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PROGRAM STUDI SARJANA TEKNIK GEOLOGI
PROGRAM STUDI MAGISTER TEKNIK GEOLOGI
PROGRAM STUDI SARJANA TEKNIK PERTAMBANGAN
Jl. Babarsari, Caturtunggal, Depok, Sleman, Yogyakarta 55281 Telp. (0274) 485390, 486986, 487540 Fax. (0274) 487249
Email: ft.mineral@itny.ac.id, website: itny.ac.id

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NIK : 1973 0058

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SUPANDI STTNAS <supandi@sttnas.ac.id>

BOEG: Reviewer Invitation for A new method of coring in coal mine: pressure–holding and continuous coring technology

1 message

Louis N.Y. Wong <em@editorialmanager.com> Mon, Sep 12, 2022 at 9:45 PM
Reply-To: "Louis N.Y. Wong" <lnywong@hku.hk>
To: Supandi Sujatono <supandi@sttnas.ac.id>

CC: lnywong@hku.hk

Dear Dr Sujatono,

As the Editor of the journal Bulletin of Engineering Geology and the Environment I want to ask you if you could review the article "A new method of coring in coal mine: pressure–holding and continuous coring technology" for a possible publication in our journal.

This is the abstract:
The quality of core sample, cost-effectiveness and coring quickly in rock stratum are one focus of question need considering in oil–gas field and special operation of coal mine, such as opening coal and gas outburst coal bed, detecting of faults distance or lithological pinch-out, etc., and rock coring technology in soft rock has a deal of work to do to improving the coring quality and coring speed. A pressure–holding and continuous coring technology (PHCCT) and device was developed in this study, and which was compared with conventional coring method in coring speed, core quality and rock quality designation (RQD); the drilling, exiting drill pipe and removing coring bit of conventional coring method wastes lots of time and resulting low efficiency; the coring speed of PHCCT is about double of conventional coring method through improving process, and PHCCT can increase RQD value of rock stratum and has almost no effect on coal bed RQD. The process parameters and
technological measures of PHCCT are also discussed in this paper, the drilling fluid pressure of 6 MPa and the drill outer bit of 94 mm are reasonable in borehole drilling in coal mine; the drilling fluid pressure–holding of PHCCT is realized through the sealing device of drill pipe and sealing fixing borehole drilling. PHCCT is significant for coal-bed and soft rock strum coring.

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With kind regards

Dr. Louis N.Y. Wong
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Bulletin of Engineering Geology and the Environment

A new method of coring in coal mine: pressure–holding and continuous coring technology

--Manuscript Draft--

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Full Title:	A new method of coring in coal mine: pressure–holding and continuous coring technology
Article Type:	Original Article
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A new method of coring in coal mine: pressure–holding and continuous coring technology

Zhao Fajun[a,b,c*], Deng Qigen[a,b], Hao Fuchang[a], Zuo Weiqin[a]

[a] College of Safety Science and Engineering, Henan Polytechnic University, Jiaozou 454000, China; zfj@hpu.edu.cn (FZ); dengqigen@hpu.edu.cn (QD); haofuchang@hpu.edu.cn (FC); zuoweiqin@163.com (WQ)

[b] State Key Laboratory Cultivation Base for Gas Geology and Gas Control, Jiaozou 454000, China

[c] Collaborative Innovation Center of Coal Work Safety, Jiaozou 4540000, China

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Abstract: The quality of core sample, cost-effectiveness and coring quickly in rock stratum are one focus of question need considering in oil–gas field and special operation of coal mine, such as opening coal and gas outburst coal bed, detecting of faults distance or lithological pinch-out, etc., and rock coring technology in soft rock has a deal of work to do to improving the coring quality and coring speed. A pressure–holding and continuous coring technology (PHCCT) and device was developed in this study, and which was compared with conventional coring method in coring speed, core quality and rock quality designation (RQD); the drilling, exiting drill pipe and removing coring bit of conventional coring method wastes lots of time and resulting low efficiency; the coring speed of PHCCT is about double of conventional coring method through improving process, and PHCCT can increase RQD value of rock stratum and has almost no effect on coal bed RQD. The process parameters and technological measures of PHCCT are also discussed in this paper, the drilling fluid pressure of 6 MPa and the drill outer bit of 94 mm are reasonable in borehole drilling in coal mine; the drilling fluid pressure–holding of PHCCT is realized through the sealing device of drill pipe and sealing fixing borehole drilling. PHCCT is significant for coal-bed and soft rock strum coring.

Key words: Coring technology and device; Coring rate; Rock quality designation; Core quality evaluation

1 Introduction

Rock coring technology (RCT) is widely used in many fields, for example, geotechnical and resource exploration (Neal et al. 2008; Levine et al. 2012), mineral development (Dennis. 2000), marine resource exploration (Dong et al. 2011), etc. Core data is also considered to be the key to calibrating various petrophysical logging data (Yan et al. 2008; Onyeji et al. 2018). RCT has been improving continually since its introduction. RCT can be categorized into three main kinds of methods: conventional coring, wire−line coring and side−wall coring (Ashena and Thonhauser 2007). The conventional coring method is consists of a coring device and a coring bit, the coring device is connected with coring bit and drill−pipes, the coring bit cuts rock core from rock body, and the coring device is used to take out rock core. The conventional coring method needs to repeatedly extract the drill−pipe and coring device to collect rock core, which wastes a large amount of time and results in a low efficiency. The wire−line coring method retrieves rock core through the inside of drill−pipe and compresses the retrieving time. Both of methods can successfully obtain rock core and provide valuable geophysical properties for geologists and reservoir engineers (Rourke and Torne 2011). Based on these two coring methods, many new RCT have been developed, such as coring−while−drilling technology (Goldberg et al. 2004), new liner systems (Hall et al. 2008; Shale et al. 2014), pressure coring technology (Schultheiss et al. 2007), anti−clogging coring system (Khan et al. 2014), expanded coring technology (Akinlosotu et al. 2014), and continuous directional coring system (Shinmoto et al. 2011a). Side–wall coring can be divided into two categories: percussion coring and rotary side−wall coring (coring with a small conventional rotary coring motor). Side–wall coring achieves coring of characteristic areas through precise depth control and positioning, but the samples of side–wall coring are usually relatively small in length than the other two kinds of methods.

Coal Safety Supervision Technical Equipment (CSSTE, 2019, NO. 28) of China requires that the coal and gas outburst coal bed must be coring before opening, and the coring of 10 m rock layer and full coal thickness must be conducting consecutively. The characteristics of these coring drilling are similar, e.g. small length (15–50 m), core containing rock and coal, a large gush of gas during drilling in coal bed, and coring difficultly. Therefore, RCT, or low efficiency (conventional coring) or low

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* Corresponding author: Zhao Fajun, Henan Polytechnic University, College of Safety Science and Engineering, 454000, Jiaozuo, China. *E-mail address*: zfj@hpu.edu.cn Tel.: +86-1593-918-3765. ORCID: 0000000253717326

cost-effectiveness (wire−line coring and side−wall coring), cannot meet the requirements of coal bed coring; it is of great practical significance to study coal bed coring technology.

According to the cutter composition, the core bit of conventional coring and wire–line coring can be divided into four types: natural diamond, polycrystalline diamond, thermally stable diamond, and impregnated bit (Shinmoto et al. 2011b), they all can excavate ring hole in rock layer. According to the amount of drilling fluid passing through the drill bit, the core bit profile has three main forms: face discharge, extended channel flushing, and jet profiles (Li et al. 2020). The high–quality micro–core could be obtained by improving the coring bit in side−wall coring system (Yuchun et al. 2017; Desmette et al. 2018), which improved the mechanical coring speed, but the deep–channel chip chute structure of the drill bit weakened the strength of bit body and blade, and affected the design of the blade wing structure and the bit configuration. Guariscor et al. (2011) proposed a design to improve the vibration when the drill bit is coring. Sun et al. (2014) used a combination of hot pressing and welding to improve the diamond coring bit and improved the drilling efficiency. Yuchun et al. (2017) used suction micro–coring drills to solve the problem of poor core–reliability. But the problem of easy wear of micro–core bit still exists.

Insulation and pressure–holding coring technology is widely used in natural gas hydrate coring. The pressure–holding coring device is adopted by the International Ocean Drilling Program, the pressure–holding coring device developed by the European Marine Science and Technology Program is Hydrate Autoclave Coring Equipment, the International Deep Sea Drilling Program used Pressure Core Barrel as the pressure–holding device; the Pressure Temperature Core Sample device was designed by Aumann & Associates (United States) commissioned by Japan Petroleum Corporation, and the Pressure Corer device designed by FUGRO N.V. was used in the South China Sea to explore the natural gas hydrate (Hu, et al. 2009). Several different coring devices are often uses as a comprehensive manner in marine coring to stabilize the thermal and pressure environment in special marine field. Although natural gas hydrate coring has a large amount of gas during coring, it is obviously economically unreasonable to use marine coring technology in coal mine, and new coring device used for coal mine is need to study.

The drilling–hole collapse may be happened during drilling, the collapse is caused by the complex interaction of coal deformation, gas flow, and coal seam structural damage (Yu et al. 2015; Xue et al. 2018).Coal has a typical pore and fissure structure (Gilman and Beckie 2000; Salmachi and Karacan 2017). The flow of gas in the pores and fissures will cause the cavitation and drill hole collapse (Salmachi and Karacan 2017). Pressure–holding and continuous coring technology (PHCCT) uses drilling fluid to maintain constantly pressure acting on drill wall, which changes the stress condition of the original hole–wall from unstable stress to stable two or three-dimensional stress, keeps hole–wall away from collapse, and is beneficial to coring from coal seam.

The purpose of this paper is to evaluate the applicability of PHCCT in coal bed coring operations: Through field experiments, the efficiency and core quality of PHCCT and conventional RCT were compared. The paper is organized as follows: Section 2 gives the details of the drill bit, drill−pipes, the system of PHCCT, and the situation of the experimental site. Part 3 introduces the experimental methods, experimental results, and the quality of coring. Section 4 discusses the factors affecting on coring quality and speed.

2 Experimental System

2.1 Devices of PHCCT

The device connection diagram of PHCCT is shown in figure 1a, which is installed at the opening of drill hole, can keep drilling fluid pressure stable at the section of coring bit. During coring operation, the drilling fluid enters drill hole from the reserved channel of sealing device, flows from outer of drill pipe to coring bit and flows back inside the drill pipe, and is discharged from the tail of the drill pipe with the rock core. The sealing device consists of two parts, the first part is the sealing section of the drill pipe (Fig. 1b), which consists of spring, shell, wear ring, sealing ring, sealing base and drilling fluid joint, its function includes sealing drilling fluid and keeps fluid pressure stable; the second part is the sealing fixing drill hole section (Fig.

1c), which fixes the first part at the opening of hole through four connecting screw, the second part includes elastic capsule, centering guide sleeve, and water−inlet of elastic capsule, etc.

The design of coring bit body adopts five rectangular grooves in the inner and outer rings (Fig. 1d), the outer rectangular groove and inner rectangular groove are 3 mm and 2 mm deep, respectively, which design makes bit under a stable drilling fluid pressure, and ensuring the hole–wall has a constantly water pressure. The coring bit is a polycrystalline diamond compact alloy cutter head, the outer diameter and inner diameter are 94 mm and 63 mm, respectively.

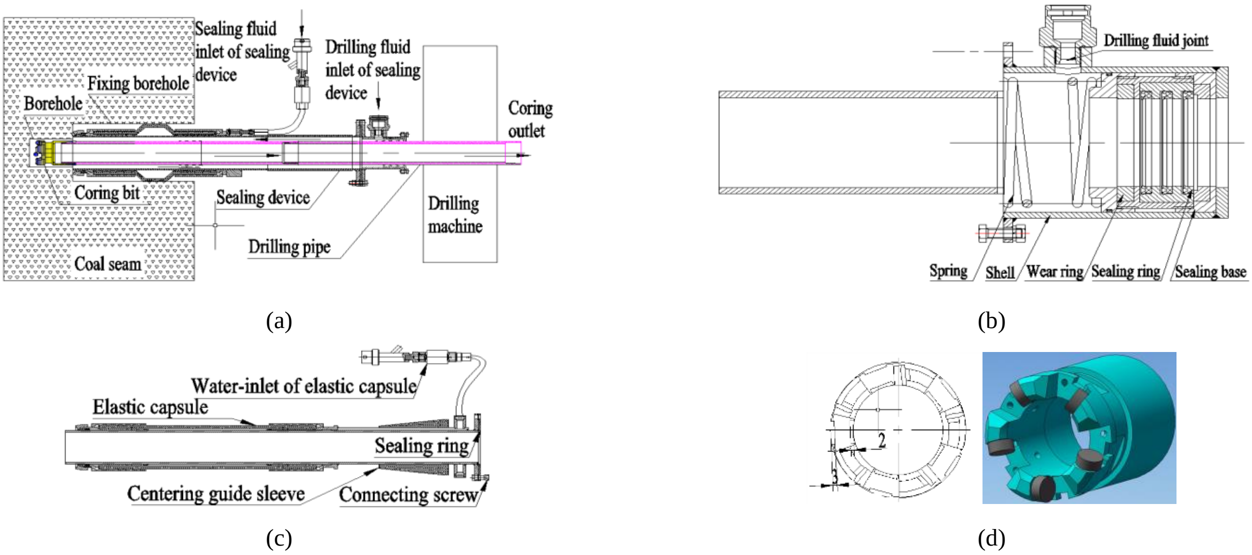

Figure 1. Diagram of pressure–holding continuous coring system: (a) Device connection diagram, (b) Sealing drill pipe section of sealing device, (c) Sealing fixing drill hole section of sealing device, (d) coring bit

The fixing hole (aperture of 133 mm and length of 1 m) needs to be constructed firstly before using PHCCT. After the fixing hole is completed, the drill pipe is passed through the sealing drill pipe section of sealing device (Fig. 1b), the sealing drill pipe section is passed through the sealing fixing drill hole section (Fig. 1c), and then the drill bit is installed on drill pipe. The device (the sealing drill pipe section is connected to sealing fixing drill hole section with bolt and nut) is put into the fixing hole by operating drill carriage, and pressure water (4.5–6.0 MPa) is injected into the water−inlet of elastic capsule to seal and fix the device (Fig. 1a). The centering guide sleeve consists of two petals, which are snapped on the outside of elastic capsule (Fig. 1c) and used for the auxiliary sealing.

Sealing drill pipe section (Fig. 1b) is used to seal the drill pipe. The drilling fluid enters the sealing device through the drilling fluid joint in figure 1b, and flows from the outside of the drill pipe to the bit, part of drilling fluid flows back with the rock core.

The coring drill pipe is made of STM−R780 high strength steel with a wall thickness of 7 mm, the inner diameter of drill pipe is 65 mm, which is larger than the inner diameter of coring bit (63 mm). The drill rig (ZYWL−3200S) is made in Jiangsu Zhongmei Co., Ltd. (Fig. 2).

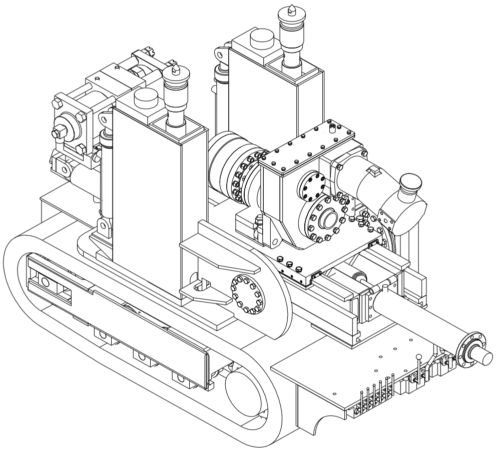

Figure 2. Schematic diagram of drill rig (ZYWL-3200S)

2.2 Experiment Location

ZhongMaCun mine of JiaoMei Co., Ltd. with the danger of coal and gas outburst is the experimental mine. According to CSSTE (2019, NO. 28), rock core and coal core must be taken out before opening Coal and Gas Outburst Seam. The geological column of the ZhongMaCun mine is shown in Figure 3, the coring rock formation is mainly sandstone with uniaxial compressive strength of 45.5 MPa, and the uniaxial compressive strength of coring coal bed is 7.0–10.5 MPa. Zhang (2003),Wu et al. (2005),and Song et al. (2017) suggested that most of the drill hole with buried depth over 300 m in ZhongMaCun mine may have a large amount of gas emission during drill hole, most of the coal drill hole has a low coring recovery rate less than 45%. It is difficult to coring in the coal bed of ZhongMaCun mine.

Distance to earth's surface(m)		Histogram 1:500	Name
Total distance	Rock stratum thickness		
407. 28	6. 30～13. 00		rock stratum
408. 47	0. 80～3. 00		
413. 32	3. 00～8. 00		
416. 98	2. 00～7. 00		rock stratum
423. 11	5. 00～13. 00		
429. 20	3. 00～8. 00		
435. 80	6. 15～6. 90		coal stratum
446. 90	9. 02～12. 10		rock stratum

Figure 3. Geological column of experimental mine

3 Experimental Methods and Results

3.1 Experiment of Drilling Fluid Pressure

The device introduced in Section 2.1 was used to study the effect of drilling fluid pressure on the coring results. Three drilling experiments were carried out under three conditions of drilling fluid pressure of 4 MPa, 6 MPa, and 8 MPa, respectively, with a bit diameter of 94 mm and length of the drill run of 32–34 m (20–21 m of rock hole and 12–14 m of coal hole). The experimental result (Fig. 4) shows that with increasing of drilling fluid pressure, the coring rate of rock formation increases and that of coal bed decreases, and 6 MPa is a relatively well drilling fluid pressure.

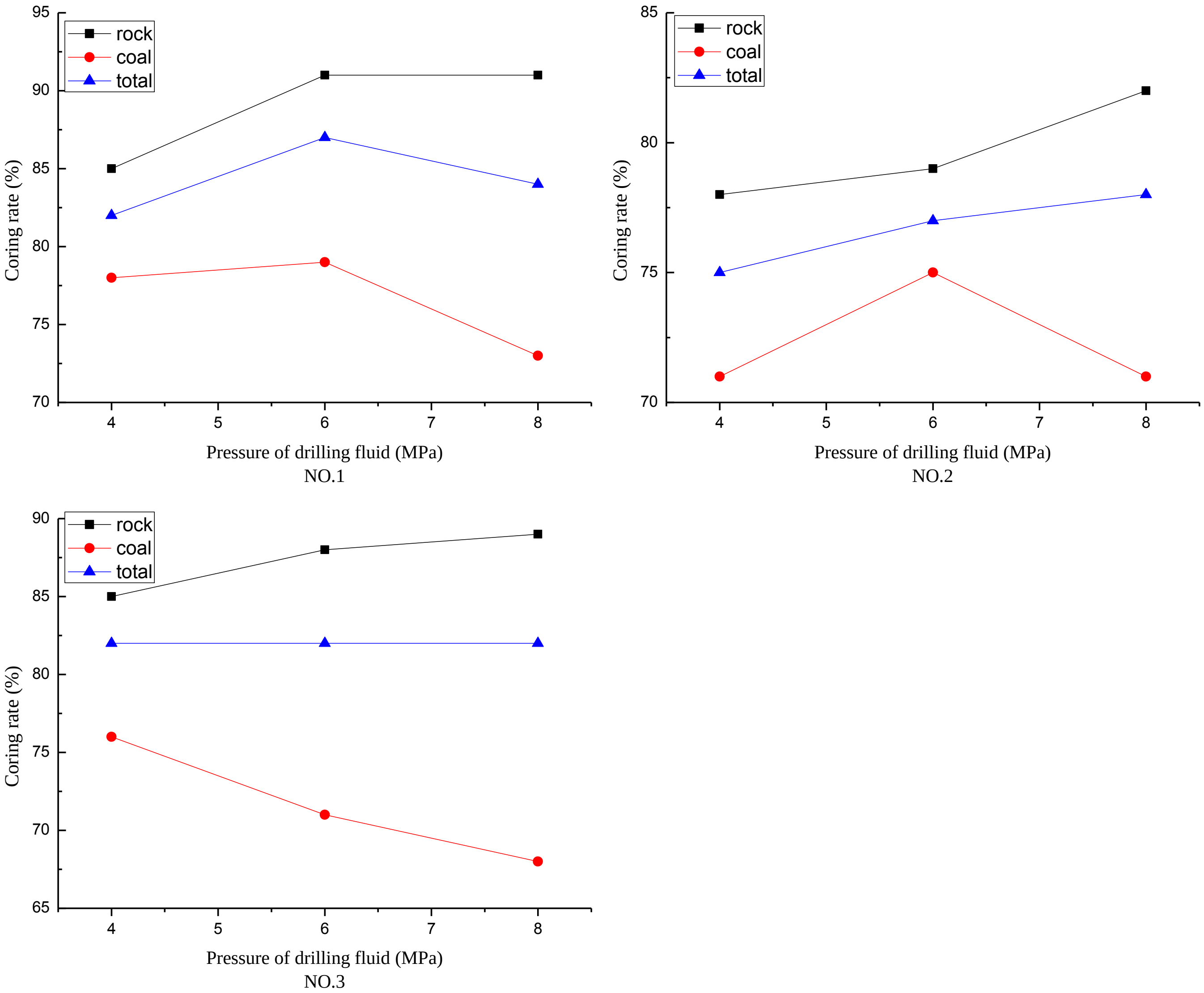

Figure 4. Relation of drilling fluid pressure and coring rate

3.2 Time Measurement of Conventional Coring

The second step of experiment is to study the time distribution of conventional coring methods, which extracts 1.0 m core in every coring cycle. The coring cycle process includes: getting ready for drilling, drilling 1 m, exiting drill pipe (EDR), removing the coring bit (RCB), removing rock core (RRC), installing coring bit (ICB), and drilling again. The average time distribution of coring process was obtained (Fig. 5) basing on the survey of three drill holes.

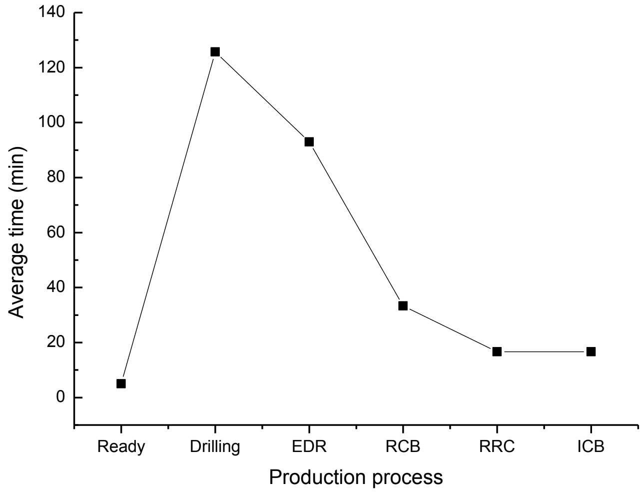

Figure 5. Time distribution of conventional coring process

Figure 5 shows the time distribution of coring cycle process, the average time of drilling, EDR, and RCB in a coring cycle process is about 113 minute (39%), 70 minute (24%) and 33 minute (11%), respectively, the other times (ready, RRC, and ICB) account for approximately 24% of all time. Therefore, the drilling, EDR, and RCB take up a lot of time and affect the coring efficiency.

3.3 Comparison of Two Coring Methods

The third step of experiment compares the efficiency of the conventional coring and PHCCT. The experimental data of the conventional coring method in Table 1 is partly obtained from the Section 3.1 and 3.2. During the PHCCT experiment, the bit outer diameter is 94 mm, 100 mm, and 80 mm, respectively, the total coring time of each drill hole in Table 1 includes: constructing fixing hole (average 10 minute), installing sealing device (about 10 minute), replacing 133 mm drill bit with experiment bit (average 4 minute), drilling and coring.

Table 1 Comparison of different coring methods

Coring Method	Bit Outer Diameter [mm]	Drilling Fluid Pressure [MPa]	Drilling Number	Weight on Bit [kN]	RPM [r/min]	Length of Drill Run [m]		Total Core Length [m]		Total Time [min]	Coring Rate [%]
						Rock	Coal	Rock	Coal		
Conventional coring method	94	6	1	125	77	20.0	12.0	17.3	8.4	241	80
		6	2	127	80	21.0	13.0	18.4	7.4	274	76
		6	3	127	80	20.0	14.0	16.2	10.2	246	78
PHCCT	80	6	1	127	81	20.0	13.0	17.1	8.8	88	78
		6	2	127	81	22.0	13.0	18.2	8.5	84	76
	100	6	1	127	80	22.0	12.0	18.4	7.9	119	77
		6	2	127	80	22.0	12.0	19.5	8.2	132	81
	94	6	1	127	80	20.0	12.0	18.2	9.5	121	87
		6	2	127	80	21.0	10.0	16.5	7.5	115	77
		6	3	127	80	24.0	13.0	21.2	9.2	116	82

The coring speed of conventional coring method calculated from data of Table 1 is 0.12–0.14 m/min, and the coring speed of PHCCT with a bit outer diameter of 94 mm, 100 mm, and 80 mm is 0.26–0.32 m/min, 0.26–0.29 m/min, and 0.38–0.42 m/min, respectively. Basing on the data in Table 1, the conventional coring method has the average coring rate of 78% (76–80%), and the coring rate of PHCCT is 80% (76-87%).

3.4 Core Quality Evaluation

The objective of coring is obtained the results required for useful geological and petrophysical investigations, rather than simply drilling the formation (Zhang. 2003), therefore, the quality of the cores is generally concerned by geologists. The causes of coring damage includes: (1) Geological factors (stress state underground, rock strength, natural cracks, and expanding clay, etc.); (2) Coring operations (such as blockage, fracturing, breaking, and cutting, etc.); (3) Core recovery and storage (pore fluid expansion, drilling fluid intrusion, thermal shrinkage and poor handling/storage, etc.). Rock quality designation (RQD) is often used to identify the quality of rock engineering. The RQD calculation formula (Eq. 1) was given by Deere and Miller (1966).

$$RQD = \frac{100\sum x_i}{L} \tag{1}$$

Where, x_i are the lengths of individual pieces of core in drill run having lengths of 0.1 m or greater, L is the total length of the drill run, m.

The RQD calculated according to Equation 1 is shown in Table 2. Table 2 shows that the conventional coring method has average RQD of 49% (rock core 47–57% and coal core 44–50%), and PHCCT method has average RQD of 55% (rock core 63–66% and coal core 43–48%).

Table 2 RQD comparison of different coring method

Coring Method	Bit Outer Diameter [mm]	Drilling Number	Length of Drill Run [m]		RQD[%]		
			Rock	Coal	Rock	Coal	Comprehensive
Conventional coring method	94	1	20.0	12.0	57	50	54
		2	21.0	13.0	50	45	48
		3	20.0	14.0	47	44	46
PHCCT	94	1	20.0	12.0	63	48	56
		2	21.0	10.0	66	46	56
		3	24.0	13.0	65	43	54

Figure 6 shows part of the coal cores and rock cores with the diameter of 94 mm collected during the experiment. The appearance of the rock core is smoother than that of the coal core, but both have the same outer diameter.

(a) coal core (b) rock core

Figure 6. Part of the cores collected during the experiment

4 Discussion

4.1 Cutting Area and Coring speed

The cutting area during coring can be described as:

$$S=\frac{\pi}{4}\left(d_O^2-d_I^2\right) \tag{2}$$

Where, S is the cutting area, mm^2; d_O and d_I are the outer diameter and inner diameter, respectively, mm.

Inner diameter of the drill bit in this experiment is 63 mm, the cutting area of different outer diameter (80 mm, 94 mm, and 100 mm) is 1908 mm^2, 3821 mm^2, and 4734 mm^2, respectively, the weight on bit is 127 kN (Table 1), so the stress acting on rock is 66.6 MPa, 33.2 MPa, and 26.8 MPa, respectively.

Figure 7 shows the relation of PHCCT coring speed values calculated according to Table 1 and the cutting area values calculated by Eq. 2. Figure 7 shows that the coring speed is very quick when the stress acting on rock is over the rock uniaxial compressive strength (45.5 MPa), and the coring speed decreases as the cutting area increases. The larger the cutting area, the lower the stress acts on rock.

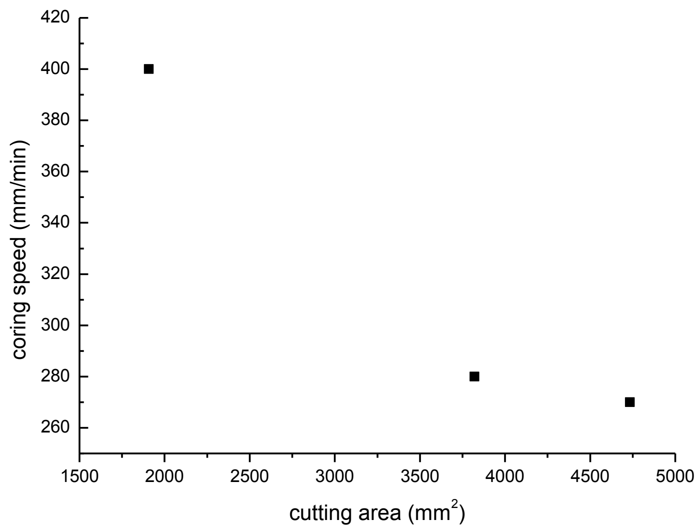

Figure 7 Relation of cutting area and coring speed

Table 1 shows that the coring speed of PHCCT (0.26–0.32 m/min) is faster than that of conventional coring (0.12–0.14 m/min) when the cutting area of conventional coring is equal to PHCCT (3821 mm^2). Figure 5 and Table 1 show that the coring efficiency of conventional coring may increase from 0.13 (33/254) m/min to 0.25 (33/134) m/min when the process of EDR and RCB in conventional coring cycle is removed, which is close to the coring speed of PHCCT (0.26–0.32 m/min), so PHCCT increases the coring speed by optimizing technology (removing EDR and RCB).

4.2 Influence of Bit Diameter on Core Quality

Table 1 shows that the average coring rate of PHCCT with bit outer diameter of 80 mm, 94 mm, and 100 mm is 77%, 82%, and 79%, respectively, the coring rate of PHCCT is related to the bit outer diameter, and the bit outer diameter of 94 mm has the highest coring rate. Figure 7 approves that the cutting area is negative relation to coring speed. The little outer diameter bit (80 mm) will impact with high stress on rock and large outer diameter bit (100 mm) will have more stress percussive frequency on rock, both of them make rock being damage more, so the outer diameter middle bit (94 mm) has maximum coring rate.

The bit outer diameter of 94 mm in Table 1 shows that the average coring rate of conventional coring (76–80%, average value of 78%) is less than that of PHCCT (76–87%, average value of 80%). The reason may be that PHCCT can keep the drilling under the state of continuous confining pressure, and the confining pressure can increase the rock strength.

Table 2 shows that PHCCT can improve the RQD comprehensive value from 46–54% to 54–56%. The reason may be that the conventional coring method will cut the rock with interval of 1 m during coring, resulting some of long core being cut.

4.3 Influence of Water on Core Quality

Zhang et al. (2018) pointed out that the coal core could increase by 2.40% after water adsorption. Zhao et al. (2017) pointed out that the coal matrix phase had no significant change after water adsorption, but some mineral in coal seam (such as calcite, nontronite, et al.) may expand and weak coal core. The PHCCT keeps the drilling under continuous confining pressure state and increases the coal strength, but the pressure–water entered in coal bed under the continuous confining pressure is more, comparing conventional coring, and more seepage water expands coal seam mineral and decreases coal strength, therefore, the average RQD value of PHCCT and conventional coring is similar as 46% (Table 2, PHCCT of 43–48%, conventional coring of 44–50%).

According to Table 2, the average rock stratum RQD value of PHCCT and conventional coring is 65% and 51%, respectively, PHCCT can increase the rock stratum RQD value of 14%. The reason may be that PHCCT increases the rock strength by the continuous confining pressure and conventional coring has no continuous confining pressure, the rock stratum has lower permeability and less water is permeated. Therefore, the PHCCT shows larger rock stratum RQD values.

5 Results

A pressure–holding and continuous coring technology device was developed and coring experiment was carried out.

(1) High drilling fluid pressure increases rock stratum coring rate and decreases coal bed coring rate, and 6 MPa is a reasonable drilling fluid pressure in boreholes drilling in coal mines.

(2) The conventional coring process wastes much time on exiting drill pipe and removing the coring bit, resulting low efficiency. The coring speed can be increased about double by pressure–holding and continuous coring technology.

(3) The pressure–holding and continuous coring technology can increase RQD value of rock stratum, but has almost no effect on coal bed.

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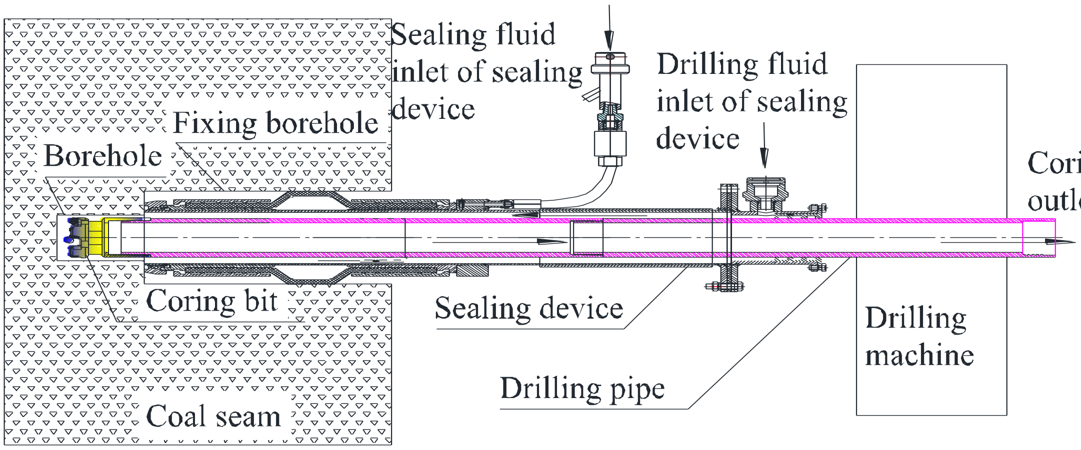
Figure



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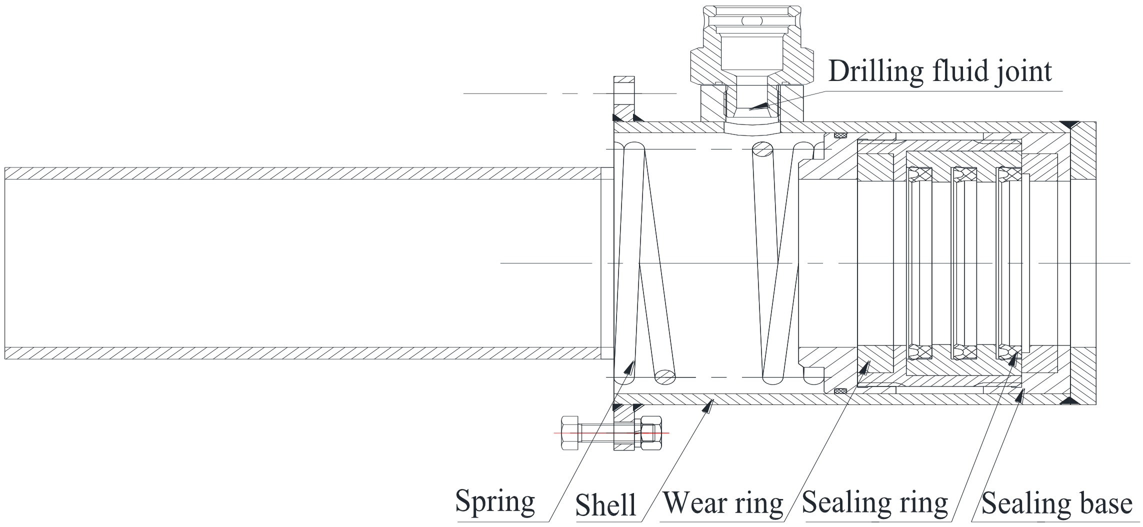

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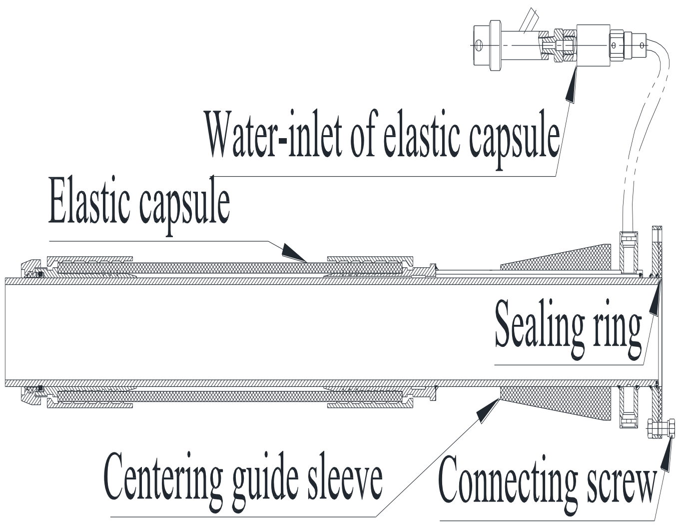

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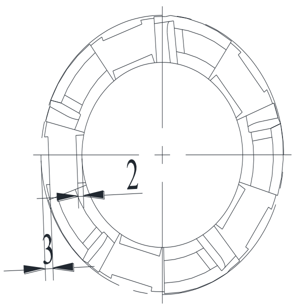

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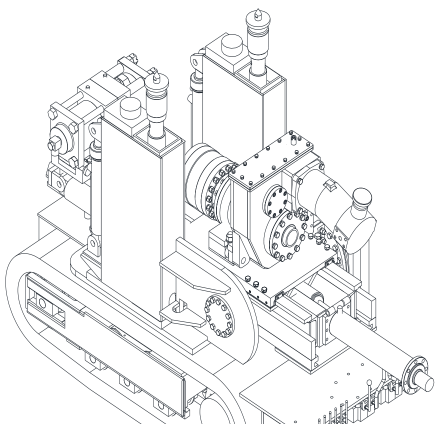

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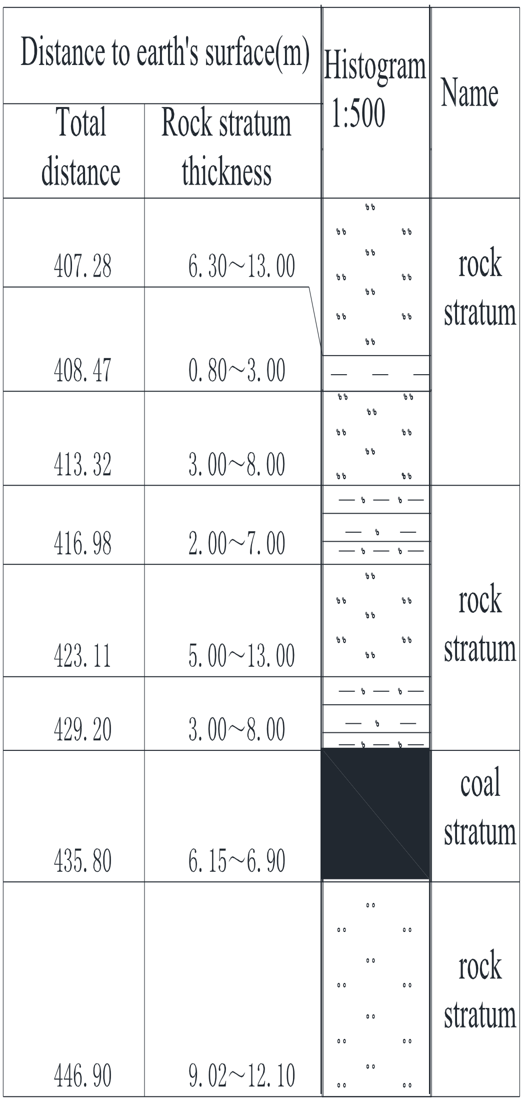
Distance to earth's surface(m)
Total distance
Rock stratum thickness
Histogram 1:500
Name
407.28
6.30~13.00
408.47
0.80~3.00
413.32
3.00~8.00
rock stratum
416.98
2.00~7.00
423.11
5.00~13.00
429.20
3.00~8.00
rock stratum
435.80
6.15~6.90
coal stratum
446.90
9.02~12.10
rock stratum

Figure 3.

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A new method of coring in coal mine: pressure–holding and continuous coring technology

--Manuscript Draft--

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Article Type:	Original Article
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A new method of coring in coal mine: pressure–holding and continuous coring technology

Zhao Fajun[a,b,c*], Deng Qigen[a,b], Hao Fuchang[a], Zuo Weiqin[a]

[a] College of Safety Science and Engineering, Henan Polytechnic University, Jiaozou 454000, China; zfj@hpu.edu.cn (FZ); dengqigen@hpu.edu.cn (QD); haofuchang@hpu.edu.cn (FC); zuoweiqin@163.com (WQ)

[b] State Key Laboratory Cultivation Base for Gas Geology and Gas Control, Jiaozou 454000, China

[c] Collaborative Innovation Center of Coal Work Safety, Jiaozou 4540000, China

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Abstract: The quality of core sample, cost-effectiveness and coring quickly in rock stratum are one focus of question need considering in oil–gas field and special operation of coal mine, such as opening coal and gas outburst coal bed, detecting of faults distance or lithological pinch-out, etc., and rock coring technology soft rock has a deal of work to do to improving the coring quality and coring speed. A pressure–holding and continuous coring technology (PHCCT) and device was developed in this study, and which was compared with conventional coring method in coring speed, core quality and rock quality designation (RQD); the drilling, exiting drill pipe and removing coring bit of conventional coring method wastes lots of time and resulting low efficiency; the coring speed of PHCCT is about double of conventional coring method through improving process, and PHCCT can increase RQD value of rock stratum and has almost no effect on coal bed RQD. The process parameters and technological measures of PHCCT are also discussed in this paper, the drilling fluid pressure of 6 MPa and the drill outer bit of 94 mm are reasonable in borehole drilling in coal mine; the drilling fluid pressure–holding of PHCCT is realized through the sealing device of drill pipe and sealing fixing borehole drilling. PHCCT is significant for coal-bed and soft rock strum coring.

Key words: Coring technology and device; Coring rate; Rock quality designation; Core quality evaluation

1 Introduction

Rock coring technology (RCT) is widely used in many fields, for example, geotechnical and resource exploration (Neal et al. 2008; Levine et al. 2012), mineral development (Dennis. 2000), marine resource exploration (Dong et al. 2011), etc. Core data is also considered to be the key to calibrating various petrophysical logging data (Yan et al. 2008; Onyeji et al. 2018). RCT has been improving continually since its introduction. RCT can be categorized into three main kinds of methods: conventional coring, wire–line coring and side–wall coring (Ashena and Thonhauser 2007). The conventional coring method is consists of a coring device and a coring bit, the coring device is connected with coring bit and drill–pipes, the coring bit cuts rock core from rock body, and the coring device is used to take out rock core. The conventional coring method needs to repeatedly extract the drill–pipe and coring device to collect rock core, which wastes a large amount of time and results in a low efficiency. The wire–line coring method retrieves rock core through the inside of drill–pipe and compresses the retrieving time. Both of methods can successfully obtain rock core and provide valuable geophysical properties for geologists and reservoir engineers (Rourke and Torne 2011). Based on these two coring methods, many new RCT have been developed, such as coring–while–drilling technology (Goldberg et al. 2004), new liner systems (Hall et al. 2008; Shale et al. 2014), pressure coring technology (Schultheiss et al. 2007), anti–clogging coring system (Khan et al. 2014), expanded coring technology (Akinlosotu et al. 2014), and continuous directional coring system (Shinmoto et al. 2011a). Side–wall coring can be divided into two categories: percussion coring and rotary side–wall coring (coring with a small conventional rotary coring motor). Side–wall coring achieves coring of characteristic areas through precise depth control and positioning, but the samples of side–wall coring are usually relatively small in length than the other two kinds of methods.

Coal Safety Supervision Technical Equipment (CSSTE, 2019, NO. 28) of China requires that the coal and gas outburst coal bed must be coring before opening, and the coring of 10 m rock layer and full coal thickness must be conducting consecutively. The characteristics of these coring drilling are similar, e.g. small length (15–50 m), core containing rock and coal, a large gush of gas during drilling in coal bed, and coring difficultly. Therefore, RCT, or low efficiency (conventional coring) or low

* Corresponding author: Zhao Fajun, Henan Polytechnic University, College of Safety Science and Engineering, 454000, Jiaozuo, China. *E-mail address*: zfj@hpu.edu.cn Tel.: +86-1593-918-3765. ORCID: 0000000253717326

cost-effectiveness (wire−line coring and side−wall coring), cannot meet the requirements of coal bed coring; it is of great practical significance to study coal bed coring technology.

According to the cutter composition, the core bit of conventional coring and wire–line coring can be divided into four types: natural diamond, polycrystalline diamond, thermally stable diamond, and impregnated bit (Shinmoto et al. 2011b), they all can excavate ring hole in rock layer. According to the amount of drilling fluid passing through the drill bit, the core bit profile has three main forms: face discharge, extended channel flushing, and jet profiles (Li et al. 2020). The high–quality micro–core could be obtained by improving the coring bit in side−wall coring system (Yuchun et al. 2017; Desmette et al. 2018), which improved the mechanical coring speed, but the deep–channel chip chute structure of the drill bit weakened the strength of bit body and blade, and affected the design of the blade wing structure and the bit configuration. Guariscor et al. (2011) proposed a design to improve the vibration when the drill bit is coring. Sun et al. (2014) used a combination of hot pressing and welding to improve the diamond coring bit and improved the drilling efficiency. Yuchun et al. (2017) used suction micro–coring drills to solve the problem of poor core–reliability. But the problem of easy wear of micro–core bit still exists.

Insulation and pressure–holding coring technology is widely used in natural gas hydrate coring. The pressure–holding coring device is adopted by the International Ocean Drilling Program, the pressure–holding coring device developed by the European Marine Science and Technology Program is Hydrate Autoclave Coring Equipment, the International Deep Sea Drilling Program used Pressure Core Barrel as the pressure–holding device; the Pressure Temperature Core Sample device was designed by Aumann & Associates (United States) commissioned by Japan Petroleum Corporation, and the Pressure Corer device designed by FUGRO N.V. was used in the South China Sea to explore the natural gas hydrate (Hu, et al. 2009). Several different coring devices are often uses as a comprehensive manner in marine coring to stabilize the thermal and pressure environment in special marine field. Although natural gas hydrate coring has a large amount of gas during coring, it is obviously economically unreasonable to use marine coring technology in coal mine, and new coring device used for coal mine is need to study.

The drilling–hole collapse may be happened during drilling, the collapse is caused by the complex interaction of coal deformation, gas flow, and coal seam structural damage (Yu et al. 2015; Xue et al. 2018).Coal has a typical pore and fissure structure (Gilman and Beckie 2000; Salmachi and Karacan 2017). The flow of gas in the pores and fissures will cause the cavitation and drill hole collapse (Salmachi and Karacan 2017). Pressure–holding and continuous coring technology (PHCCT) uses drilling fluid to maintain constantly pressure acting on drill wall, which changes the stress condition of the original hole–wall from unstable stress to stable two or three-dimensional stress, keeps hole–wall away from collapse, and is beneficial to coring from coal seam.

The purpose of this paper is to evaluate the applicability of PHCCT in coal bed coring operations: Through field experiments, the efficiency and core quality of PHCCT and conventional RCT were compared. The paper is organized as follows: Section 2 gives the details of the drill bit, drill−pipes, the system of PHCCT, and the situation of the experimental site. Part 3 introduces the experimental methods, experimental results, and the quality of coring. Section 4 discusses the factors affecting on coring quality and speed.

2 Experimental System

2.1 Devices of PHCCT

The device connection diagram of PHCCT is shown in figure 1a, which is installed at the opening of drill hole, can keep drilling fluid pressure stable at the section of coring bit. During coring operation, the drilling fluid enters drill hole from the reserved channel of sealing device, flows from outer of drill pipe to coring bit and flows back inside the drill pipe, and is discharged from the tail of the drill pipe with the rock core. The sealing device consists of two parts, the first part is the sealing section of the drill pipe (Fig. 1b), which consists of spring, shell, wear ring, sealing ring, sealing base and drilling fluid joint, its function includes sealing drilling fluid and keeps fluid pressure stable; the second part is the sealing fixing drill hole section (Fig.

1c), which fixes the first part at the opening of hole through four connecting screw, the second part includes elastic capsule, centering guide sleeve, and water–inlet of elastic capsule, etc.

The design of coring bit body adopts five rectangular grooves in the inner and outer rings (Fig. 1d), the outer rectangular groove and inner rectangular groove are 3 mm and 2 mm deep, respectively, which design makes bit under a stable drilling fluid pressure, and ensuring the hole–wall has a constantly water pressure. The coring bit is a polycrystalline diamond compact alloy cutter head, the outer diameter and inner diameter are 94 mm and 63 mm, respectively.

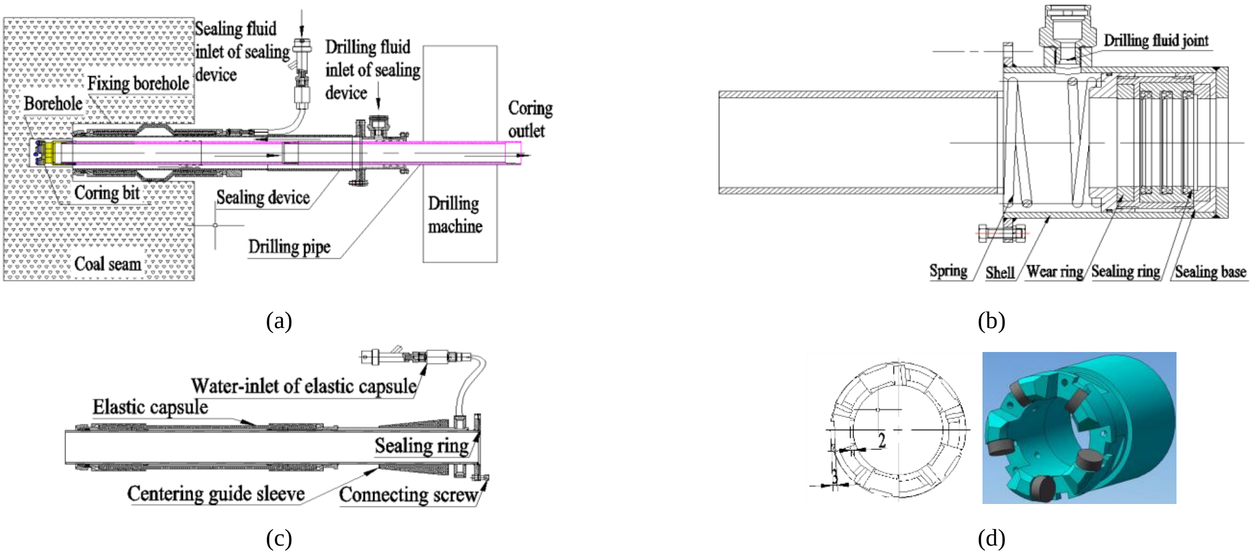

Figure 1. Diagram of pressure–holding continuous coring system: (a) Device connection diagram, (b) Sealing drill pipe section of sealing device, (c) Sealing fixing drill hole section of sealing device, (d) coring bit

The fixing hole (aperture of 133 mm and length of 1 m) needs to be constructed firstly before using PHCCT. After the fixing hole is completed, the drill pipe is passed through the sealing drill pipe section of sealing device (Fig. 1b), the sealing drill pipe section is passed through the sealing fixing drill hole section (Fig. 1c), and then the drill bit is installed on drill pipe. The device (the sealing drill pipe section is connected to sealing fixing drill hole section with bolt and nut) is put into the fixing hole by operating drill carriage, and pressure water (4.5–6.0 MPa) is injected into the water–inlet of elastic capsule to seal and fix the device (Fig. 1a). The centering guide sleeve consists of two petals, which are snapped on the outside of elastic capsule (Fig. 1c) and used for the auxiliary sealing.

Sealing drill pipe section (Fig. 1b) is used to seal the drill pipe. The drilling fluid enters the sealing device through the drilling fluid joint in figure 1b, and flows from the outside of the drill pipe to the bit, part of drilling fluid flows back with the rock core.

The coring drill pipe is made of STM–R780 high strength steel with a wall thickness of 7 mm, the inner diameter of drill pipe is 65 mm, which is larger than the inner diameter of coring bit (63 mm). The drill rig (ZYWL–3200S) is made in Jiangsu Zhongmei Co., Ltd. (Fig. 2).

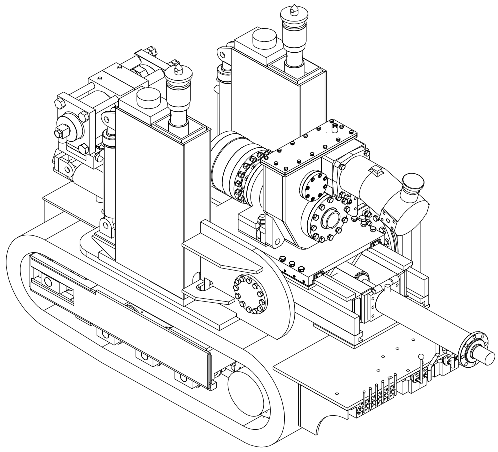

Figure 2. Schematic diagram of drill rig (ZYWL-3200S)

2.2 Experiment Location

ZhongMaCun mine of JiaoMei Co., Ltd. with the danger of coal and gas outburst is the experimental mine. According to CSSTE (2019, NO. 28), rock core and coal core must be taken out before opening Coal and Gas Outburst Seam. The geological column of the ZhongMaCun mine is shown in Figure 3, the coring rock formation is mainly sandstone with uniaxial compressive strength of 45.5 MPa, and the uniaxial compressive strength of coring coal bed is 7.0–10.5 MPa. Zhang (2003),Wu et al. (2005),and Song et al. (2017) suggested that most of the drill hole w[illegible]uried depth over 300 m in ZhongMaCun mine may have a large amount of gas emission during drill hole, most of the coal drill hole has a low coring recovery rate less than 45%. It is difficult to coring in the coal bed of ZhongMaCun mine.

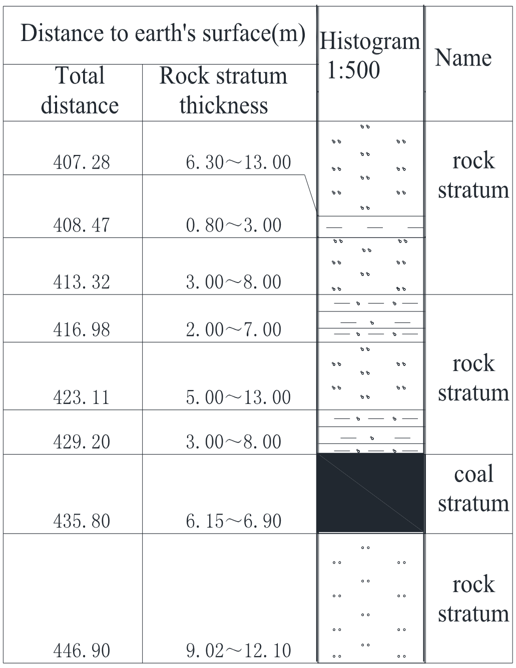

Figure 3. Geological column of experimental mine

3 Experimental Methods and Results

3.1 Experiment of Drilling Fluid Pressure

The device introduced in Section 2.1 was used to study the effect of drilling fluid pressure on the coring results. Three drilling experiments were carried out under three conditions of drilling fluid pressure of 4 MPa, 6 MPa, and 8 MPa, respectively, with a bit diameter of 94 mm and length of the drill run of 32–34 m (20–21 m of rock hole and 12–14 m of coal hole). The experimental result (Fig. 4) shows that with increasing of drilling fluid pressure, the coring rate of rock formation increases and that of coal bed decreases, and 6 MPa is a relatively well drilling fluid pressure.

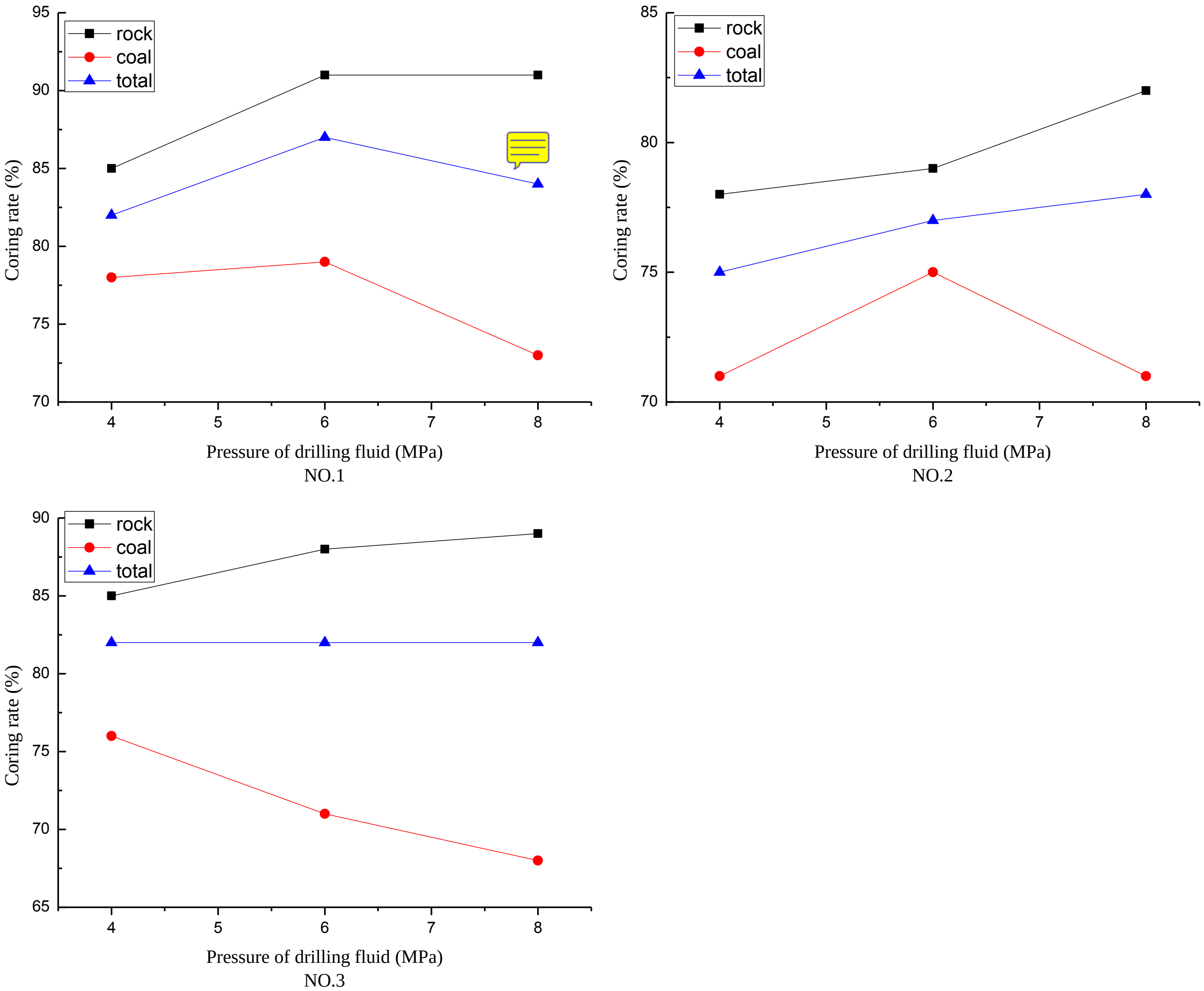

Figure 4. Relation of drilling fluid pressure and coring rate

3.2 Time Measurement of Conventional Coring

The second step of experiment is to study the time distribution of conventional coring methods, which extracts 1.0 m core in every coring cycle. The coring cycle process includes: getting ready for drilling, drilling 1 m, exiting drill pipe (EDR), removing the coring bit (RCB), removing rock core (RRC), installing coring bit (ICB), and drilling again. The average time distribution of coring process was obtained (Fig. 5) basing on the survey of three drill holes.

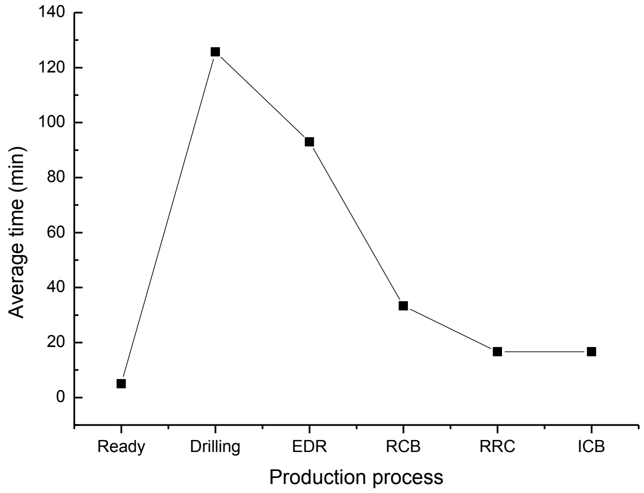

Figure 5. Time distribution of conventional coring process

Figure 5 shows the time distribution of coring cycle process, the average time of drilling, EDR, and RCB in a coring cycle process is about 113 minute (39%), 70 minute (24%) and 33 minute (11%), respectively, the other times (ready, RRC, and ICB) account for approximately 24% of all time. Therefore, the drilling, EDR, and RCB take up a lot of time and affect the coring efficiency.

3.3 Comparison of Two Coring Methods

The third step of experiment compares the efficiency of the conventional coring and PHCCT. The experimental data of the conventional coring method in Table 1 is partly obtained from the Section 3.1 and 3.2. During the PHCCT experiment, the bit outer diameter is 94 mm, 100 mm, and 80 mm, respectively, the total coring time of each drill hole in Table 1 includes: constructing fixing hole (average 10 minute), installing sealing device (about 10 minute), replacing 133 mm drill bit with experiment bit (average 4 minute), drilling and coring.

Table 1 Comparison of different coring methods

Coring Method	Bit Outer Diameter [mm]	Drilling Fluid Pressure [MPa]	Drilling Number	Weight on Bit [kN]	RPM [r/min]	Length of Drill Run [m]		Total Core Length [m]		Total Time [min]	Coring Rate [%]
						Rock	Coal	Rock	Coal		
Conventional coring method	94	6	1	125	77	20.0	12.0	17.3	8.4	241	80
		6	2	127	80	21.0	13.0	18.4	7.4	274	76
		6	3	127	80	20.0	14.0	16.2	10.2	246	78
PHCCT	80	6	1	127	81	20.0	13.0	17.1	8.8	88	78
		6	2	127	81	22.0	13.0	18.2	8.5	84	76
	100	6	1	127	80	22.0	12.0	18.4	7.9	119	77
		6	2	127	80	22.0	12.0	19.5	8.2	132	81
	94	6	1	127	80	20.0	12.0	18.2	9.5	121	87
		6	2	127	80	21.0	10.0	16.5	7.5	115	77
		6	3	127	80	24.0	13.0	21.2	9.2	116	82

The coring speed of conventional coring method calculated from data of Table 1 is 0.12–0.14 m/min, and the coring speed of PHCCT with a bit outer diameter of 94 mm, 100 mm, and 80 mm is 0.26–0.32 m/min, 0.26–0.29 m/min, and 0.38–0.42 m/min, respectively. Basing on the data in Table 1, the conventional coring method has the average coring rate of 78% (76–80%), and the coring rate of PHCCT is 80% (76-87%).

3.4 Core Quality Evaluation

The objective of coring is obtained the results required for useful geological and petrophysical investigations, rather than simply drilling the formation (Zhang. 2003), therefore, the quality of the cores is generally concerned by geologists. The causes of coring damage includes: (1) Geological factors (stress state underground, rock strength, natural cracks, and expanding clay, etc.); (2) Coring operations (such as blockage, fracturing, breaking, and cutting, etc.); (3) Core recovery and storage (pore fluid expansion, drilling fluid intrusion, thermal shrinkage and poor handling/storage, etc.). Rock quality designation (RQD) is often used to identify the quality of rock engineering. The RQD calculation formula (Eq. 1) was given by Deere and Miller (1966).

$$RQD = \frac{100\sum x_i}{L} \quad (1)$$

Where, x_i are the lengths of individual pieces of core in drill run having lengths of 0.1 m or greater, L is the total length of the drill run, m.

The RQD calculated according to Equation 1 is shown in Table 2. Table 2 shows that the conventional coring method has average RQD of 49% (rock core 47–57% and coal core 44–50%), and PHCCT method has average RQD of 55% (rock core 63–66% and coal core 43–48%).

Table 2 RQD comparison of different coring method

Coring Method	Bit Outer Diameter [mm]	Drilling Number	Length of Drill Run [m]		RQD[%]		
			Rock	Coal	Rock	Coal	Comprehensive
Conventional coring method	94	1	20.0	12.0	57	50	54
		2	21.0	13.0	50	45	48
		3	20.0	14.0	47	44	46
PHCCT	94	1	20.0	12.0	63	48	56
		2	21.0	10.0	66	46	56
		3	24.0	13.0	65	43	54

Figure 6 shows part of the coal cores and rock cores with the diameter of 94 mm collected during the experiment. The appearance of the rock core is smoother than that of the coal core, but both have the same outer diameter.

(a) coal core (b) rock core

Figure 6. Part of the cores collected during the experiment

4 Discussion

4.1 Cutting Area and Coring speed

The cutting area during coring can be described as:

$$S = \frac{\pi}{4}\left(d_O^2 - d_I^2\right) \tag{2}$$

Where, S is the cutting area, mm^2; d_O and d_I are the outer diameter and inner diameter, respectively, mm.

Inner diameter of the drill bit in this experiment is 63 mm, the cutting area of different outer diameter (80 mm, 94 mm, and 100 mm) is 1908 mm^2, 3821 mm^2, and 4734 mm^2, respectively, the weight on bit is 127 kN (Table 1), so the stress acting on rock is 66.6 MPa, 33.2 MPa, and 26.8 MPa, respectively.

Figure 7 shows the relation of PHCCT coring speed values calculated according to Table 1 and the cutting area values calculated by Eq. 2. Figure 7 shows that the coring speed is very quick when the stress acting on rock is over the rock uniaxial compressive strength (45.5 MPa), and the coring speed decreases as the cutting area increases. The larger the cutting area, the lower the stress acts on rock.

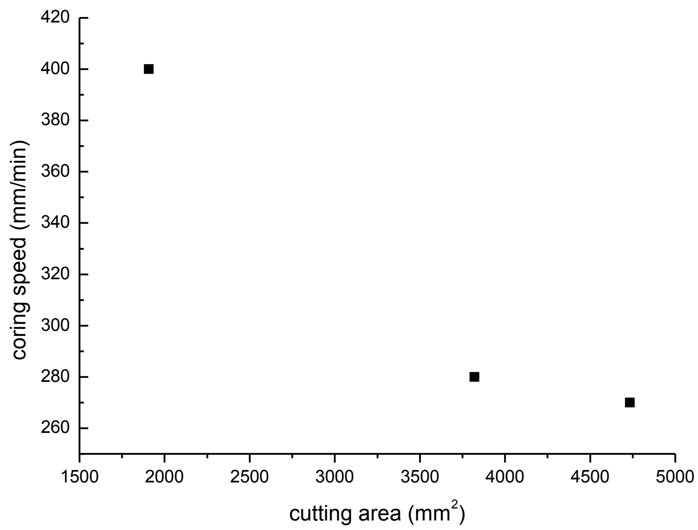

Figure 7 Relation of cutting area and coring speed

Table 1 shows that the coring speed of PHCCT (0.26–0.32 m/min) is faster than that of conventional coring (0.12–0.14 m/min) when the cutting area of conventional coring is equal to PHCCT (3821 mm^2). Figure 5 and Table 1 show that the coring efficiency of conventional coring may increase from 0.13 (33/254) m/min to 0.25 (33/134) m/min when the process of EDR and RCB in conventional coring cycle is removed, which is close to the coring speed of PHCCT (0.26–0.32 m/min), so PHCCT increases the coring speed by optimizing technology (removing EDR and RCB).

4.2 Influence of Bit Diameter on Core Quality

Table 1 shows that the average coring rate of PHCCT with bit outer diameter of 80 mm, 94 mm, and 100 mm is 77%, 82%, and 79%, respectively, the coring rate of PHCCT is related to the bit outer diameter, and the bit outer diameter of 94 mm has the highest coring rate. Figure 7 approves that the cutting area is negative relation to coring speed. The little outer diameter bit (80 mm) will impact with high stress on rock and large outer diameter bit (100 mm) will have more stress percussive frequency on rock, both of them make rock being damage more, so the outer diameter middle bit (94 mm) has maximum coring rate.

The bit outer diameter of 94 mm in Table 1 shows that the average coring rate of conventional coring (76–80%, average value of 78%) is less than that of PHCCT (76–87%, average value of 80%). The reason may be that PHCCT can keep the drilling under the state of continuous confining pressure, and the confining pressure can increase the rock strength.

Table 2 shows that PHCCT can improve the RQD comprehensive value from 46–54% to 54–56%. The reason may be that the conventional coring method will cut the rock with interval of 1 m during coring, resulting some of long core being cut.

4.3 Influence of Water on Core Quality

Zhang et al. (2018) pointed out that the coal core could increase by 2.40% after water adsorption. Zhao et al. (2017) pointed out that the coal matrix phase had no significant change after water adsorption, but some mineral in coal seam (such as calcite, nontronite, et al.) may expand and weak coal core. The PHCCT keeps the drilling under continuous confining pressure state and increases the coal strength, but the pressure–water entered in coal bed under the continuous confining pressure is more, comparing conventional coring, and more seepage water expands coal seam mineral and decreases coal strength, therefore, the average RQD value of PHCCT and conventional coring is similar as 46% (Table 2, PHCCT of 43–48%, conventional coring of 44–50%).

According to Table 2, the average rock stratum RQD value of PHCCT and conventional coring is 65% and 51%, respectively, PHCCT can increase the rock stratum RQD value of 14%. The reason may be that PHCCT increases the rock strength by the continuous confining pressure and conventional coring has no continuous confining pressure, the rock stratum has lower permeability and less water is permeated. Therefore, the PHCCT shows larger rock stratum RQD values.

5 Results

A pressure–holding and continuous coring technology device was developed and coring experiment was carried out.

(1) High drilling fluid pressure increases rock stratum coring rate and decreases coal bed coring rate, and 6 MPa is a reasonable drilling fluid pressure in boreholes drilling in coal mines.

(2) The conventional coring process wastes much time on exiting drill pipe and removing the coring bit, resulting low efficiency. The coring speed can be increased about double by pressure–holding and continuous coring technology.

(3) The pressure–holding and continuous coring technology can increase RQD value of rock stratum, but has almost no effect on coal bed.

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Figure

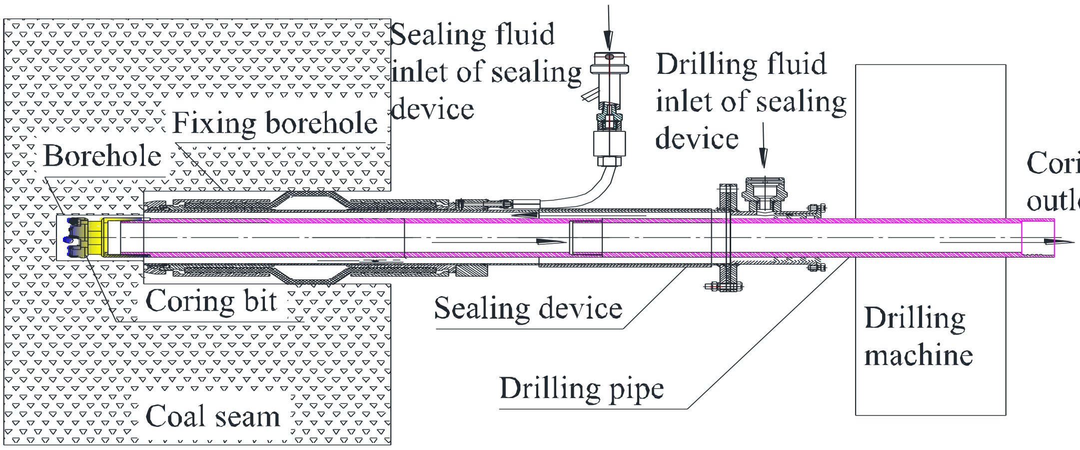
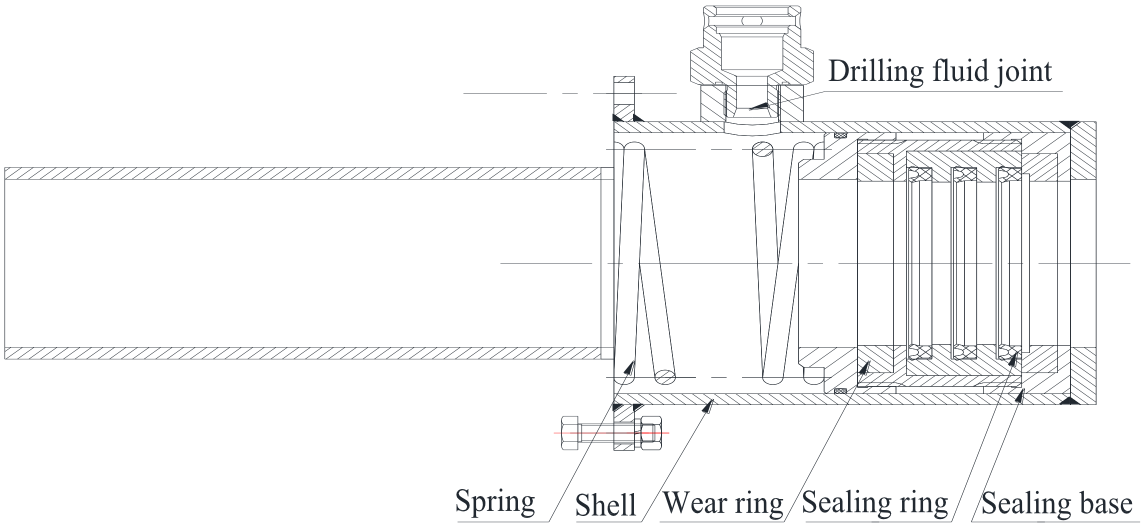


Figure 1a.



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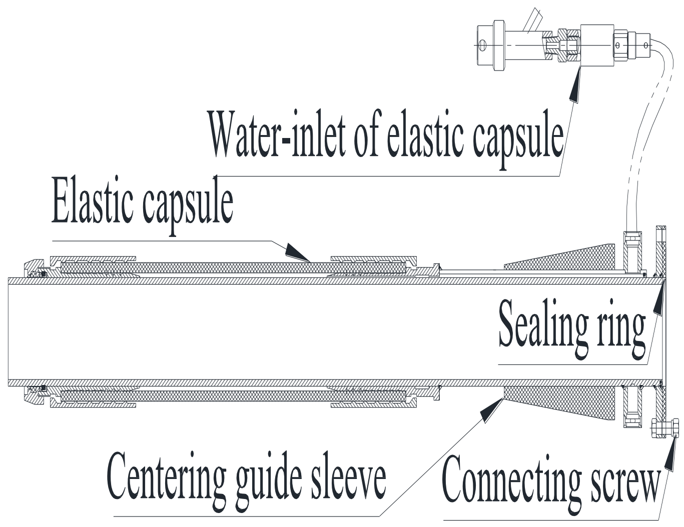

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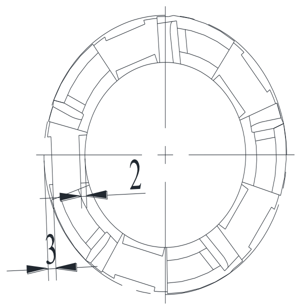

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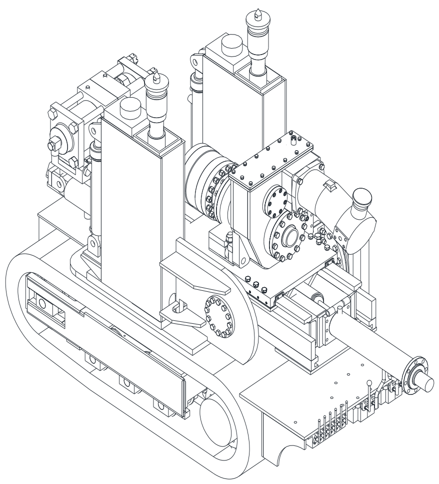
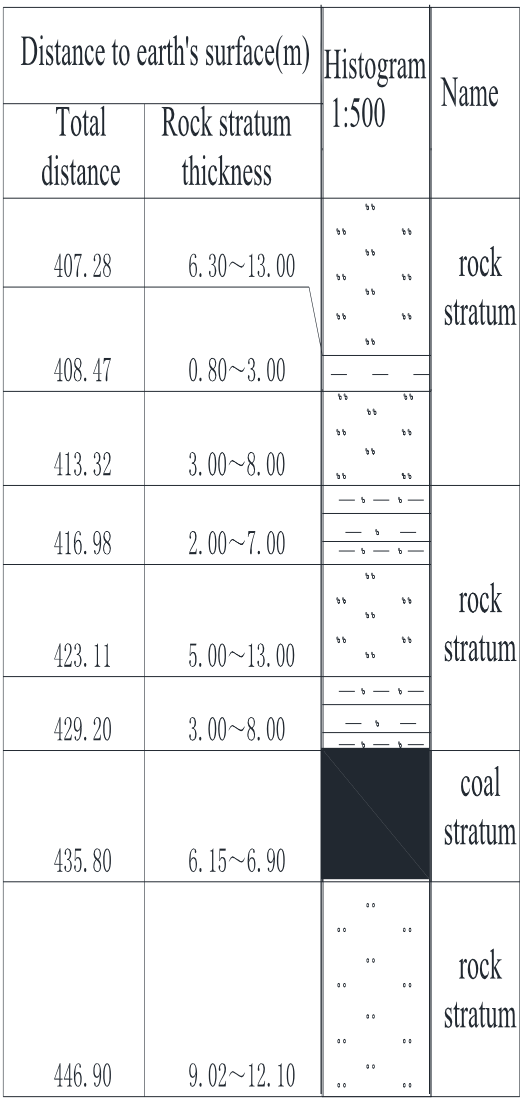


Figure 2.



Distance to earth's surface(m)
Total distance
Rock stratum thickness
Histogram 1:500
Name
407.28
6.30~13.00
408.47
0.80~3.00
413.32
3.00~8.00
rock stratum
416.98
2.00~7.00
423.11
5.00~13.00
429.20
3.00~8.00
rock stratum
435.80
6.15~6.90
coal stratum
446.90
9.02~12.10
rock stratum

Figure 3.

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