Development of PDC Drill Bits for MWD Directional Drilling in Underground Coal Mine

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Abstract

Design of high quality PDC drill bits is necessary to perform MWD directional drilling for underground coal mine. Relatively deepened analysis was carried out here from the structural parameters to the type selection of cutting teeth of PDC drill bits. A 96mm matrix-body PDC drill bit for directional drilling was developed followed by field tests, for which four branch holes were dilled. The average drilling speed was 4.12m/h and the total drilling footage was 1001.6m. The experimental results indicate that the deflecting effect as well as the service life of the developed drill bit can completely meet the application requirements.

Keywords: measurement-while-drilling (MWD); directional drilling; PDC bit

1. Introduction

The drillability of coal strata is low in the drilling boreholes in coal mines, and the carbide bits or PDC bits are used commonly. As is known to all, the PDC bit has not only the excellent wear resistance of diamond bit, but the strong impact toughness of carbide bit, all of these are helpful to improve its drilling efficiency and useful life, so the cost is reduced obviously, and the PDC bit has become the alternative to the carbide bit. Therefore the PDC bit is recommended in the directional drilling of boreholes in underground coal mine.

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Gas extraction is an effective means to ensure the safety of coal mine production. Many deep multi-branch holes are drilled by directional drilling in order to improve the effect of gas extraction in hard coal strata [1]. So the deflecting function and wear resistance of bit should be considered in the design, meanwhile the useful life and comprehensive benefits must be considered too, so the matrix-body PDC drill bit was selected.

1.1. Structure and crown shape of bit

Compared with the normal bit, the directional drilling bit must be advantageous to deflect, and have very strong cutting capacity to the lateral well. Except that, it has long useful life and good comprehensive benefits, so the followed basic principles must be considered while the structure and crown shape of bit were designed.

1.1.1. Crown shape of bit

The crown shape of bit should be designed within a similar plane or concave conical [2], under this condition, the lateral side of bit is very sharp to strengthen the lateral cut, which is advantageous to deflect without affecting the axial cutting. The crown shape can’t be designed to the convex conical, because the lateral cut capacity is very low and the lateral cutting rock is disturbed, and all of these are disadvantageous to deflect.

1.1.2. Bit type

The directional bit should be designed as full face drilling bit. The rock core can keep the hole direct and prevent the hole from deflecting, which is disadvantageous to deflect and drill multi-branch holes. At last, the bit was designed as concave conical coreless bit, and the height difference was 5~6 mm.

The deflecting is very important during directional multi-branch holes drilling, and the demand of radius retention ability is different from the normal PDC bit. The effect of radius retention ability must be excellent and the height must be controlled, because the high radius retention is disadvantageous to deflect and drill branch holes.

The drill bit should have the ability of accident prevention and dealing with minor incidents. Because the coal strata are from soft to middle hard mainly, the water way of bit should be big for making the flushing fluid bring the rock cuttings. The anti-cutting teeth were designed for lifting the drill pipes when the hole was collapsed slightly.

1.2. Optimal selection of cutting teeth

When the bit works, the PDC cutting tooth cuts the strata directly, so it bears very big dynamic load. The PDC cutting tooth is worn abnormally because of chipping cutter, breaking and PDC losing, which can cause the bit scrapped.

The common sizes of PDC are 100mm, 133mm, 160mm and so on, based on the drilling conditions and strata, different size is selected. If the diameter is smaller, and the PDC can cut strata deeper, and the contact area between PDC and rock is smaller, that is, cutting resistance is smaller, so the small diameter PDC is advantageous to drill hard rock or incomplete rock; however, the smaller diameter PDC causes less cutting area, so the drilling efficiency is lower.

The rock is soft-medium hard, and the drillability ranging from IV to VI, and the abrasion from weak to moderate, so it is important to improve the lateral drilling capacity of bit in the branch hole drilling process, therefore the optimal diameter of PDC is 100mm or 133mm, and the 160mm PDC should not be selected.
In the continuous deflecting drilling process, the outside PDC cutting teeth of bit wear heaviest, so special PDC cutting teeth should be used, which have high hardness, high wear resistance, high impact toughness and high thermal stability[3]. These PDC cutting teeth were handled through high-polished method to reduce the adhesion between cuttings and PDC, which is helpful to improve cuttings transport condition and reduce the possibility of bit balling. The small arranging teeth space of bit will restrict the choice of PDC, and except considering the performance of PDC, the size and bit structure should be considered overall.

1.3. structure parameters of PDC bit

The welding angle and bypass angle are main structure parameters of PDC bit; the structure parameters have a direct impact on the performance of PDC bit.

1.3.1 Melding angle of PDC bit

The negative front angle melding way is the most helpful to cut rock in several melding ways, and which will not only extend the life of PDC, but also improve cutting speed. If the melding angle become small and the cutting resistance will become big, this melding way is adaptive to drill soft rock; if the melding angle big, and the cutting resistance small, this melding way is adaptive to drill hard rock. Based on the theoretical analysis and practice experience, the optimal melding angle (α) is 13° ~17°, when the drill ability ranges from IV to VI. (Fig.1)

![Fig.1. Melding angle of PDC bit](image)

1.3.2 Bypass angle of PDC bit

Because the contact area between PDC bit and the bottom of hole, so its drilling efficiency is very high, therefore it is important to duly clear out cuttings, especially adhesive strata, the cuttings has strong adhesion, which is helpful to lead bit balling, this phenomenon can reduce the drilling speed of PCD bit.

In order to reduce bit balling, the method of increase the pump volume and drilling pressure is used; in addition, to reduce the exposed height of PDC or the size of waterway can produce high-speed fluid, which can flush cuttings, however, if the gap between PDC bit and strata is too small, the cuttings will be stopped in the gap, which will increase the clearing out cuttings resistance. So the bypass angle (β) was designed on the PDC bit (Fig.2), when the PDC bit is rotary drilling, the cuttings will transfer outside as a result of the fluid force(F), so the existence of bypass angle is advantageous to make cuttings away from the front of PDC.
The existence of bypass angle is helpful to clear out cuttings, but it also can reduce the effective cutting force, meanwhile it increases the difficulty of melding PDC tightly, so the bypass angle should not be big, ranging from $3^\circ$ to $5^\circ$.

Fig.2. Bypass angle of PDC bit

2. Development of PDC bit

2.1. Structure design of PDC bit

According to user requirements, the diameter of PDC bit was determined as 96mm. The quantity of PDC on the drill bit will influence its life and drilling efficiency. If the bit includes many PDCs, its anti-vibration and anti-shear will improve obviously, but the drilling pressure on per PDC will reduce, which will lead to a low drilling efficiency.

There are two PDCs in the center concave part of the PDC bit, the diameter of PDC is 13.3mm. The convex groove part was designed as bicyclic arrangement, and there were four PDCs uniform on the outer circle, this arrangement is helpful to deflect and rotate smoothly; there were two PDCs on the inner circle.

The melding angle of PDC bit was designed as $15^\circ$, and bypass angle $5^\circ$. According to these parameters, the PDC bit was manufactured, which not only has sharp lateral cutting capacity to improve the effect of drilling branch hole, but also melds PDCs tightly to increase its life. Fig.3 is the crown shape of PDC bit. The connecting cone thread is $2\frac{3}{8}$"REG.

Fig.3. crown shape of $\Phi96$ directional drilling PDC bit

2.2. processing method of PDC bit

There are two processing methods to manufacture the PDC bit, steel-body and matrix-body. The steel-body PDC bit is easy to manufacture, but its radius retention ability and life will be reduced. The matrix-body PDC bit can avoid these disadvantages, so it was used in large.
These difficulties, like molding, low efficiency and high cost, must be solved for manufacturing matrix-body PDC bit by pressureless metal infiltration. For solving the problem, the soft molding process was used. The connecting thread was processed by CNC lathe for twisting the PDC bit easily.

The PDC bit was tested in the D5#—1 hole, south chengzhuang mine, jincheng city, shanxi province, and the azimuth and inclination of the hole is 202.64° and 5°, the depth is 500m. And this stratum is broken, and the coal layer is banded structure, in addition, the coal layer includes coal gangue. The up layer is medium-grained sandstone, including longitudinal cracks; and the down layer is fine-grained sandstone and argillaceous sandstone.

The rig experimented is ZDY6000LD, and the mud pump is BW-320. The drilling tools was made up of 96mm directional drilling PDC bit+73 mm non-magnetic screw motor(1.25°/1.5°)+73 mm non-magnetic drilling pipes+73 mm cable drilling pipes. The PDC bit was rotated by motor. The pump volume is 165~200 L/min, and pump pressure 2~4.5 MPa, the drilling fluid is water. The deflecting effect of this PDC bit is very good, and the PDC bits has high wear resistance, strong rock broken and clear cuttings out easily, the test results is very good. A main hole and four branch holes were drilled by this PDC bit, and the drilling efficiency was 4.12m/h, the drilling footage is 1001.6m. Fig.4 is the diagram of the real drilling path.

Because the existence of anti-cutting teeth, the lifting drill pipes was very easily. The outer PDC cutting teeth wore slightly, black and shiny, this phenomenon was normal.

Fig.4.Diagram of real drilling path

3. Conclusions

According to the actual situation of coal directional drilling, the demands of deflecting ability, long life, high efficiency and processing easy were considered synthetically, the 96mm matrix-body PDC bit was developed. These conclusions can be summarized:

(1) If the structure and crown shape of PDC bit were designed reasonably, the long-distance continuous deflecting can be carried out easily.

(2) The arrangement of PDC cutting teeth is right, and the PDC cutting teeth selected can satisfy the demand of drilling strata.
(3) The cost was reduced and the quality of PDC bit was insured by using soft molding processing. 
(4) The results indicated that the design of matrix-body PDC bit achieved the expected target.

References

