Experimental research on device with multi-turn overlapping loops by applying mine TEM

According to the special work environment in underground coal mine, a qualitative research is done to find the relationship among the turn-off time, the quality of received signal and the device with overlapping loops with different areas, different shapes and different turns. Through a detection experiment, the above relationship is gotten, and a design of the device with overlapping loops is proposed. Then the developed device with overlapping loops is used in engineering detection. The result shows that the device with overlapping loops can be used in coal mine underground to carry on advanced detection of geological rich-water body probably existing ahead of the heading face.

Keywords: *Coal mine, TEM, device with overlapping loops, turn-off time, advanced detection.*

1. Introduction

The quality of the TEM source signal is the guarantee of obtaining the high quality response signal and the high precision data inversion. The quality of the source signal and the quality of the received signal about the geological body response are directly related to the device with overlapping loops. The previous research done by other experts is mainly focus on inductor effect, transition process and turn-off time of the ground device with overlapping loops and it is rare that the research done according to the characteristics of coal mine underground to find the relationship among the turn-off time, the received signal and the parameters including the area, the shape and the turns of the transceiver device with overlapping loops [1-5]. Therefore, based on the previous studies done by other experts, using a TEM instrument called YCS40 developed by China Coal Technology Engineering Group Chongqing Research Institute, combined with field experiments done in the coal mine underground tunnel, the relationship among the turn-off time, the received signal and the parameters including the area, the shape and the turns of the transceiver device with overlapping loops is expected to find and the device with overlapping loops is expected to develop suited for coal mine underground.

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2. Experiment on device with overlapping loops by applying mine TEM

2.1 TEM ADVANCED DETECTION PRINCIPLE AND FIELD DETECTION CRAFT

The device with overlapping loops, including a transmitting loop and a receiving loop, is the unique combination of TEM. When the transmitting loop is excited by the signal described as formula 1, a stable magnetic field is established in the geological body and the free space near the device with overlapping loops before the current in the transmitting loop is turn off [6]-[9].

$$I(t) = \begin{cases} I & t < 0 \\ 0 & t \geq 0 \end{cases} \quad \ldots \quad (1)$$

As shown in Fig.1, when t=0, the current disappears immediately. At the same time, the magnetic field established by the current disappears as well. The primary magnetic field changes so fast that an induced current is produced by the electrically conductive geological body. According to Lenz's law, the induced current establishes a new magnetic field to ensure that the magnetic field in the detection space can't disappear at once. So, an induced signal about the geological body can be received by the receiving loop [10-13].

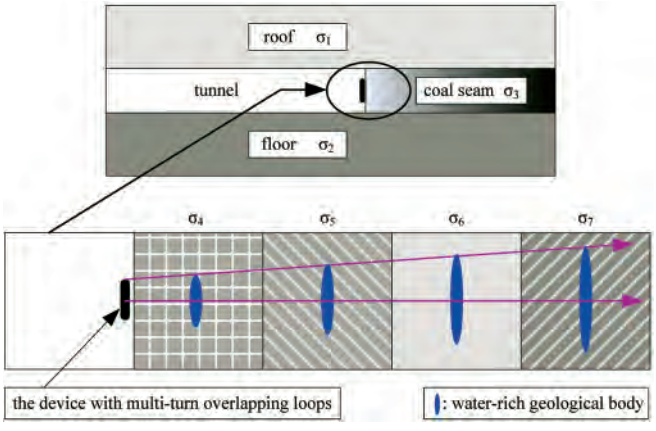

Fig.1 The TEM advanced detection principle

As shown in Fig.2, due to the resistive loss of the electrically conductive geological body, the induced current attenuates rapidly and the magnetic field established by it

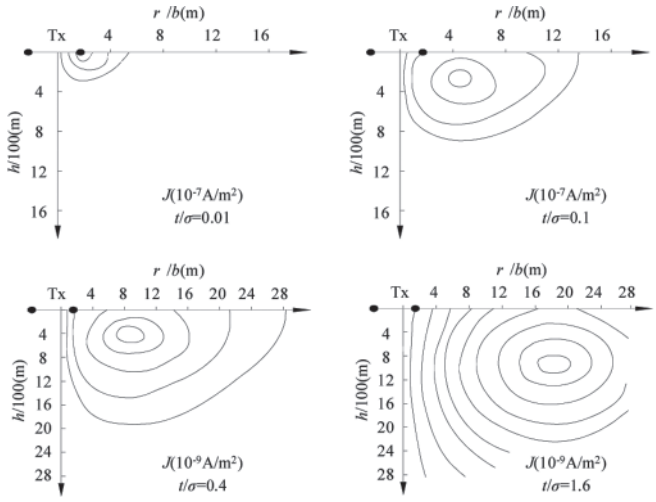

Fig.2 Current density contours in the cross-section via the center of Tx and perpendicular to magnetic lines

attenuates rapidly as well. The rapid attenuating magnetic field induces weaker eddy currents in the nearby underground medium. The process will continue until the magnetic field energy is used up by the resistive loss of the electrically conductive geological body. This is the transient electromagnetic process in the earth. The electromagnetic field accompanying the process is the earth's transient electromagnetic field [14-15].

To conduct research on the heading face in coal mine underground, YCS40 and an experimental device with overlapping loops are used. As shown in Fig.3, the detection craft diagram of the heading face is described.

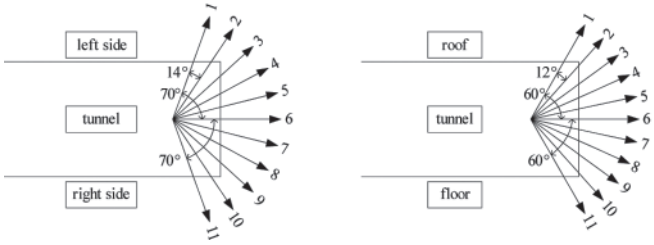

Fig.3 Advanced detection craft of the heading face in underground coal mine

2.2 Experimental design in underground coal mine

The experimental site is a heading face of Wen Ming Coal Mine belongs to Huo Zhou Coal Power Group. According to the special work environment in underground coal mine and under the condition that it is rare that the research done to find the relationship among the turn-off time, the received signal and the parameters including the area, the shape and the turns of the transceiver device with overlapping loops, three experimental schemes are designed as shown in Table 1.

3. Analysis and discussion on experimental data of TEM advanced detection

3.1 Relationship between parameters of device with overlapping loops and turn-off time

The interference intensity of the primary magnetic field is determined by the turn-off time. The interference, which causes the serious distortions of early-stage signal and the loss of shallow stratum resolution, makes the final inversion interpretation including blind area. So the turn-off time is an important index to a TEM instrument. In addition to the transmitting circuit itself, the area, shape and the turns of the

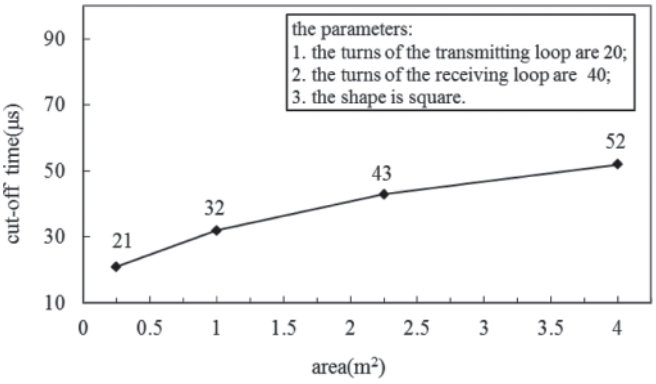

Fig.4 The turn-off time versus the area of the device with overlapping loops

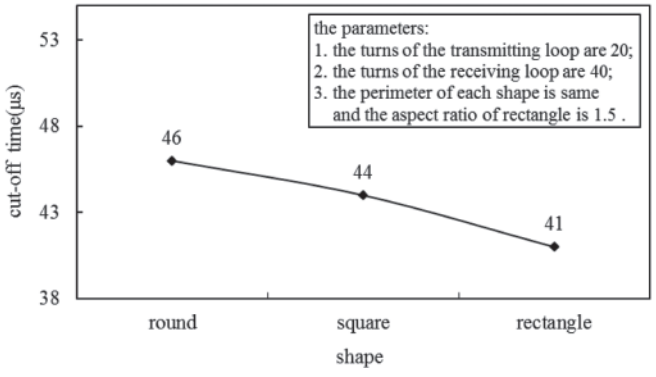

Fig.5 The turn-off time versus the shape of the device with overlapping loops

Table 1: Three experimental schemes of the device with overlapping loops

The experimental scheme	The transmitting loop	The receiving loop
Loop material	Silicone line cross-sectional area: 4cm^2	Silicone line 1cm^2 cross-sectional area: 1cm^2
No.1: different areas	0.5m×0.5m, 1m×1m, 1.5m×1.5m, 2m×2m	
No.2: different shapes	Round, square, rectangle	
No.3: different turns	10, 20, 30, 40	10, 20, 40, 60

device with overlapping loops have great influence on the turn-off time. As shown in Figs.4-7, the relationship between the turn-off time and the device with different areas, different shapes and different turns is obtained by detection experiments.

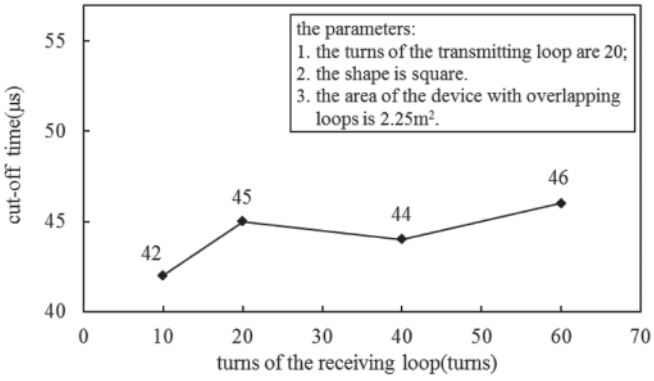

Fig.6 The turn-off time versus the turns of the receiving loop

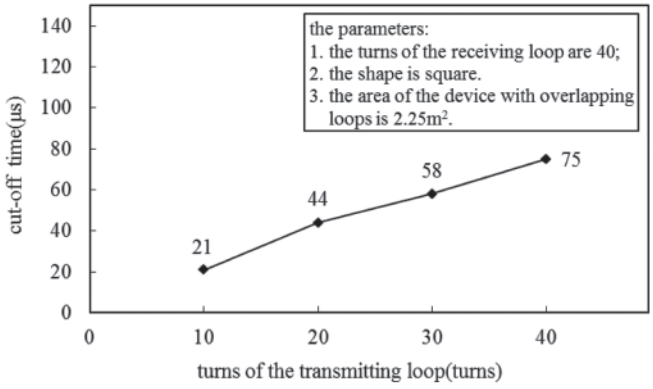

Fig.7 The turn-off time versus the turns of the transmitting loop

From the above figures, it is concluded that:

(1) When the area of the device with overlapping loops increases from 0.25m^2 to 4m^2, the turn-off time correspondingly increases from 21μs to 52μs. The law of change is basically linear.

(2) For the round, square or rectangular device with overlapping loops, the turn-off time is round 44μs. The shape has little effect on the turn-off time.

(3) It can be seen that with the increase of the turns of the receiving loop, the turn-off time changes around 44μs. The turns of the receiving loop has little effect on the turn-off time.

(4) As the turns of the transmitting loop increase, the turn-off time increases rapidly. When the turns of the transmitting loop is 40, the turn-off time reaches 75μs. The turns of the transmitting loop is one of the key factors that affect the turn-off time.

The above analysis shows that the turn-off time is less affected by the shape of the device with overlapping loops and the turns of the receiving loop. Instead, it is sensitive to the area and the turns of the transmitting loop and the laws of change are basically linear. The increase of the turns of the device with overlapping loops leads to an increase in the weight of the device with overlapping loops, which is not convenient for the field detection. In order to reduce the impact of turn-off time, the selection of the turns of the transmitting loop is very important. For the short-range advanced detection, it is recommended to select fewer turns of the transmitting loop and 10 turns is preferred. For the long-range advanced detection, it is recommended to select more turns of the transmitting loop and 40 turns is preferred.

3.2 Effect of device with overlapping loops on quality of received signal

The inversion interpretation is directly related to the quality of the received signal. Due to the effect of the turn-off time, the received signal is interfered by the primary field. So in addition to minimize the impact of turn-off time, how to improve the quality of the received signal is also an important research focus. In the limited space of the underground coal mine, it is probable to improve the quality of the received signal by changing the area, the shape and the turns of the device with overlapping loops in the case of the certain detection equipment. These aspects are researched below.

When the area of the device with overlapping loops is 0.25m^2, the received signal is very weak. As shown in Fig.8, in order to display clearly in the chart, the voltage of the received signal is amplified 10000 times. The amplified signal fluctuates around zero, the attenuation characteristic of the early-stage or late-stage signal is not obvious and the

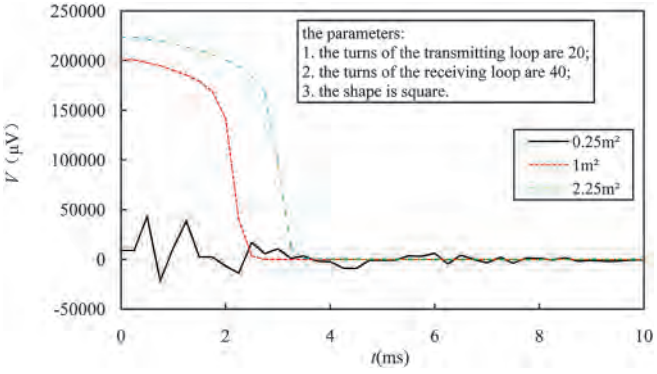

Fig.8 The voltage of received signals versus time at different areas of the device with overlapping loops

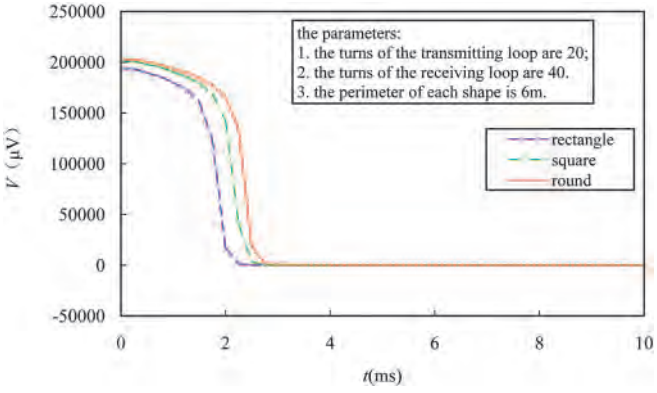

Fig.9 The voltage of received signals versus time at different shapes of the device with overlapping loops

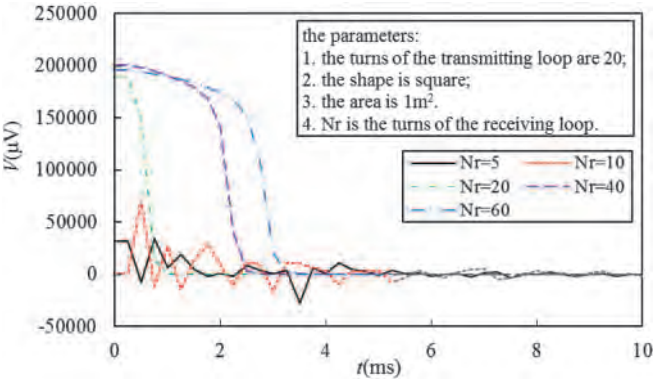

Fig.10 The voltage of received signals versus time at different turns of the receiving loop

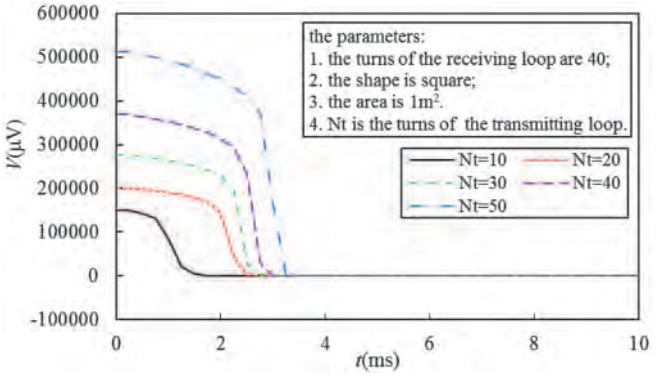

Fig.11 The voltage of received signals versus time at different turns of the transmitting loop

effective observation window is very short. In other words, the received signal is basically invalid and cannot be used to carry out the final inversion interpretation. When the area of the device with overlapping loops is $1m^2$, the attenuation curve is basically normal. The valid data is enough to meet the demand of the final inversion interpretation. When the area of the device with overlapping loops is $2.25m^2$, the attenuation curve is normal. The valid data is more and the late-stage signal is smooth. Namely, the received signal can meet the demand of the final inversion interpretation.

Because the areas of different-shaped devices with overlapping loops are also different, so the received signals are also different. It is important to study the law of change for the development of the device with overlapping loops. As shown in Fig.9, the initial voltage of the received signal of the round device with overlapping loops is over 200mV. The number of the valid data is significantly more than that of the other two devices and the signal attenuation is slowest. Compared to the round device, the initial voltage of the received signal of the square device is lower. The number of the valid data is fewer and the signal attenuation is faster. The initial voltage of the received signal of the rectangular device is lowest. The number of the valid data is fewest and the signal attenuation is fastest.

When the turns of the transmitting loop remain unchanged and the turns of the receiving loop change, the valid received signals also have a large change. As shown in Fig.10, when the turns of the receiving loop are 5 and 10, in order to display clearly in the chart, the voltages of the received signals are amplified 10000 times. However, the received signals are still very weak and the valid data is little. When the turns of the receiving loop are 20, the signal attenuation is fast and the valid data is enough. When the turns of the receiving loop are 40, the signal attenuation is slower and the valid data is more. When the turns of the receiving loop are 60, the signal attenuation is lowest and the valid data is most.

As shown in Fig.11, when the turns of the receiving loop remain unchanged and the turns of the transmitting loop increase, the early-stage received signal tends to saturate. In particular, when the turns of the transmitting are 40, the received signal appears flattened, and the quality of the late-stage received signal is appropriately improved.

In summary, in the limited space of the underground coal mine, the quality of the received signal can be improved by increasing the area of the device with overlapping loops, increasing the turns of the receiving loop and the turns of the transmitting loop respectively. When the perimeter of the device with overlapping loops is fixed, the performance of the round device is best.

4. Engineering application

The TEM advanced geological detection is done at a heading face of Wen Ming Coal Mine belongs to Huo Zhou Coal Power Group. The area of the device with overlapping loops is $2.25m^2$ and the shape is square. The goal of the detection is to identify the water-rich situation of the geological body 100 meters in front of the heading face. The turns of the transmitting loop are 40 and the turns of the receiving loop are 60. Advanced detection is carried out by scanning horizontally and vertically. The numbers of the horizontal and vertical detection points are both 11. The horizontal scanning range is ±70° and 14° for a step. The vertical scanning range is ±60° and 12° for a step.

As shown in Figs.12 and 13, the time window of the valid signal is from 1000μs to 25902μs, and the secondary field attenuation is basically normal, meeting the demand of the geological detection. Because the turns of the transmitting loop are such many, the received signals of each detection point tend to saturate in the early stage, are smooth in the middle stage and have a “lifting” phenomenon in the late stage which is caused by noise interference. In other words, all the valid signals about the geological anomalous body are received. Overall, the detection curves are reliable, and the received signals meet the requirements of data quality evaluation.

The geophysical map, as shown in Figs.14 and 15, is finally obtained from the received signals by data editing,

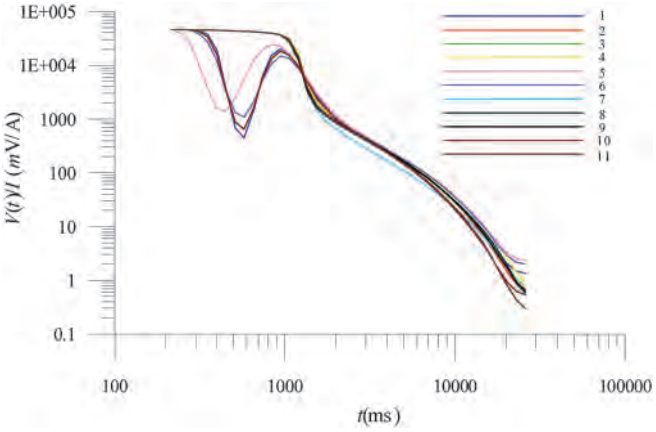

Fig.12 The attenuation curve of the horizontal detection: V(t)/I versus time

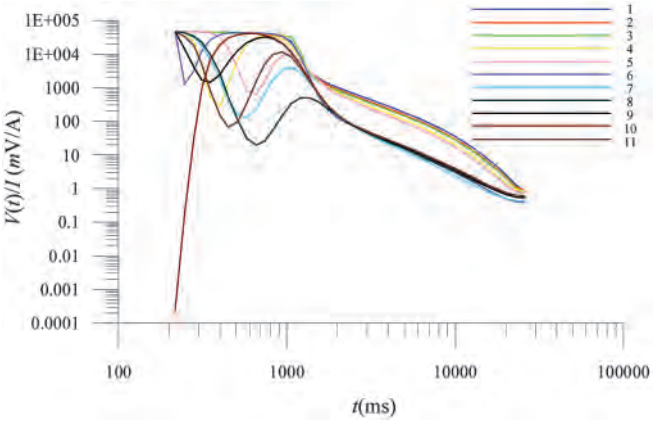

Fig.13 The attenuation curve of the vertical detection: V(t)/I versus time

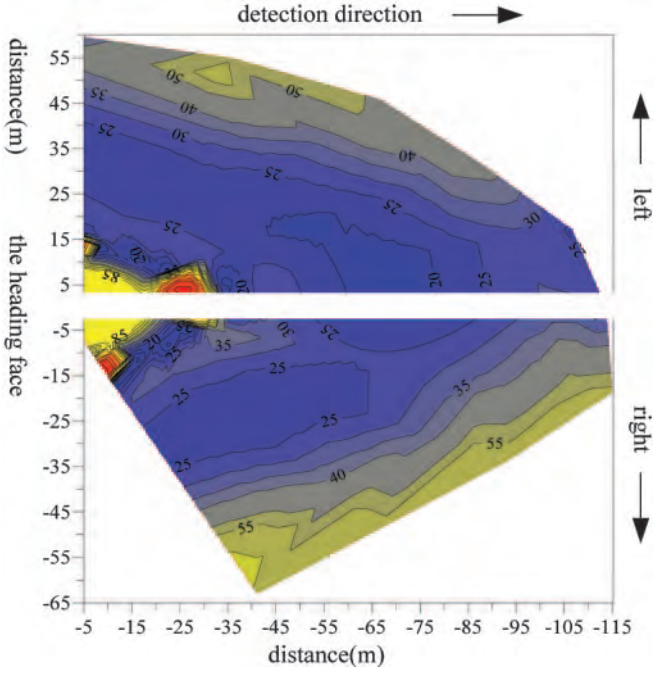

Fig.14 The apparent resistivity contours of the horizontal detection

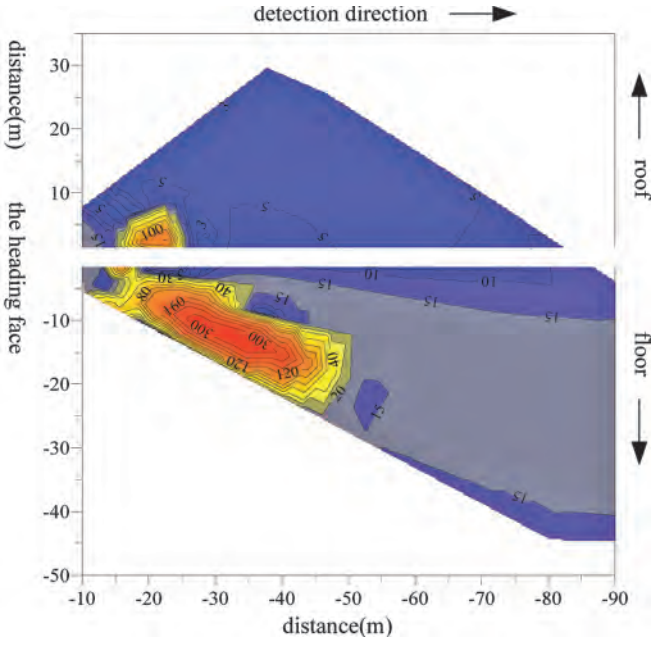

Fig.15 The apparent resistivity contours of the vertical detection

filtering, apparent resistivity calculation and time-depth transform. From the results in Figs.14 and 15, it is concluded that:

(1) Within 115m ahead of the heading face, as the resistivity is generally relatively low, the area belongs to the low resistance area; especially the area in the head of the heading face in the range of 40~80m, there may be a runoff groundwater.

(2) Within 90m ahead of the heading face, the resistivity difference between the roof and floor is great. The resistivity of the roof is comparatively large while the resistivity of the floor is comparatively little. It is presumed that there may be a large water-rich body or a runoff groundwater in the roof stratum.

The detection result is consistent with the result of the field drill and the error is ±2.5m. The experimental results show that the device with overlapping loops meets the requirement of the advanced detection of the water-rich situation in underground coal mine.

5. Conclusions

According to the actual situation of the heading face in coal mine underground, through a number of detection experiments, by analyzing the received signals, we conclude that:

(1) The turn-off time is mainly affected by the area and the turns of the transmitting loop, while it is basically unaffected by the shape of the device with overlapping loops and the turns of the receiving loop.

(2) The quality of the received signals is greatly affected by the turns of the receiving loop, the shape of the device

with overlapping loops and the turns of the transmitting loop.

(3) In the limited space in underground coal mine, three points need to be noted. First, when the perimeter is fixed, the round device with overlapping loops has the largest effective area. Second, the turns of the transmitting loop are determined according to the specific detection requirement. Last, the receiving loop should have as many turns as possible if the total weight is allowed.

(4) Through the field detection and the final verification, the developed device with overlapping loops has achieved good detection effect and can be used in the underground coal mine.

Acknowledgments

The project is supported by National Science and Technology Major Project of the Ministry of Science and Technology of China (Grant No. 2016ZX05045-002-0003).

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Printed by Pradip Kumar Chanda at The Indian Press Pvt. Ltd. 93A Lenin Sarani, Kolkata 700 013 and published by him for Books & Journals Pvt. Ltd. from 6/2 Madan Street, Kolkata 700 072.