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DEVELOPMENT OF HIGH-TEMPERATURE MWD SYSTEM FOR GEOTHERMAL WELL DRILLING

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ABSTRACT

Starting in 1992 a high temperature MWD system was developed for geothermal well drilling through a NEDO (New Energy and Industrial Technology Development Organization in Japan) project. This system features both electronic and mechanical devices, and it can operate in a 200 degree centigrade environment. The electronic device consists of many kinds of components including resistors, condensers, transistors, diodes, ICs, relays also memories, A/D converters, multiplexers, crystal clocks, and operational amplifiers. The sensing devices are flux gate type azimuth sensors, servo accelerator type inclination sensors and a diode type temperature sensor. A rithium type battery is adapted to the power supply. These mechanical devices include a direct current motor to move a pulse generating valve, and a multi stage mechanical seal system. The main specifications are 50 hours operating time in a 200 degree centigrade environment and 5 hours survival time in a 220 degree centigrade environment. Because of the hard formation of geothermal well drilling, anti-vibration performance is 30G for 6 hours. Anti-shock performance is 1,000G in a half millisecond. The sonde is the pressure barrel and includes all electronic and mechanical devices. The outer diameter is 44.4 mm (= 1.75 inch) and the length is 12 m. Acquisition data include azimuth, inclination, tool face and bore hole temperature. Sensors for weight on bit, bit torque and bore hole pressure will also be developed in the future. A pressure pulse device is utilized in order to transmit bore hole information data from the bottom to the surface by emitting a positive pulse up signal to the mud.

Two prototypes have now been manufactured and their performances have been verified through field tests both in Japan and overseas. Those tests have been successfully carried out under normal temperature conditions. Another field test is planned under a high temperature condition in a geothermal well.

1. INTRODUCTION

In general, the cost for drilling wells is more than half of the total cost for geothermal power generation. Decreasing the cost of drilling improves the cost minimization of power generation by geothermal energy and also increases power production. The MWD systems have been usually adapted for well drilling in oil fields, and this yields an efficient drilling, accurate controlling of well path and avoids other troubles in drilling. This can shorten the drilling period and decrease the drilling cost. On the other hand, for the geothermal well drilling it is expected that the MWD systems will give the same result as for oil drilling. However, the MWD systems cannot easily be adapted for high temperature geothermal well drilling, because their thermal specification is limited up to 175 degree centigrade. Therefore, it has been necessary to develop a high temperature MWD system suitable for geothermal well drilling. Figure 1 shows our concept of the MWD system.

2. SPECIFICATION

Target performance of our developing MWD system is shown in Table 1. This system features high temperature electronics which can operate under 200 degree centigrade and has a wire line retrievable sonde whose outer diameter is 44.4 mm(1.75 inch).

The present MWD system consists of detecting devices and an analyzing system. The detecting devices are divided into bottom hole devices and a surface equipment, and the former is composed of a sonde and a sensor sub. The sonde is set in a nonmagnetic drill collar just above a drill bit by the wire line method, and it senses the direction, inclination and tool face. On the other hand, the sensor sub is arrayed between a drill pipe and a bit or down hole motor and when put down to the well bottom, then measures the well bore temperature, pressure, weight on bit and torque. Data collected by the sensor sub is transferred to the sonde through a electromagnetic coupler. This bore hole information is converted to mud pulses generated by a pulsar valve located at the top of the sonde, and sent to the surface equipment. The surface equipment has both a pressure transducer for sensing mud pulses and a data processing computer for decoding from sequential mud pulses to physically meaningful values of the bottom hole information.

A prototype of the sonde which was manufactured in 1996, and partially developed in 1998 is shown in Figure 2. Its specification is shown in Table 2. Through actual drilling tests, our high temperature MWD system was evaluated during 1997 and 1998. Recent results of our research and development for the MWD system are described below.

3.HEAT-PROOF PERFORMANCE

As mentioned above, the heat-resistance limitation of normal MWD system is below 175 degree centigrade. However, our target is to develop a sonde which can operate in a 200 degree centigrade environment. To manufacture such high temperature sonde, it is necessary to assemble high temperature sensor and electronic devices. So we have not developed new electronics, that chosen those having a high heat-resistance performance by the screening method as shown in Figure 3. Through conducting various heating tests on electronics, it has been found that their life time is from 100 to 250 hours in a 200 degree centigrade environment.

We have adapted these screened high-temperature electronics to the azimuth sensor, inclination sensor, temperature sensor and some electronic circuits. The azimuth sensor is composed of flux gate type gyro-sensors, the inclination sensor consists of servo type accelerometers and the temperature sensor is made of PN-junction diodes. All of these sensors and circuits have successfully attained the target specification of 200 degree centigrade through heating tests in our laboratory. In this year a full-scale test will be carried out in a geothermal well to evaluate the heat-proof performance of the sonde.

3.1Screening for electronics

The screening as shown in Figure 3 proceeds as follows:

Desk screening
Electronic components are subjected to the screening in accordance with their manufacturing process studies and in anticipation of their heat-resistance performances.

1st screening
Critical temperature for maintaining the basic performance is identified. The tests are intended to ascertain in the shortest time any prospect of usability or unusability under an ambient temperature, with the objective aimed only at functions and by omitting the measurement of detailed properties.

2nd screening
As for the electronic parts judged to be usable through the 1st screening, detailed properties necessary for the circuit design are then measured. When results of an application to the object circuit have been judged to be impossible, the desk screening is resumed.

Temperature correction of sensors

Temperature correction must be made after conversion into digital data. Output from sensors is converted into digital data and read by a microprocessor system, and then an applicable correction is made on the basis of temperature obtained from an inner unit temperature sensor. There is a problem concerning the temperature dependency on the temperature sensor itself and the other sensor. However, it is possible to obtain the true temperature regardless of the existence of non-linearity and temperature drift, if the converted value from the output of the temperature sensor into the digital signal has only one value for the true temperature. Therefore, temperature correction for sensors can be made right after correcting the value of the temperature sensor.

4.MUD PULSE TRANSMITTING PERFORMANCE

There are three types of mud pulse transmitting systems. These are a positive pulse up type, a negative pulse down type and a mud siren type. The positive pulse up type has been adopted for the present MWD system that has a pulsar valve such as in Figure 4. A high temperature DC motor drives the pulsar under the control of a signal processor so the pulsar valve can open or shut the mud flow in the drilling pipe in an instant. The positive pulse is generated when the pulsar valve shuts quickly. Figure 5 shows the mud pulses obtained at the surface in an actual well test.

The propagating speed of a mud pulse is about 1,500m/sec. in fresh water and the pulse amplitude decreases faster as the propagating distance becomes longer. Therefore, we investigated the transmitting performance of the mud pulsar through tests in our laboratory and in some actual wells. The result obtained from these tests is shown in Figure 6. The loops consist of relative 200m and 500m length steel pipe assembly set on the ground horizontally, and a mud pump for the mud circulation. Through the test in an actual well at the prototype sonde location of about 500m depth, a mud pulse peak value of 40kPa was obtained and also pulse signals were successfully decoded into physical information data.

Since the hydraulics characteristics in wells vary depend on the well, we are planning to investigate the transmitting performance of the mud pulsar in another well. Due to the stroke of mud pump, the rotation of down hole motor and the mud injection from the bit nozzle, the mud pressure often fluctuated. These pressure fluctuations made noise during the transmission of mud pulses. Therefore we are now studying noise canceling techniques by utlizing a parametric model algorithm and a digital filter.

5.OPERATING MODE OF THE SONDE

The present MWD system has three kinds of operating modes: the sensing mode when the drilling stops, the directional drilling mode and the rotary drilling mode, as shown in Figure 7. These modes are essential for accurate sensing and economizing on battery capacity. Each mode can be selected automatically by mud circulation or bit rotation.

The sonde has two kinds of switches. One is called a mud circulation switch, the other is a rotary revolution switch. The former switch operates when the accelerometer senses some fluid exited vibration of the sonde during mud circulation, and the latter switch turns on when the directional sensor counts some bit rotations as shown in Figure 8.

For practical use, it is necessary to increase the data transmission rate by an optimization such that the tool face data is only transmitted at the directional drilling mode, and at the rotary drilling mode, only the temperature data is transmitted sequentially.

6.RETRIEVABLE MECHANISM

The present MWD system has a retrievable function, which makes it possible to retrieve or release the sonde at an arbitrary depth and timing. At the top of sonde a hook, a so called spear point, is attached and tools for both releasing and over shooting are equipped to join the hook as shown in Figures 9 and 10. A landing rod with a key system is set at bottom of the sonde to correct the direction of the sonde as shown in Figure 11.

To release the sonde, we grasp the spear point by the releasing tool at first, and then drops the sonde down into the drill pipes by the wire line. When setting the sonde at bottom hole, the key way of the landing rod automatically coincides with the key of the mule shoe sub and consequently the tool face angle can fit into the correct sonde direction.

On the contrary, to retrieve the sonde, we drop the over shot tool down into the drill pipes, and next grasp the spear point, finally by rewinding the wire line we can return the sonde to the surface.

7.DRILLING TEST RESULTS

A full-scale test was carried out at the actual well in 1998. This is shown in Figure 12. The main results are described as follows:

Mud circulation switch

It was confirmed that when the pump stopped, the mud circulation switch operated and then the sonde started sensing. However, when the pump started up, the sonde began data transmission.

Data transmission

The sonde decoded the bottom hole data into pulse signals and correctly transmitted the data to the surface equipment at depths of 100m, 250m and 470m. It kept its function normally under each mud circulation quantity of 900, 1100 and 1300 liter/min. It was confirmed from measured data that the inclination sensor and temperature sensor worked accurately.

Sleeve of mud pulsar

After changing from the fixed type sleeve on the pulsar valve to the drill collar type sleeve, it was confirmed that the pulse signal was also smoothly generated and transmitted the data to the surface.

Interval of mud pulsation

The interval of mud pulse signal corresponds to the bottom hole data. It is desired to minimize the interval because of increasing the data transmission rate. In spite of changing the standard (= minimum) pulse interval from 2.0sec to 1.0sec, data continued to be transmitted.

Rotary revolution switch

This switch functions by sensing the terrestrial magnetism. Because of the non-magnetic drill collar, the switch could not sense the terrestrial magnetism, so this function could not be proved in this test.

Endurance while drilling

It was confirmed that the sonde could keep its functions stable for 16 hours of drilling under severe shocks and vibrations.

Strainer

During the test, we used a strainer since some alien substances among the mud circulation damaged the pulsar. We cheked whether the strainer inserted into the kelly influenced the mud pulse propagation in the drill pipe. It was found that its influence was small and the mud pulse could be sensed correctly at the surface.

8.CONCLUSIONS

When we successfully develop the MWD system for practical use, the following benefits will be obtained:

・Accurate well trajectory control

・Due to the smooth well path, we can be free from troubles in the well e.g. torque or drag increase while drilling.

・We can avoid damages on the drilling tools such as bit and down hole motor by the accurate sensing of bore hole temperature.

・By quick formation evaluation, the depth to stop drilling is properly judged.

・Enhancement of the bit life and avoidance of bit sticking in the hole through an appropriate control of both weight on bit and bit torque.

On the other hand, technical tasks to be resolved for practical use became clear through this work as follow;

・Need to improve the heat resistance performance of the assembled sonde for each component.

・Need to investigate the durability in a complex environment when a high temperature condition and a vibration are combined.

・Need an effective noise cancellation method and strengthening of the mud pulse signal in order to transmit the signal correctly in spite of such severe conditions as noises during circulation, irregular mud conditions and also long propagating distances. We are now studying a parametric model and digital filtering method.

・Need to shorten the length of sonde by electrical economizing.

ACKNOWLEDGEMENTS

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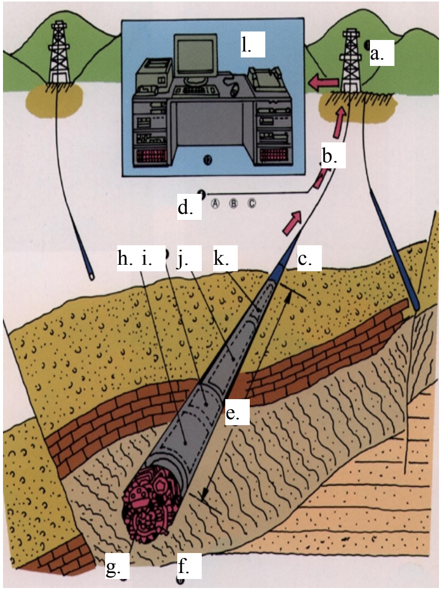

a. Drilling Rig
b. Mud Pulse Telemetry System
c. Drill Pipe
d. Bottom Hole Data
e. MWD Assembly
f. MWD System
g. Bit
h. Sensor Assembly
i. Mud Turbine Generator and Regulator
j. Converter of Sensor Data to Mud Pulse
k. Pulsar
l. MWD Surface Unit for Data Acquisition & Analysis

Figure 1. Concept of MWD system

Table 1. Target performance of our MWD system

Service company	Anadrill		Baker-Huges INTEQ	Halliburton Energy	Sperry-sun Drilling	The present MWD
System name	Slim-1	POWER-PULSE	NAVITRAK	DIS	SOLAR 175	-
Type	Sonde	Sub	Sonde	Sub	Sub	Sonde
Outer diameter(mm)	44.45	171.45	44.45	120.65	171.45	44.45
Length(mm)	8400-9600	7500	6600	4500	3450	12000
Maximum temperature (degree centigrade)	150	150	150	150	175	200
Maximum pressure(MPa)	105	140	140	140	158	70
Power supply	Battery (800Hr)	Turbine generator	Battery (200Hr)	Battery (400Hr)	Turbine generator	Battery (50Hr)
Data transmission rate (seconds/No.)	10-120	3 or 11	10,13 or 20	6.9-34.5	8.7	15-30
Sensing data	Directional Temperature Vibration Gamma ray	Directional Temperature Vibration Gamma ray	Directional Temperature	Directional Temperature Gamma ray	Directional Temperature	Directional Temperature
Wire line retrievable	Possible	Impossible	Possible	Possible (only Electronics)	Impossible	Possible

Table 2. Speification of the present MWD

Dimension	Length(m)		Outer diameter(mm)
Sonde	12.0		44.45
Sub	2.0		165.1
Sensing Items			
Sonde	Range	Resolution	Accuracy
Azimuth	0-360°	0.1°	1.0°
Inclination	0-90°	0.1°	0.2°
Tool face	0-360°	0.1°	2.0°
Temperature	20-220℃	1.0℃	2.0℃
Sensor sub			
WOB	0-30ton	0.1ton	10%FS
Torque	0-1000kgm	10kgm	10%FS
Bore hole temp.	20-220℃	1.0℃	2.0℃
Bore hole pressure	0-50Mpa	0.1Mpa	2%FS
Max. pressure	100Mpa		
Max. operating temp.	200℃(continuous)		
Max. survival temp.	220℃(5Hours)		
Anti-vibration	30G(50-500Hz,6Hr))		
Anti-shock	1000G		
Data transmission rate	15-30sec.		
Transmission system	Positive pulse up		
Power supply	Rithum Battery(50Hr), Turbine generator		

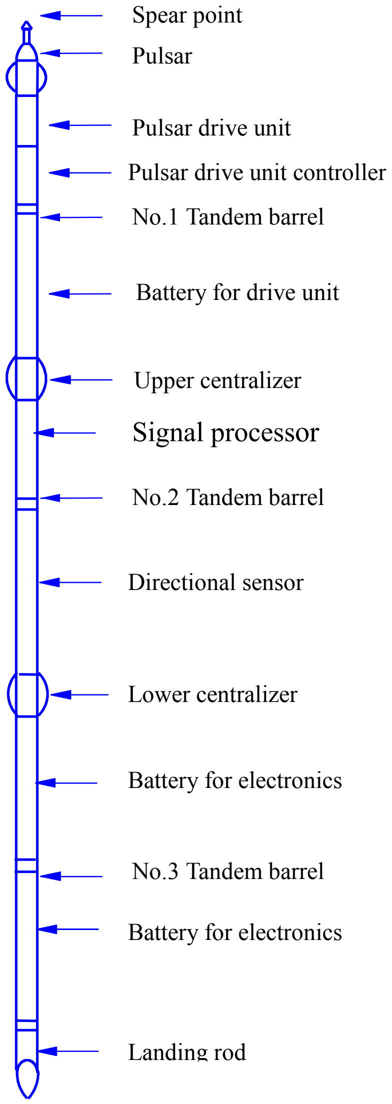

Figure 2. Assembly of MWD sonde

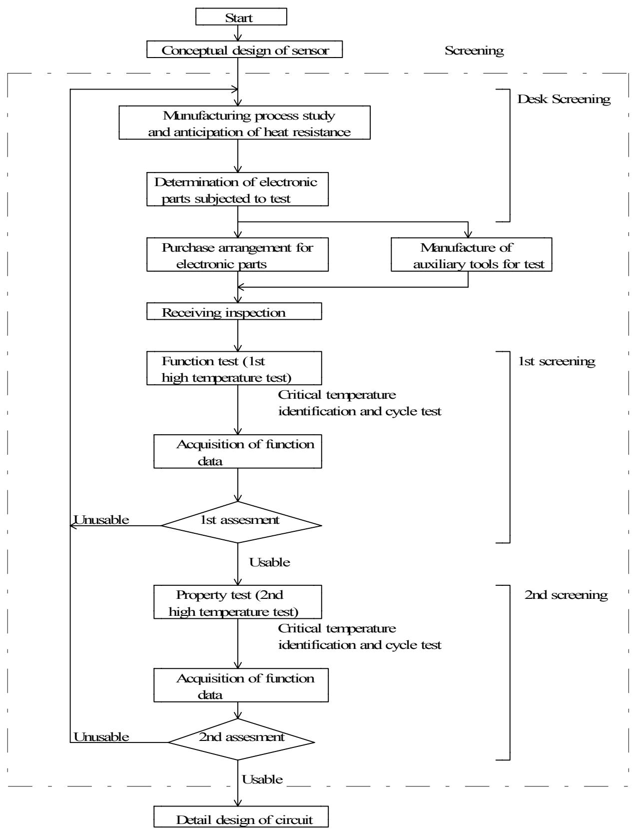

Figure 3. Flow chart of high temperature screening for electronics

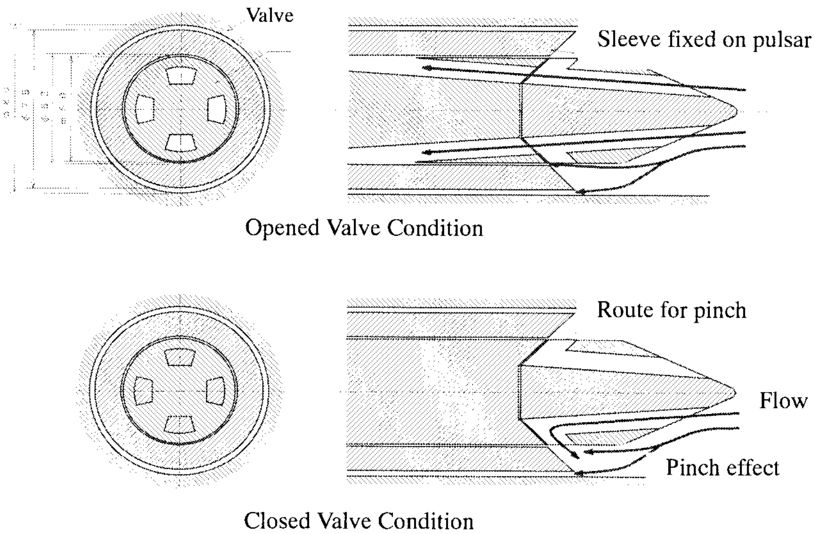

Figure 4. Pulsar valve utilizing hydrodynamic pinch effect

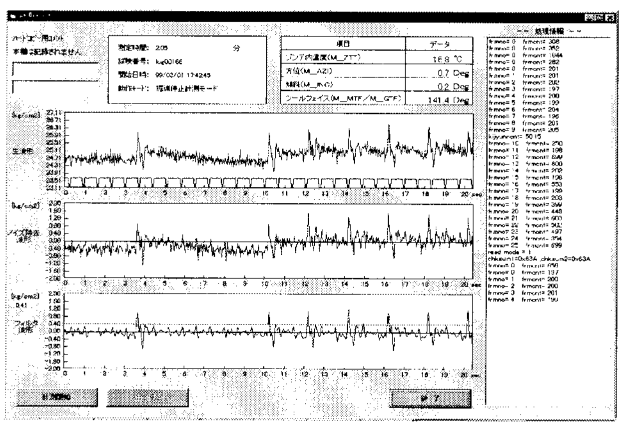

Figure 5. Mud pulses obtained in an actual well

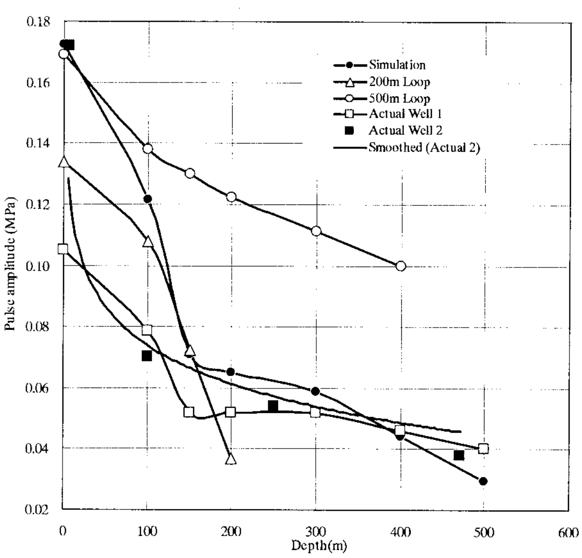

Figure 6. Propagation of mud pulse

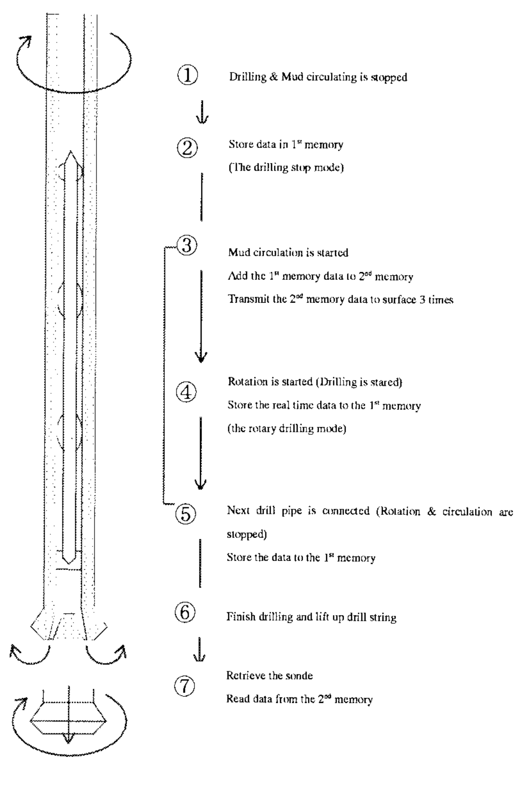

Figure 7. Operating modes of the sonde

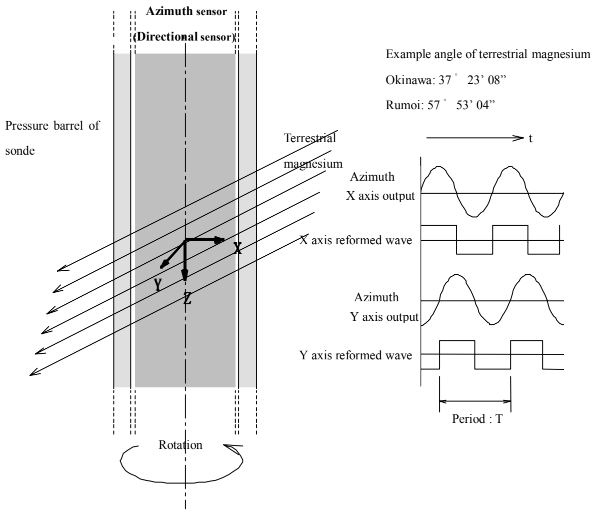

Figure 8. Operating mechanism for rotary revolution switch

Figure 9. Releasing tool(Right) and spear point

Figure 10. Over shooting tool(Left) and spear point

Figure 11. Landing rod

Figure 12. Prototype MWD in the actual well