

DEVELOPMENT OF MWD SYSTEM FOR GEOTHERMAL WELLS

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ABSTRACT

In 1997, **NEDO** (New Energy and Industrial Technology Development Organization) commenced a new R&D project on the development of a heat-resistant MWD (Measurement While Drilling) system, which enables acquisition of real-time bottomhole data (azimuth, inclination, tool-face, temperature) while drilling geothermal wells. In 1998, we conducted a test of the MWD system at a well in the test field of JNOC-TRC (Japan National Oil Corporation Technology Research Center) in Kashiwazaki and concluded that the interference of the drilling noise with the signal was excessive and that the decoding method needed to be improved because the MWD system using mud circulation pressure changes was being developed. In 2000, we modified the format of the data transmission, decode algorithm at the surface unit, noise filter, transmission protocol, etc. Moreover, in 2001, we conducted other tests at the Kashiwazaki field and at the Ogiri geothermal field to evaluate the performance of each function and component of the MWD system. During the test in the Ogiri field, we succeeded in transmitting mud pulses from a depth of about **800m** to the surface while drilling a reinjection well. In addition, the bottomhole data obtained by the MWD system were concordant with well data. This MWD system has great heat-resistance and is expected to be put to practical use.

1.0 INTRODUCTION

The R&D project "Development of MWD System for Geothermal Wells" has been conducted by the Geothermal Energy Development Department in NEDO since 1991 as a part of the

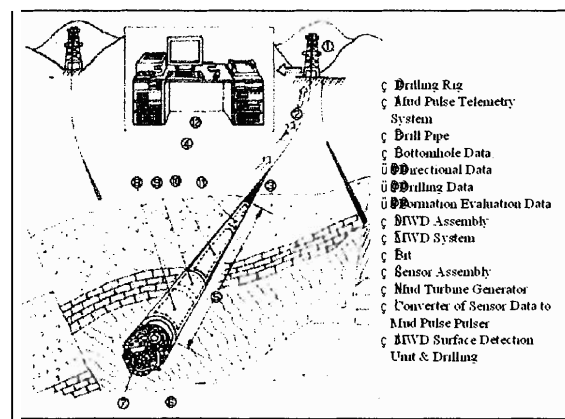


Figure 1. Conceptual diagram of MWD system.

New Sunshine Program. Since drilling efficiency and well trajectory accuracy are recently becoming more essential, the demand to develop a real-time acquisition system of bottomhole information during the drilling of geothermal wells is increasing. The conceptual design and development targets of the MWD system in this project are shown in Figure 1.

It is said that well drilling expenses account for approximately half of the costs involved in developing geothermal energy, and that reduction of the drilling expenses will contribute significantly to diminishing geothermal power generation costs. The MWD system, which is widely used in the drilling of petroleum wells, contributes to drilling efficiency, well trajectory accuracy, trouble avoidance, etc. As a result, drilling costs are reduced by curtailing the number of drilling days. The MWD system has been used in drilling geothermal reinjection wells and has provided satisfactory results as the formation temperatures around the reinjection

wells are low and the MWD system for petroleum wells is sufficient (Jotaki and Shimada, 1998). The maximum operating temperature of the MWD system for petroleum wells is limited to about **150-175°C**, and the system is not applicable to drilling of hot geothermal wells. For this reason, the development of a MWD system resistant to high-temperature circumstances is desired and necessary to diminish the cost of geothermal energy development.

The MWD system measures bottomhole information, such as direction of the borehole, azimuth and inclination of tool face, bit load and torque, temperature, and pressure by various Sensors installed near the drilling bit assembly, and transmits such information to the surface by electrical cable, mud pulse, electromagnetic waves, etc., in real time. NEDO is developing MWD with the mud pulse transmission system, where the data are transmitted by pressure changes in the circulating mud flow. The transmission speed of the mud pulse system is slow, but the pulse generating mechanism is quite simple, and it is adopted in most existing MWD systems. Moreover, extensive expertise has been accumulated in drilling of petroleum wells using the mud pulse method. Mud pulse transmission is, possibly, a suitable system for the heat-resistant MWD system.

There are three kinds (positive and negative mud pulse systems and mud siren - continuous sine waves system) of mud pulse generating mechanisms and a positive system was adapted in which the increase of the mud pressure relates to significant data. If the pulser valve, which exists at the top of the MWD sonde, carries out the opening-and-closing operation according to measurement data, mud circulation pressure is changed, transmitted and detected.

The development of the high-temperature MWD has been as follows;

1. FY1991 Feasibility study; MWD system concept design
2. FY1992-1994 Development and experiment of sonde composition parts
3. FY1995-1996 Manufacturing of prototype sonde No. 1
4. FY1997-1999 Well tests
5. FY2000 Manufacturing of prototype sonde No. 2

6. FY2001 Well tests in geothermal well drilling

In 1998, we conducted a test of the MWD system at the Kashiwazaki field, the test field of JNOC-TRC, and concluded that the interference of the drilling noise with the signal was excessive and the mud pulse decoding techniques needed to be improved (Kondo et al., 1999). In 2000, we modified the form of the mud pulse, decode algorithm of the surface unit, noise filter, transmission protocol, etc. In 2001, we conducted other tests at the Kashiwazaki field and at the Ogiri geothermat field to evaluate the performance of each function and component of the MWD system. At the test in the Ogiri field, we succeeded in transmitting mud pulses from a depth of about 800m to the surface while drilling. In addition, the bottomhole data decoded from the mud pulses were concordant with previous well data.

In this paper, we will describe the improvements to the sonde in 2000 and the experimental results from 2001.

2.0 SONDE IMPROVEMENT

2.1 Pulse Transmission

The original design of the pulse transmission is shown in Figure 2. The MWD sonde generates a sharp pulse in the mud circulation flow and translates the data with a time interval between pulses. At the surface, a pulse sensor detects that positive pressure change and recognizes it as a signal. Measuring the interval between pulses, the signal is then decoded to reveal bottomhole data. The signal transmission using the pressure change in the circulation mud has several disadvantages as follows, though the transmission is widely accepted: 1) signals are occasionally concealed by high amplitude noises, 2) signals cannot propagate over a long distance because of their impulse shapes, 3) signals are deformed due to the attenuation and the deformed signals occasionally result in errors in reading.

The conceptual diagrams of data transmission after the improvements are illustrated in Figure 3. Several points on the improvements are discussed as follows.

Bottomhole data	Some synchronized pulses	Temperature (12deg.C)	Azimuth (345deg.)	Next data
Digital code		0 1 2 3 4 5		
Pulse interval	4	4 5 6 7 8 9		
Pulse				
Mudpulse				
Readpulse interval				
Decode to digital code		0 1 2 3	* Digital code = ,q□~,S□□],S	
Display data		Temperature (12deg.C)	Azimuth (345deg.)	Next data

Figure 2. Original design of the pulse transmission.

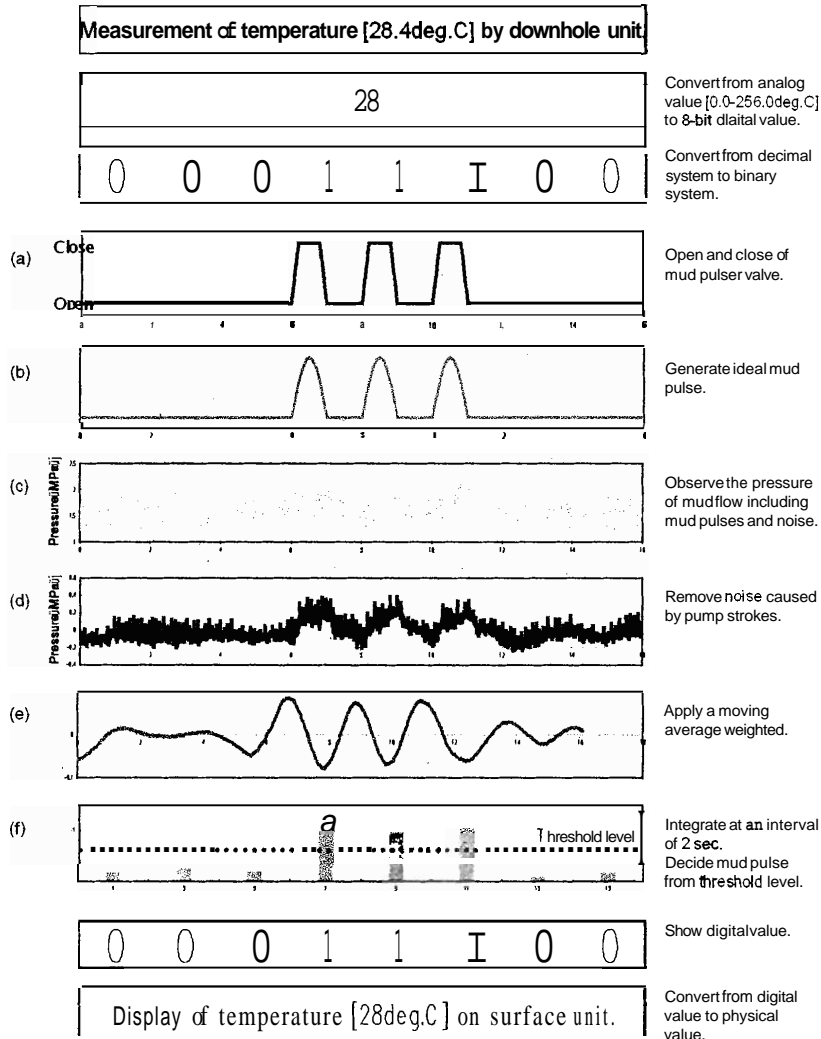


Figure 3. Conceptual diagrams of data transmission with mud pulses.

Firstly, the length of pulse data was improved. Before the improvement, the waveform of an impulse with a short cycle was selected in order to obtain larger pulse amplitude. However, the impulse has large attenuation and long-distance signal transmission is difficult. In the Kashiwazaki experiment in 1998, it became clear that the amplitude of the pulse declined exponentially to propagation distance. Moreover, the attenuation of the mud pulse is much larger when the frequency of the pulse becomes high. It is, therefore, necessary to expand the pulse cycle, in order to perform long-distance signal transmission. However, if the pulse cycle is lengthened, signal transmission requires more time. We relegated the half-pulse cycle to 1 second, and decided that 1 bit is transmitted every 2 seconds. Since the tool face data is composed of 9 bits, the entire update requires 18 seconds. If the difference from previous data is transmitted, the updating time is compressible and might be 8-10 seconds.

Secondly, the coding method was improved. Before the improvement, the interval between pulses was quite important in encoding data. As shown in Figure 2, pulse intervals are determined for adding the data to the base interval (4sec, for example). The pulse intervals are, therefore, variable. Missing or misreading of the pulse creates an unrecoverable result not only of the corresponding data but also of the subsequent data. After the improvement, the amplitude of the pulse is of importance, as shown in Figure 3. Misreading the start pulse consumes significant time, and manual processing to detect the start pulse by an operator is utilized to increase the reliability of the decoded data.

Thirdly, decoding the data is possible by manual processing. The decoding system is always seeking the start pulse of the data sequence, but the bottomhole data are converted to the sequence of the binary data and of the pulse height. The data are transmitted within a fixed interval, and missing or misreading the pulse produces only errors in the corresponding data. The improved coding method is more reliable.

Fourthly, an integration process was added. After removing noise caused by pump strokes, the waveform of the signals was still jagged (Figure 3d). The moving average technique was applied to the jagged waveform to produce a smooth form (Figure 3e). Integrating the square

of the waveform with respect to time, we can get the power of the wave Over time. Summing the power for an interval of 2 seconds, Figure 3f is obtained. Calculation of the power is a tool to enhance signals and to detect signals without error.

Fifthly, a stacking process was added. Stacking is a very useful and powerful technique to enhance signals and to reduce noise. This technique, however, needs the guarantee of the detection of the start pulse. After the improvement, the start pulse is easily recognized and the stacking technique is applicable.

2.2 Other Improvements

In 1999, the following experiments and improvements were carried out.

Reduction of the sonde length from 12m to 10m

The battery occupies more than half the space in the sonde. Consumption of electricity has been reduced to minimize the number of batteries and to save space.

Optimization of transmission information

The MWD system has 3 operational modes and the data length for the transmission at each mode was optimized.

Technology for assembling heat-resistant batteries

A battery does not cover all temperature environments. The maximum operating temperature of a heat-resistant battery is high, but the minimum operating temperature is also high. Therefore, a combination of various heat-resistant batteries was required.

Increase in the reliability of the retrievable equipment

The MWD system has a retrievable option that enables the installation and recovery of the sonde at arbitrary depths and times. The retrievable option is quite important to rescue the sonde from a higher temperature circumstance when the cooling system breaks down. The mechanism and material to catch and release the sonde were modified and examined. The retrievable equipment has become more reliable.

3.0 WELL EXPERIMENTAL RESULTS

In July 2001, an experiment for evaluating the MWD sonde was carried out at the test well in the Kashiwazaki JNOC-TRC field (hereinafter referred to as 'Kashiwazaki experiment'). Kashiwazaki is not located in a geothermal field but in a petroleum field. The temperature around the well is low. In October 2001, another experiment was carried out at the reinjection well in Ogiri geothermal field, in which drilling was under way by Nittetsu Kagoshima Geothermal Co., Ltd. (hereinafter referred to as 'Ogiri experiment').

3.1 Kashiwazaki Experiment

The Kashiwazaki experiment, which was performed before the Ogiri experiment, was carried out for the purpose of evaluating the practicality of pulse transmission and the retrievable function under low-temperature circumstances.

In the pulse transmission test, the pulse was clearly detected with a transmission distance of about 500m. Decoded data was appropriate as compared with well data that had been obtained before the experiment. In the pulse propagation characteristics (Figure 4), the pulse amplitude remains at a high level after the improvement and the decay ratio (gradient of the slope) was less during the Kashiwazaki experiment in 2001 than that in 1998. This means the pulse signal transmitted further without decay after the improvement. In addition, it has become clear why the pulse intensity from the experiment in 1998 was weaker than that in 2001. The weak intensity of the pulse was due to the loose adjustment of the valve gap. As seen in Figure 5, the relationship between the inflow speed of the mud and the amplitude of the pulse signal was clarified at the closed valve condition. The slower the inflow speed is, the weaker the pulse intensity becomes and the more difficult the pulse transmits. If inflow speed is high, pulse intensity becomes large but the motor drive torque also increases. Intense torque will damage the motor. The range for proper operation is shown at the top of Figure 5. To control the velocity of the mud flow suitable for the operation range, a sleeve was selected and attached to the valve.

Both catching and releasing operations for the retrieval equipment were examined 14 times and

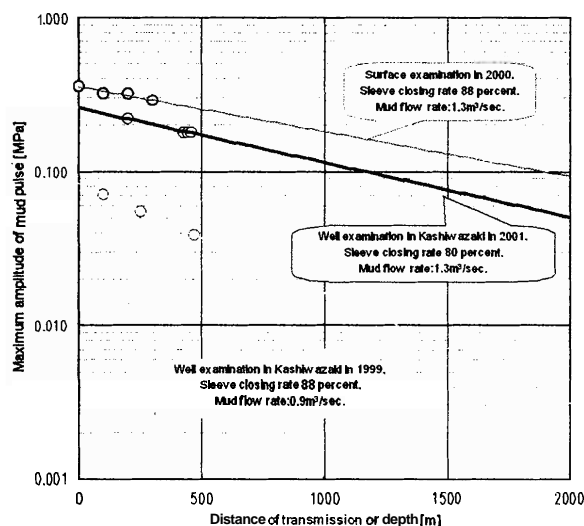


Figure 4. Mud pulse transmission characteristics.

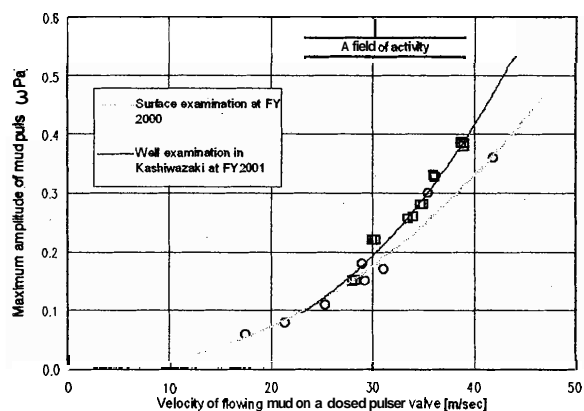


Figure 5. Amplitude of pulse vs. flow velocity.

were successful at depths up to 500m. The practical ability of the pulse transmission and the retrievable function was investigated during the Kashiwazaki experiment.

3.2 Ogiri Experiment

The experiment on the MWD sonde was performed during the rotary drilling for a reinjection well at the Ogiri geothermal field. The temperature variation in the sonde with time is shown in Figure 6. As the sonde descended to a depth of 24m, the temperature rose gradually, and then began to fall at the start of mud circulation. The same experiment was performed also at depths of 300m and 590m. At a depth of 810m, the temperature in the sonde rose to 110°C, but fell abruptly upon start of circulation. The experiment was started around 23:50 on October 17, and was ended around

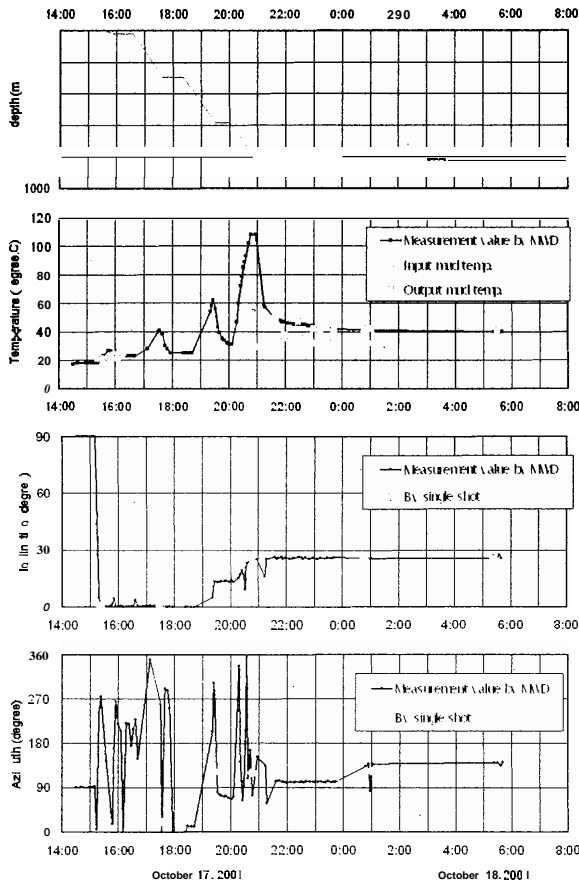


Figure 6. Results of well experiment in Ogiri.

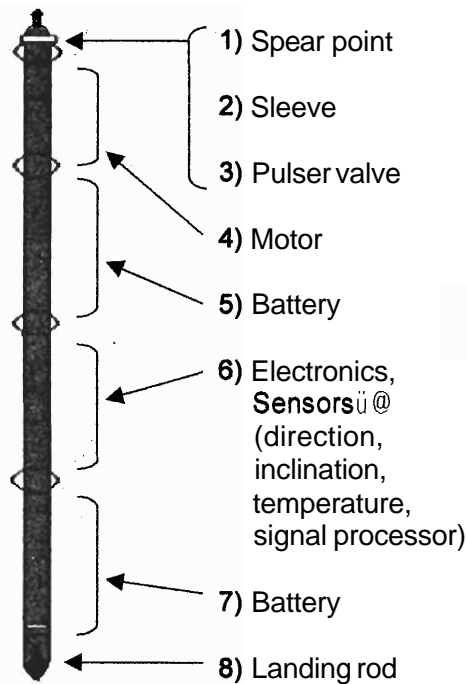


Figure 7. Configuration of the MWD sonde No.2.

5:30 on October 18. The measured temperature in the sonde was concordant with that estimated from the temperature measurement at the input and the output of the mud circulation. The inclination angle is in accord with the measurements of the Eastman formula inclination meter. Measurement regarding the direction of the borehole was not possible because the direction is measured by magnetic compass and the conductive casing pipe was inserted to a depth of 813m.

From the above results, although not all subjects were acceptable, we were able to check practicality in an actual geothermal well.

4.0 CONCLUSIONS

The configuration of the MWD sonde is shown in Figure 7, and its most recent specifications are listed in Table 1.

As a result of the well demonstrations in Kashiwazaki and Ogiri, the pulse transmission has been evaluated and the accuracy of the measurements has been examined.

The following points are extracted as further subjects:

- a) The energy consumption and the length of the sonde need to be shortened. One of the

Table 1. Specifications of the MWD sonde No.2.

		Target	Prototype
Size	Length	9m	10m
	Diameter	50.8mm(2")	44.4mm
	Weight	ü	85kg
Measurement	Azimuth	Possible	Possible
	Inclination	Possible	Possible
	Tool face	Possible	Possible
	Tool temperature	Possible	Possible
	Temperature	200ü A	200ü A
	Pressure	98MPaG (1000kgf/cm ²)	68MPaG
	Working time	50hr	50hr
Telemetry	Type	Positive mud pulse	Positive mud pulse
	Distance	ü	ü
	Rate	ü	About 30sec
Etc.	Retrievable function	Possible	Possible
	Operation mode	ü	3 modes
	Momory function	ü	500 data set

methods to save energy is to generate electricity or rotary power using the energy of the mud water flow.

- b) The plinth of the pulse generation valve is not resilient enough. Changing its material or structure can increase its strength.
- c) The signal transmission speed **can** be shortened by compressing the data.
- d) The reliability of the processing will be further increased by generating the first pulse regularly.
- e) The accuracy of the tool face needs to be measured with a DHM **assembly**.

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