Research on Application of BJZM-MWD1 Measurement While Drilling System

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Abstract. Measurement While Drilling system has been more and more widely used in directional drilling construction on the surface of mines. The system provides guidance for drilling construction, because it can transmit drilling parameter signals such as the deviation angle, azimuth and tool face angle collected by downhole tools to the ground through the mud, and then the signals are analyzed and decoded by computer software to restore the actual parameter data. In drilling construction, the self-developed BJZM-MWD1 Measurement While Drilling system encountered problems such as great variation in the amplitude and width of mud pulse signals and the interference of pulse signals. By filtering and amplifying the mud pressure generated by the pulse signal, and improving software decoding algorithm, the stability and reliability of the system have been greatly improved, meeting the requirements in site construction.

1. Introduction

Measurement While Drilling (MWD) is a technology for downhole real time signal measurement and transmission during drilling process, with such characteristics: to get geological information near the drill bit without interrupting its normal drilling process, and turn the information into wireless signals to transmit them up to the ground; next, these signals will be analyzed and processed by ground system, by which the signals can be decoded in an encoding way that matches the downhole tools so as to obtain information required for construction like orientation data, stratum features and drilling parameters\textsuperscript{1}. And it can draw various types of logging curves to provide basis for next construction procedure\textsuperscript{2}. In recent years, with the popularization and application of directional drilling technology in coal mine gas drainage\textsuperscript{3-6}, fire prevention in goaf\textsuperscript{7-9} and regional control of water disaster\textsuperscript{10-15}, MWD has also been continuously applied and developed\textsuperscript{16-18}.

Beijing China Coal Mine Engineering Co., Ltd developed the BJZM-MWD1 Measurement While Drilling (MWD) system in 2012. In February, 2019, problems such as great variation in the amplitude and width of mud pulse signals and the interference of pulse signals occurred in the big-shift directional horizontal drilling in water hazard controlling project at 4th Panel in Zhaogu No.2 Coal Mine. To solve above problems, the author used the data acquisition interface to filter and amplify the mud pressure generated by the pulse signal, and optimized software decoding algorithm, which greatly improved the stability and reliability of the system and ensured accurate data.
2. The problems in the application of BJZM-MWD1 MWD system

2.1A brief introduction to BJZM-MWD1 MWD system

BJZM-MWD1 MWD system consists of surface equipment and downhole tools. Surface equipment includes data acquisition interface, pressure sensor, driller’s display, computer and software; downhole tools includes a master controller, an inclinometer probe, a battery and a pulse signal generator. The information collected by downhole tools such as deviation angle, azimuth and tool face angle can control the valve switch of the pulse signal generator according to certain coding rules, making regular changes on the mud pressure to generate mud pulse signals. The signals will be transmitted to the surface through the mud in the drill pipe, and will be detected by the pressure sensor installed on the mud pipeline. Then connect to the data acquisition interface for A/D conversion, turn the signals into digital signals. Finally, use computer software to analyze and decode the digital signals in order to restore the data of deviation angle, azimuth and tool face angle. The system can monitor the borehole track in real time and offer, high quality, highly reliable and accurate drilling curves[19]. It increases the success rate of drilling, shortens the drilling cycle, reduces the cost, and improves the economic benefits. Therefore, it is being used more and more widely.

2.2The application of BJZM-MWD1 MWD system in engineering

2.2.1Engineering situation

Zhaogu No.2 Coal Mine is located at the south of Taihang Mountain and east of Jiaozuo Coalfield. It is under the jurisdiction of Huixian County, Xinxiang City. The center of the mine field is 30 km southeast of Xinxiang City, 60 km southwest of Jiaozuo City, and 12 km northeast of Huixian County. The 14040 working face is at the 4th Panel in the Zhaogu No.2 Coal Mine, mining II1 coal seam. The thickness of II1 coal seam is 5.7 ~ 6.2 m, with an average of 6.05 m; the inclination of coal seam is 2.5 ~ 8.5°, with an average of 5.5°. The coal seam is stable with a simple structure, and a 2107 m-long working face. The hydrogeology conditions of the working face are complicated, and there are aquifers of L8 limestone and Ordovician limestone underneath. The elevation of the L8 limestone aquifer roof is -711 ~ -793 m, the elevation of the II1 coal seam roof is -678 ~ -760 m, and the L8 limestone is about 27 m above the II1 coal seam; the Ordovician limestone aquifer is 109.12 ~ 115.5 m above the II1 coal seam, and the current water level elevation is + 59 ~ + 62 m.

For safe mining, surface directional drilling is used to make advanced exploration on 14040 working face floor and grout. Emphasis is placed on finding out the rich water status of the L8 limestone aquifer floor of the coal seamII1 and the structural development of the working face, grouting the L8 limestone aquifer, improving the integrity and water permeability of the rock of the coal seamII1 floor within a certain thickness range; transforming L8 limestone aquifer into aquifuge, increasing the thickness of the aquifuge between the coal seamII1 floor and the bottom of Ordovician limestone aquifer, improving the ability of resisting water pressure.

According to the overall layout and drilling construction design of 14040 and 14050 working faces, a main hole (signed as G1 hole) is arranged at the south of projection on the surface of the 14040 working face’s middle area to control the L8 limestone aquifer in the northwest area of the 14040 working face. G1 main hole is divided into 6 branch holes, from northeast to southwest signed as G1-1 hole, G1-2 hole, G1-3 hole, G1-4 hole, G1-5 hole, and the distance between holes is designed to be 60 m; and G1-6 hole as the complement blind area hole. Another main hole (signed as G2 hole) is placed at the ground projection to the south of the open-off cut of 14040 working face to control the L8 limestone aquifer of the southeast area of the 14040 working face floor. G2 main hole is divided into 8 branch holes. From northeast to southwest the horizontal holes are signed as G2-1 hole, G2-2 hole, G2-3 hole, G2-4 hole, and G2-5 hole with a distance of 40 ~ 60m; G2-6 hole, G2-7 hole, and G2-8 hole are placed near the open-off cut as the complement blind area holes. As a result, the regional harness of the L8 limestone aquifer of the 14040 working face floor is realized (Figure 1).
It is designed to construct the straight hole section in the alluvium. As the topsoil layer is thick, the
topsoil section needs to be inclined at a certain angle. In the bedrock section, the continuous inclined
construction enables the hole enter the displacement bedding of the L8 limestone. The branch points of
drilling can be determined according to the geological conditions. The branch holes then enter the
working face through the inclined section, and the final borehole is drilled in the L8 limestone. After
the construction of the branch holes, an exploration area will basically be formed in the L8 limestone
of the coal seamII floor.

![Figure 1. The trajectory design of holes](image)

The drilling rig used at the construction site: TD-2000 hydraulic top drive drilling rig; drilling tools:
Φ152.4 mm PDC bit, Φ127 mm screw, Φ127 mm non-magnetic drill collar, and Φ 89mm drill pipe;
mud pump: 3NB 1000C mud pump, Φ120 mm cylinder liner; motor: YKK450-6 (380 V, 560 kW)
motor; inverter: IVNT GD200-630G-4F inverter, which is used to control the motor with output
frequency controlled at 43~45 Hz, the mud pump displacement controlled at about 17 L/s, the pressure
of the mud controlled at 14~16 MPa; the mud: specific gravity 1.17 ~ 1.12, viscosity 29 ~ 33 s; the
sensor for recording mud pressure: current type, two wires; power: DC24V, range: 0 ~ 40 MPa, output:
4 ~ 20 mA, converted to DC 0.66 ~ 3.3 V by circuit for A/D sampling.

2.2.2 Site layout and data acquisition of BJZM-MWD1 MWD system
BJZM-MWD1 system is exploited in the construction of G2 hole. In this system, the computer and
data acquisition interface are placed in the inclinometer room, the driller's display is installed on the
derrick in front of the driller's operating platform, and the pressure sensor is installed on the main pipe
of the mud pipe. The data acquisition interface, the driller's display and the pressure sensor are
connected by a 5-core cable with a shielding layer. The downhole tools are placed in the non-magnetic
drill collar, installed between the screw and the drill pipe, and a pressure plate is placed on the
downhole tools to prevent them from moving back and forth, affecting data measurement and
transmission. The system collects mud pressure values, stores them in a database, and processes them
to achieve functions such as storage, analysis, decoding, display, and alarm. The system collects mud
pressure values and stores them in a database for processing, with strong functions such as storage,
analysis, decoding, display, and alarm. It measures the borehole track of G2 hole and its branches
holes, providing evidence for orientation and rectification, and ensuring normal drilling construction.

2.2.3 Problems in the application of BJZM-MWD1 MWD system
In the BJZM-MWD1 MWD system, the basis for data identification is pulse signals, and that for pulse
signals is pulse width. Pulse signals are generated by the main controller and can be divided into two
types: the mark pulse signal and data pulse signal. The duration of the mark pulse signal is 2 s, and its
width value is 100; the duration of the data pulse signal is 1 s, and its width value is 50. The pulse
signals generated by the pulse generator which controlled by main controller can cause changes in
mud pressure. The mud pressure and pulse signal width will change with different working conditions, which can also affect the data identification.

Under the laboratory environment, the high level of the control signal generated by the main controller is DC3.3V, and the low level is DC0V. The peak value of the mark pulse signal pressure and data pulse signal pressure in data acquisition interface is 40 MPa. The width value of the mark pulse signal varies between 99 and 102, while the width value of the data pulse varies between 49 and 52[20]. The control signal generated by the master controller is shown in Figure 2.

![Figure 2. Master control signal waveforms](image)

In practical construction, the downhole tools need to be tested for proper working at the orifice before going down the well. While testing, do not connect the drill bit, or otherwise the casing will be damaged. Start the pump according to the parameters of normal drilling. After the pressure sensor signal enters the data acquisition interface, the pressure of the mark pulse signal is 0~3 MPa, and the pressure of the data pulse signal is 0~1.6 MPa. The width value of mark pulse signal varies between 143 and 171, and that of the data pulse signal varies between 112 and 146.

When the depth of G2-1 hole is 2000 m after the tools reach the hole bottom and the pressure sensor signals enter the data acquisition interface, the pressure of the mark pulse signal is 0~1 MPa, and the pressure of the data pulse signal is 0~0.7 MPa. The pulse signal width value varies between 120~153, and the data pulse width value varies between 93~125. The collected pulse signals are shown in Figure 3, from left to right, where the first three waveforms are marker pulse signals, and the other four waveforms are data pulse signals.

![Figure 3. Data encoding waveforms at the interval of 2s between the second and third pulse signals](image)

The variation of mud pressure generated by the collected pulse signals is shown in Table 1. Under the same condition, the mud pressure generated by the pulse signal is different at the orifice and the hole bottom 2000 m deep. After reaching the hole bottom, there will be a loss of about 2 MPa.

| Serial number | Mud pressure collection site | Control pulse signal pressure (MPa) | Data pulse signal pressure (MPa) | Control pulse signal width value | Data pulse signal width value |
|---------------|-----------------------------|-----------------------------------|---------------------------------|-------------------------------|-------------------------------|
| 1             | Laboratory                  | 0~40                              | 0~40                            | 99~102                        | 49~52                         |
| 2             | Hole top                    | 0~3                               | 0~1.6                           | 143~171                       | 112~146                       |
| 3             | Hole depth 2000 m           | 0~1                               | 0~0.7                           | 120~153                       | 93~125                        |
3. Causes of problems in BJZM-MWD1 MWD system and solutions

As for practical use of the BJZM-MWD1 MWD system, under the same conditions, the pressure peak value of the mark pulse signal is about twice the pressure peak value of the data pulse signal, but the width value of the mark pulse signal is not about twice that of the data pulse signal, which is much different from the theoretical value. In addition, the maximum width value of the data pulse signal sometimes exceeds the minimum width value of the mark pulse signal, which causes great trouble to the data identification. Through careful analysis, this phenomenon appears because the main controller generates a control signal which drives the valve stem to move with the valve head. As the mud passage blocks, the mud pressure in the drilling tool increases. Then when the mud passage opens the mud pressure in the drilling tool, it returns to a normal level where a pulse signal is formed. Different pulse signals are generated according to actual needs, representing different data, which are transmitted from the well to the surface through the mud, and analyzed by computer software so as to restore the data. In the process of mud pressure generation and transmission, the pulse signal can be deformed and attenuated if it is affected by vibration and resistance of drilling tools, mud resistance, and hole wall. From Figure 3, we can see that when there are continuous pulse signals, the mud pressure attenuation is large. For example, the first, second, and third pulse signals are all mark pulses, but the peak pressures of the first signal and the third pulse signal are very different. It is because of the time interval of 2s between the second pulse signal and the third pulse signal. When the mud pressure generated by the previous pulse signal has not returned to the normal level, a new pulse control signal is generated, so the new mud pressure is superimposed on the previously generated mud pressure, reducing signal width and the effective mud pressure. For another reason, the pulse generator controls the switch of the solenoid valve to block or open the mud passage by driving the valve stem back and forth, causing changes in the mud pressure and generating a pulse signal. As the solenoid valve requires a large current during operation, it should be controlled by charging and discharging the capacitor in order to reduce the damage to the battery. Capacitor charging and discharging takes time. Only when the capacitor charging and discharging process is fully completed can the solenoid valve be controlled to produce an excellent pulse signal, and therefore, only when the capacitor charging and discharging process is fully completed can the solenoid valve produce good pulse signal. If the interval between the two charging and discharging processes of the capacitor is too short, the generated pulse signals will affect each other. For example, the fourth and seventh pulse signals are both data pulse signals, but the pressure generated by the fourth pulse signal becomes small because it is affected by the pressure generated by the previous two mark pulse signals and becomes smaller. As a result, the system identification software cannot simply use the pulse signal width as an indicator for data identification. It must also consider the pressure changes caused by pulse signals in order to realize more accurate data identification.

The quality of the pulse generator directly affects the quality of the pulse signal. Thus, it is necessary to operate it strictly following the regulations, to perform good maintenance work, and to test for normal operation before the pulse generator goes down well.

In addition, we can increase the time interval between pulse signals, improve the pressure peak and width of the pulse signals, and reduce the impacts between pulse signals, in which way the effect is obvious, but the total data transmission time will increase and the transmission efficiency will reduce (Figure 4).

![Figure 4. Data encoding waveforms at the interval of 3s between the second and third pulse signals](image-url)
It can be seen from Figure 4 that the amplitude of the third control pulse signal is close to 0.9 MPa, the width of it is smaller than that of the second control pulse signal, and the shape differs much from that of data pulse signal, making it easier to distinguish, further reducing the identification difficulty and increasing the accuracy of data analysis. In the test at wellhead, the minimum width value of the control pulse signal can reach 152, and the minimum value at the 2000m-deep hole bottom is 129, which are obviously higher than the data pulse signal width values (Table 2).

**Table 2. Variation of mud pulse signal at the interval of 3s between the second and third pulse signals**

| Serial number | Mud pressure collection site | Control pulse signal pressure (MPa) | Data pulse signal pressure (MPa) | Control pulse signal width value | Data pulse signal width value |
|---------------|----------------------------|---------------------------------|-------------------------------|---------------------------------|-------------------------------|
| 1             | Laboratory                 | 0~40                            | 0~40                          | 99~102                          | 49~52                         |
| 2             | Hole top                   | 0~3                             | 0~1.6                         | 152~171                         | 112~146                       |
| 3             | Hole depth 2000 m          | 0~1                             | 0~0.7                         | 129~153                         | 93~125                        |

There are two seating styles for downhole tools of MWD system that use mud to transmit data: upper seating style and lower seating style. Each has its benefits and drawbacks. The pressure of the pulse signal generated by the upper seating style method is uniform and stable, and it is less affected by the drilling depth. However, if fish trouble occurs, it is not easy to salvage it, which will cause large losses. The pressure of the pulse signal generated by the lower seating style method changes greatly and is easily affected by the drilling depth. The deeper is the drilling, the greater is the pressure loss of pulse signals, which sometimes affects the data identification. In the construction of vertical drilling, it is easy to salvage it in fish trouble, and the loss can be reduced, but in the drilling of the horizontal section, a pressure plate needs to be placed on the tools to avoid the problem of running off key and to ensure the safe normal operation. The pulse generator used in the BJZM-MWD1 MWD system uses the lower seating style method, so it is more easily affected by the drilling depth, mud flow, and mud pressure. Considering these effects, the mud pressure generated by the pulse signal is filtered and amplified by the data acquisition interface, and with the optimized software decoding algorithm, the effects can be effectively reduced to provide accurate data identification.

As the depth of the well increases, the mud flow and pressure at the end of the borehole will become smaller, and the mud pressure generated by the pulse signal will also get smaller, which can affect data transmission and data identification. To produce a good pulse signal, the mud pressure should not be less than 0.2 MPa. There are two ways to solve this problem. One is to increase the mud flow, the force of the mud on the valve head, and the mud pressure. However, due to the limitation of the displacement of the mud pump, it cannot be increased indefinitely. At the same time, excessive mud flow adds scouring pressure on downhole drilling tools, increasing losses and reducing the service life of the equipment. The other way is to increase the mud pressure and reduce the over-flow area by replacing the combination of the current-limiting loop and the valve head. Since it is troublesome to replace the valve head or the current-limiting loop we need to consider the technical level and proficiency of the personnel. We should try to minimize the times of replacement and the number of replaced parts in the field construction and to reduce problems. Altogether, we should comprehensively consider mud flow, the combination of current-limiting loop and valve head so as to meet the use requirement.

**4. Discussion on other problems**

With computer decoding software, the pulse signal waveform and the data identification rate can be improved by adjusting the magnification of the collected mud pressure value. Moreover, the accuracy of data recognition can be improved by modifying the determination criteria of the synchronization
pulse and data pulse, which is, to change the synchronization pulse width value and the data pulse width value.

The RS232 bus is used for data transmission between the data acquisition interface and the computer, which is slow and susceptible to electromagnetic interference. There is no RS232 interface of most computers, so they can only be converted to an RS232 interface through a USB interface which has poor compatibility and is prone to failure. In addition, due to slow communication speed and a large amount of data of the RS232 bus, sometimes it cannot complete the reading at one time when the computer reads the mud pressure value collected by the data acquisition interface, and then it must wait for a sampling period, which affects later data processing. Therefore, USB bus or Ethernet bus can be considered to use in data acquisition interface to increase data transmission speed and reduce fault points.

The CAN bus is used for data transmission between the data acquisition interface and the driller's display. It supports the CAN2.0B communication protocol. The advantages of the CAN bus include strong electromagnetic interference resistance, long transmission distance, good real-time performance, high reliability, fast communication rate, simple structure, flexible networking, and high cost performance. It is increasingly widely used because it is also easy to be installed and maintained. However, the CAN bus can only transmit 8 bytes at one time. When the data to be transmitted is larger than 8 bytes, it needs to be transmitted more times, which is slow and inefficient. Therefore, it is advised to organize its own communication protocol by combining the excellent electrical performance of the CAN bus driver and the flexible characteristics of the RS485 bus communication protocol so that the system have higher resistance common mode voltage capability and better anti-interference ability. It also can help improve the system’s stability, reliability, transmission over longer distances, and data transmission efficiency[21].

There are many types and various structural forms of pressure sensors. We can choose a sensor depending on its erosion resistance, corrosion resistance, high temperature resistance, high sensitivity, stability and reliability. Because the pressure sensor collects change information of mud pressure, it should be installed on the mud standpipe near the rig and away from the mud pump to reduce the impact on the pulse signal causing by the pressure change of the mud pump. Additionally, there are lots of electrical equipment around the well site, which generate complex and changeable electromagnetic signals. They are superimposed on the mud pressure signals by pressure sensors. Although the current sensor has strong anti-interference ability, the electromagnetic signal still generates interference signal about 2 ~ 3 Mpa. By using shielded wire, to make the length of shielded wire as short as possible, to make the diameter of the wire as thick as possible, and the shield layer is grounded at the data transmission interface end. Those above methods help to reduce interference signal about 1 ~ 2 Mpa. And at last with the use of hardware and software filtering, it is effective to solve the problem of electromagnetic signal interference and guarantee accurate and reliable data identification.

There is also a noteworthy problem- the great effects on the pulse signal causing by the rig operator in practical operation. Through field observation, we can know that during compound drilling, the drill bit and the drill rod rotate at the same time. Relatively speaking, the drilling speed is so fast that it makes the transmitted pulse signal seriously deformed, and sometimes the pulse signal is lost, which affects the data decoding and leads to data errors. Since this measurement data is not very important, it can be ignored. However, in directional drilling, the measurement data is critical. It is necessary to ensure that the data transmission is stable, accurate, and reliable, and to ensure that the drilling direction advances toward the design trajectory. When rig operator suddenly lowers the drilling tool, the drill bit reaches bottom hole instantly, blocking the mud passage, causing a sudden change in mud pressure, which affects the normal pulse signal and the data identification, finally making drilling more difficult. Therefore, in the process of drilling, especially in directional drilling, the rig operator must be cautious and must lower the drilling tool slowly and uniformly to make uniform mud pressure change, only in which way can we ensure the stability and consistency of the generated pulse signal and lay a good foundation for data identification.
5. Conclusion

BJZM-MWD1 Measurement While Drilling (MWD) system effectively solved the problems of the great variations in the amplitude and width of mud pulse signals and the interference of pulse signals in the construction of G2 main hole in the advanced exploration and grouting project of 14040 working face’s floor limestone. It ensured the smooth progress of the project. Since the project started on February 18, 2019, the measurement and orientation of the G2 main hole, one survey hole, G2-1 branch hole and G2-2 branch hole have been successfully completed. Currently, construction of other branch holes is in progress. The BJZM-MWD1 MWD system is simple in structure, easy to install and operate. Its stability, reliability, high accuracy of drilling measurement data and accurate drilling trajectory control help to achieve one hole formation, which is consistent with the designed drilling tract and meets the design requirements.

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