reasonable, and the effect of roof cutting pressure relief along the goaf is good, which meets the requirement of goaf retaining roadway for charge control.

VI. Conclusion

By dividing the rock hardness coefficient and using the improved empirical formula to determine the charge range under different rock conditions, and fully combining the distinct characteristics of the interval between composite roof strata, the single hole charge formula is determined.

According to the actual roof conditions of Fuxing Coal Mine, the charging structure of the energy gathering tube is designed strictly according to the distribution of roof strata, and the consumption of single-hole explosive is determined to be 1.875 Kg, with ideal blasting effect.

Observing the stability of surrounding rock of return air roadway in 917 working face of Fuxing Coal Mine, the maximum roof to floor convergence is 259 mm; the maximum two-sided convergence is 191 mm; the pressure of hydraulic support reaches the maximum value of 44.1Mpa at the tail of the machine, and the pressure relief effect is remarkable.

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