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UPGRADING THE ACOUSTIC BOREHOLE TELEVIEWER FOR GEOTHERMAL FRACTURE MAPPING*

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ABSTRACT

The importance of fracture characterization in geothermal logging has long been recognized. The acoustic borehole televiewer is probably the single most useful tool for determining location, orientation, and characterization of fractures. However, since the televiewer was developed for low temperature oil and gas exploration, it has not been capable of reliable operation at geothermal temperatures. This paper reviews the theory of operation of the acoustic televiewer, identifies the problems associated with its operation at both high and low temperatures, and reviews a program to upgrade the tool. Major results of the program have been: 1) a high temperature acoustic transducer, 2) an improved acoustic window, 3) more reliable electronics, and 4) the elimination of troublesome slip rings.

INTRODUCTION

Productivity of geothermal wells is primarily determined by fluid flow thru fracture systems. A production well usually penetrates one or more open fractures that are either naturally occurring or hydraulically induced. To understand fluid flow in geothermal wells, data is needed to characterize these fracture systems. The acoustic borehole televiewer (ABT) has been used to obtain much useful data about fracture systems as they intersect the borehole. (Keys, 1979).

The televiewer, like many other logging sondes being used for geothermal well logging, was originally developed for use in oil and gas wells. Many problems are experienced in the hot and highly corrosive geothermal environment that lead to instrument failure. An effort to upgrade the televiewer for geothermal operation at temperatures up to 275°C and pressures up to 4000 psi centers around the modification of the mechanics and electronics of a commercially produced prototype tool. The USGS Water Resources Division with their vast experience in using the televiewer and the manufacturer (Simplec Mfr. of Dallas, TX) are working with Sandia in the identification of problem areas and possible solutions. The modified tool will be lab tested and eventually field tested in a geothermal environment to prove out the design. When proven, these modifications will be turned over to industry to make the upgraded tool commercially available.

THEORY OF OPERATION

The fundamental parts of the acoustic borehole televiewer are shown in Figure 1. The motor rotates the transducer and the flux gate magnetometer at a rate of three revolutions per second with electrical signals coupled through a set of slip rings which are not shown. The acoustic sensor housing is filled with high temperature oil which serves to lubricate the motor and other rotating components as well as to couple acoustic energy from the transducer to the acoustic window.

The flux gate magnetometer and its associated circuitry senses the earth's magnetic field and generates an orientation pulse each time the transducer rotates through magnetic north.

The acoustic transducer is a 1/2 inch diameter disc of piezoelectric material electroded on both faces. This transducer is a transmitter and a receiver of acoustic energy. The transducer is pulsed with a burst of high frequency (1.3 MHz) electrical energy at a rate of 1500 pulses per second by the transmitter pulse generator. The bursts are emitted through the acoustic window into the borehore fluid, reflected off the borehole wall, returned and picked up by the transducer. It is the amplitude of this reflected energy pulse that is used by the televiewer system to form the log.

Communication with the downhole protion of the system is through a four to seven conductor logging cable. The cable provides the power for the electronics and the motor and carries signals from the televiewer to the surface.

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To log the hole, the televiewer is pulled up at a rate of 5 ft/min so that a spiral strip of the borehole wall is probed. Depth information is obtained from an optical encoder connected to a pulley wheel over which the cable travels.

The three signals providing depth, orientation and reflected signal amplitude information are used by the surface electronics panel to generate vertical, horizontal and intensity signals for the electron beam of an oscilloscope cathode ray tube. As smooth portions of the wall are scanned, the reflected signal will be uniform in amplitude and produce uniform intensity traces on the oscilloscope. As discontinuities are scanned, the amplitudes of the reflected signals will drop due to scattering of energy and the intensity of the oscilloscope trace will decrease. These discontinuities may be in the form of fractures, chips, wash outs, or rough spots. When the oscilloscope face is photographed, the result is an oriented acoustic image, providing a descriptive reproduction of the borehole wall split open and laid flat.

Figure 2 is a sample log showing three parallel fractures which show up as sine wave shaped dark lines. Details on the reading and interpretation of the televiewer logs have been published by Keys (1979) and Zemanek (1969).

TRANSDUCER

The piezoelectric material orginally used for the transducer is ceramic lead metaniobate. It was thought that lead metaniobate, which has a curie temperature of 400°C would work well at 275°C. However, initial testing indicated an increase in dielectric permittivity and hence capacitance by almost an order of magnitude in going from room temperature to 275°C. Dielectric leakage resistance also decreased from greater than 20MΩ to less than 200Ω over the temperature range. Even though the lead metaniobate retains its piezoelectric properties at 275°C, the capacitance change tends to detune the pulsing network which then produces bursts of electrical energy that are not of the same frequency as the transducer resonance. This results in a significant drop in electromechanical conversion efficiency at high temperature. In addition, when the transducer's dielectric leakage resistance drops below the transformed mechanical impedance of the coupling fluid (which seems to be around 1 to 5KΩ), the voltage level of the reflected energy pulse will drop.

A survey of transducer materials was conducted and three materials were found which had relatively high electromechanical coupling coefficients and curie temperatures higher than lead metaniobate. Discs of the proper size and resonant frequencies were ordered from manufacturers for comparison in the laboratory.

To evaluate transducer operation at high temperature in the mode it is actually to be used, a test fixture was built to go inside an autoclave capable of heating a liquid to 275°C and holding a pressure of 3000 psi. The transducer is mounted inside the autoclave in a position so that its emitted energy pulse is reflected off the autoclave bottom. It is pulsed by a circuit similar to the one used in the televiewer (the pulsing and sensing circuits are external to the autoclave), and the reflected signal is picked up by the transducer and displayed on an oscilloscope. Capacitance, leakage resistance, and reflected signal peak amplitude were measured at ambient temperature and again at 275°C (3000 psi) allowing 20 hrs for stabilization. The results of this testing are shown in Table 1 as well as numbers for coupling coefficient and curie temperature obtained from the manufacturers. The data indicates both the modified lead titanate transducer and the lithium niobate transducer work well over the temperature range. However, both the lead metaniobate and sodium bismuth titanate suffer large changes in capacitance and small leakage resistance at 275°C, which cause reduced efficiency.

ACOUSTIC WINDOW

The original low temperature televiewer used a rubber boot as the acoustic window; the rubber is a good impedence match to the fluids on both sides of it, and worked well at high pressure using a bellows to equalize the pressure across the window. However, rubber disintegrates at high temperature in the corrosive brine.

The first high temperature televiewer used a high temperature plastic, made by DuPont, called Vespel for the acoustic window. The window was sealed to the tool body by an o-ring sealing surface, but thermal expansion of the plastic caused leakage unless a wire wrap was used. Failure analyses showed that stresses put on the Vespel window by the wire wrap together with embrittlement of the Vespel in contact with the brine, limited the life of this window.

Testing done at Westinghouse by J. Wonn (1979) indicated that a teflon window with a flanged sealing surface might survive the temperature. The window and sealing surface has been redesigned to accommodate a teflon window. Additional testing has shown this to be a good solution for operation to 275°C.

J. Wonn (1979) has also shown that a very thin (.002") metallic winodw may be used as a solution to operation at temperatures much higher than 275°C. The manufacturing process for this type of window has not yet been identified and concern over the fragility of this type of window has delayed its incorporation into the prototype tool.

ELECTRONICS

The electronics used in the televiewer is packaged inside a dewar flask that uses a 138°C melting point eutectic metal as a heat sink. The temperature inside this dewar can be held below 138°C for sufficient time to log most wells, however, the inside temperature can range from 0°C to 138°C. Temperature stable design techniques are being applied in the redesign of the electronics to assure reliable operation over this severe temperature range. The pulser circuitry has been redesigned to accommodate the increase in capacitance of the transducer. The receiver circuitry is being redesigned to boost the dynamic range of the overall system, thus making information available that was previously masked by cable noise. Also, a new magnetometer circuit, that uses less power but has increased sensitivity, has been incorporated into the prototype tool.

The original televiewer used a point to point wiring technique which required hand wiring and made repair difficult. The modified instrument uses printed circuit boards that eliminate crosstalk problems, improve reliability, simplify fabrication, standardize instruments, and make field repair simple and straightforward.

ELECTROMECHANICAL COMPONENTS

The Sandia prototype televiewer uses the elastomer o-ring equipped Gearhart Owen Ind. (GOI) seven conductor cablehead for making electrical and mechanical connection to the cable. A high temperature Sandia-GOI cablehead design exists that utilizes metal seals and an insulating oil (Krytox by DuPont) for keeping water off the electrical wire terminations. Since the televiewer log takes a relatively short time period to run, it was felt the metal sealing system was not needed. However, many problems have been experienced with short circuiting in the low temperature cablehead. To alleviate these probems, the standard GOI cablehead has been redesigned to use the same insulating oil termination system that is used on the high temperature cablehead.

Two electrical components are rotated by the motor: the flux-gate magnetometer and the acoustic transducer. The electrical connection to these rotating components has been by silver slip rings. Besides expense, several problems have been experienced with the slip rings: 1) they must be kept clean to operate properly, 2) the brushes wear and must be replaced regularly, 3) brush holders lose their spring and fail to hold the brushes on the rings at high temperature, and 4) contact bounce generates electrical noise. Sandia has done away with the slip rings and implemented a system of rotating transformers. A rotating transformer is one where the primary winding is stationary and the secondary winding rotates or vice versa. The new system occupies the same space as the slip rings with very little modification to the acoustic sensor housing. Ferrites were supplied by Ceramic Magnetics, Inc., of Fairfield, NJ. The transformer wire used is high temperature anodized aluminum. The rotating transformer set has been successfully tested to 275°C and a commercial version is now being fabricated by Ceramic Magnetics.

SURFACE EQUIPMENT

The camera and oscilloscope method of recording the log in the field requires the operator to watch the depth counter, open and close the shutter at the proper times, pull out film, wait 10 seconds for film to develop, make adjustments if necessary, and cut and piece together the log. Considerable time and effort could be saved by going to some type of continuous recording method. The televiewer system is being adapted to a fiber optic continuous grey scale recorder. The log will be recorded on a continuous roll of dry silver photographic paper which is thermally developed as the log is run.

The manufacturer of the televiewer has recently added a video tape recorder to the televiewer system which records the raw data in the field for playback in the lab. This will enable the user to perform many types of video enhancement in the lab which were unavailable in the field. Amoco Research has done considerable work in the area of image enhancement of televiewer logs as reported by A. H. Jaegler (1980).

SUMMARY

The acoustic borehole televiewer has been established as a useful tool for geothermal fracture mapping. Many key components, specifically the transducer, electronic circuitry, acoustic window, slip ring assembly, and cablehead, have been upgraded and tested in the laboratory for high temperature operation. Work is continuing in the areas of circuit design, component testing, and surface panel improvements with a goal of a field test (in cooperation with the USGS Division of Water Resources) in an actual 275°C goethermal well. The eventual goal will be making the 275°C version of the televiewer commercially available to the industry.

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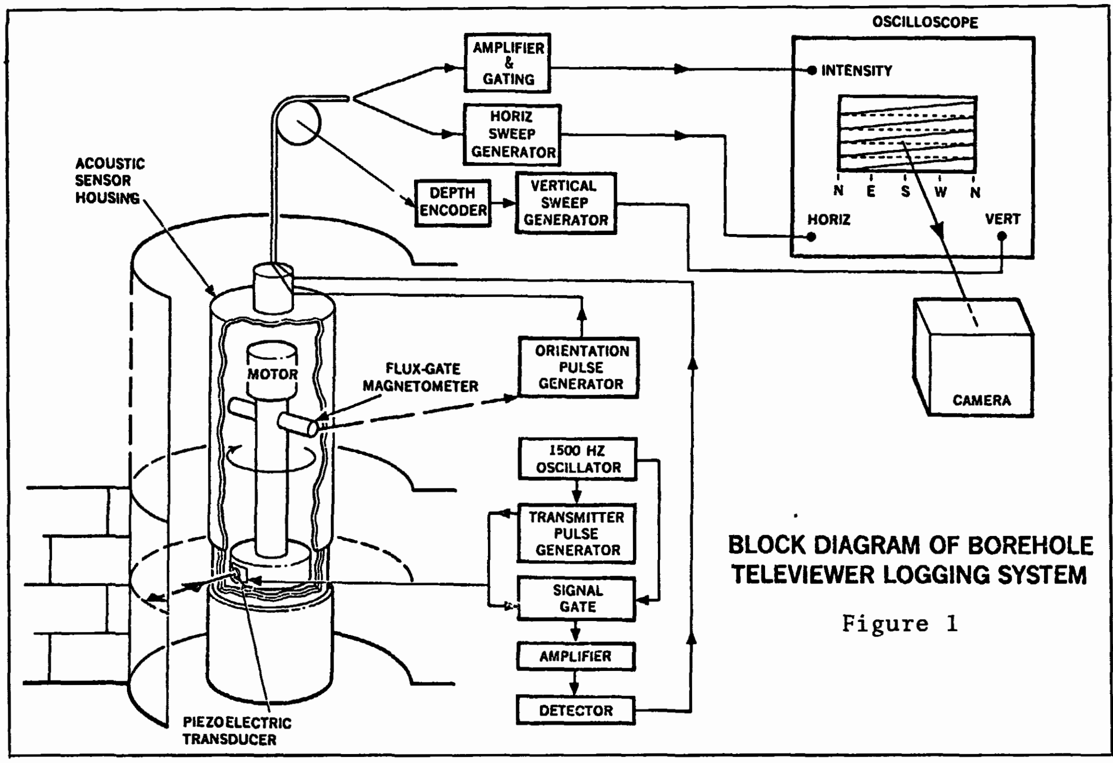

BLOCK DIAGRAM OF BOREHOLE TELEVIEWER LOGGING SYSTEM

Figure 1

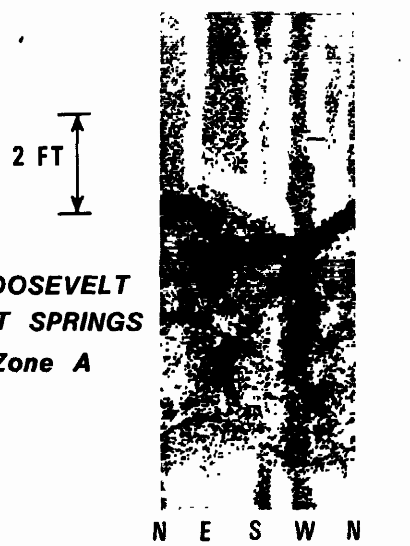

Fig. 2 Acoustic Televiewer Log Example (Keys 1979)

TABLE 1

RESULTS OF AUTOCLAVE TESTS OF CANDIDATE TRANSDUCER MATERIALS

	†LEAD METANIOBATE	†MODIFIED LEAD TITANATE	†SODIUM BISMUTH TITANATE	LITHIUM†† NIOBATE
CURIE TEMPERATURE*	400°C	500°C	600°C	1250°C
ELECTROMECHANICAL COUPLING COEF. K_t*	.85	.75	.41	.50
CAPACITANCE (pf)				
AT 25°C	300	235	105	35
AT 275°C	2040	625	1000	55
LEAKAGE RESISTANCE				
AT 25°C	>20MΩ	>20MΩ	>20MΩ	>20MΩ
AT 275°C	165Ω	38K	4.5KΩ	>20MΩ
REFLECTED SIGNAL PEAK AMPLITUDES				
AT 25°C	400mV	.800mV	80mV	200mV
AT 275°C	30mV	1000mV	20mV	200mV

*Data obtained from manufacturer

†Supplied by Kerames Inc.

††Supplied by Specialty Engineering Assoc.