Geothermal Resources Council, TRANSACTIONS Vol. 5, October 1981

ACOUSTIC CEMENT BOND LOGGING DIAGNOSTICS FOR GEOTHERMAL APPLICATIONS

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ABSTRACT

For the successful and safe operation of a geothermal well, casing and cement conditions must be accurately determined. Cement bond logs are needed to detect channels or water pockets in the cement between the pipe and the formation and to determine the condition of the cement bond to the pipe and to the formation. Instrumentation for making such measurements is limited by the temperature capabilities (<175°C) of existing logging equipment which was developed for the oil and gas industry. This paper reviews an acoustic system of the type that is needed for geothermal cementing inspection, identifies the principle deficiencies in its high temperature use, and describes Sandia's R&D project for developing high temperature acoustic cement bond logging diagnostics.

INTRODUCTION

Downhole conditions very often cause casing and cementing problems in geothermal wells. For example, cement may be washed out or dissolved by water in a crossflow, or the cement may be displaced in a lost circulation zone. In either case, the pipe could collapse due to lack of support from the cement and formation. Moreover, the pipe could collapse catastrophically due to rapid heating of entrapped water when the geothermal well is flowed for the first time. A cement inspection tool is essential for the successful operation of a geothermal well.

An acoustic cement bond logging (CBL) tool is the most versatile and widely used tool in the field for cement inspection. This tool is used to determine the quality and extent of the physical bond between the casing pipe and the surrounding cement sheath, and between the cement and formation. The log measures the amplitude of acoustic signals reflected from the casing pipe and the amplitude of later arrivals which are indicative of the bonding of the cement to the formation.

Because of the temperature limitations of presently available commercial tools, wells usually have been cooled down prior to logging. When the temperature of a well is reduced, the steel pipe contracts more than the cement sheath, and thus leaves a "micro-annulus" between the pipe and the cement. Although this space is small, it will destroy the apparent bond registered by the CBL. According to Knutson and Boardman (1978), many field operators consider commercial CBL logs from geothermal wells to be of doubtful validity because the logs usually do not show a bond between cement and casing.

An accurate CBL log can be obtained in a high temperature well only if the tool is run at the well temperature. The temperatures of geothermal wells are typically above 200°C: it is Sandia's objective to develop a cement inspection instrument for operation up to 275°C. This instrument should also prove useful in logging steam injection wells, as well as hot oil and gas wells.

PRINCIPLES OF OPERATION

Figure 1 illustrates the cement bond sonde and the related signal paths. For casing which is suspended freely in a well with no cement between the casing and formation there is little acoustic energy transmitted beyond the casing wall and the signal strength seen by the receiver will be high. However, when hardened cement is bonded to the

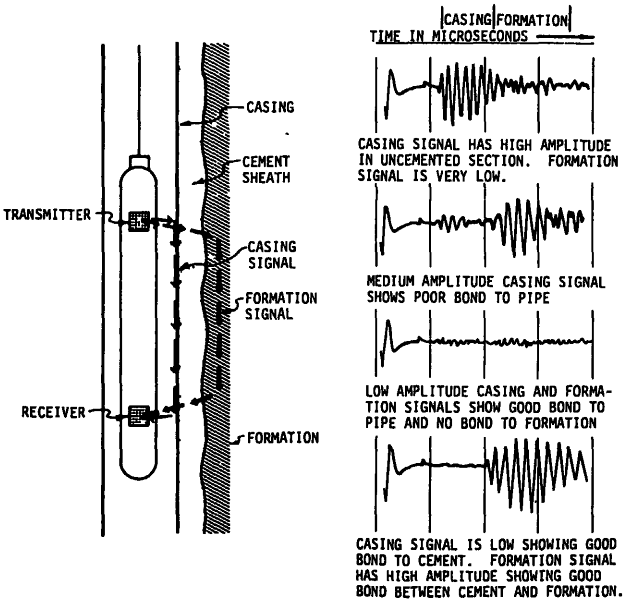

Figure 1. Cement bond sonde and acoustic signals.

casing, the amplitude of the signal transmitted along the casing will be drastically reduced. Laboratory investigations have shown that there is a relationship between the strength of the echo signal and the degree of cement bonding (Grosmangin et. al., 1961). The acoustic velocity in a steel pipe is 17,544 feet per second (or interval transit time of 57 µs/ft) while the velocities in cement and in the formation are lower. It can be determined from the arrival times of the various signals whether they are coming from the pipe or elsewhere.

The casing and its surrounding cement are relatively transparent to acoustic signals if the cement bondings to both the pipe and the formation are good. A large formation signal will arrive at the receiver inside the cased hole at a time different from the first arrival of the casing signal due to the different acoustic velocities in the pipe and in the formation. On the other hand, if the bonding is poor, i.e., if a space exists between the pipe and the cement, or between the cement and the formation, little formation signal will be observed. This is because of the low transmission coefficient across a boundary at which the acoustic impedance mismatch is large (e.g., air to steel pipe and air to formation are examples of boundaries exhibiting large impedance mismatches). The amplitudes and arrival times of the acoustic echoes can thus be used to determine the degree of cement bonding.

It is customary to use the amplitude of the reflected casing signal in a free pipe as a reference for evaluating other signals to determine the percentage of bonding. The "Variable Intensity Log", commonly abbreviated to VIL, is a continuous display of the acoustic signal in the form of a variation of light intensity. These displays, shown in Figure 2, produce characteristic patterns --"Acoustic Signatures"--for various degrees of cement bonding between the casing and formation.

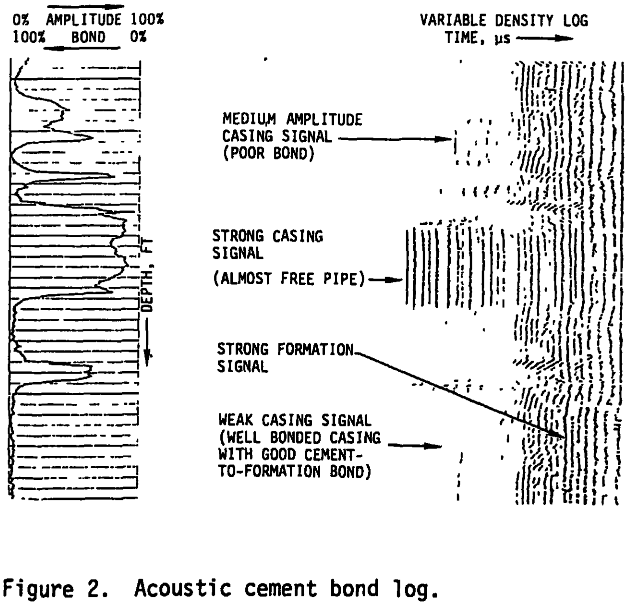

Figure 2. Acoustic cement bond log.

SANDIA'S R&D PROGRAM

Figure 3 shows a circuit capable of generating high current pulses for an acoustic transmitter at room temperature. In this circuit, the capacitor C_1 supplies energy through the SCR (Semiconductor Controlled Rectifier) to the acoustic transmitter.

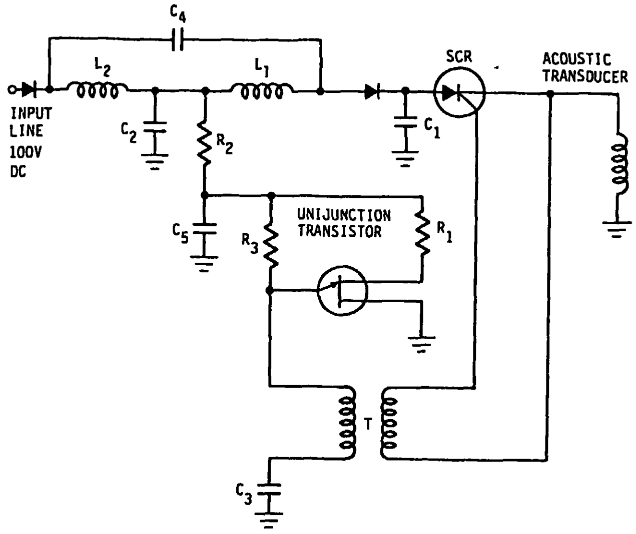

Figure 3. Cement bond transmitter schematic.

After the SCR is fired, L_1 boosts the input voltage to a much higher value across C_1, recharging it. L_2 and C_2 prevent the ripples from feeding back to the input. To provide a reference for the received signal, the capacitor C_4 provides a high frequency path back to the input line for detection of the pulse produced when the SCR conducts. R_1, R_2 and C_5 limit the imposed voltage on the unijunction transistor which will not be triggered until the capacitor C_3 is sufficiently charged. Thus, the R_3C_3 time constant will determine the firing frequency of the SCR. Transformer T sharpens and boosts the amplitude of the trigger pulse to the SCR. In this figure, component values have not been specified because they would be different for different acoustic transducers and temperature ranges. This is a fundamental transmitter schematic in commercial acoustic CBL tools. Some commercial tools may contain more complex electronic switching circuits in order to run the CBL in conjunction with other logging tools. The basic schematic is, however, quite similar. Some tools use bipolar transistors to generate the trigger signals.

Commerical SCRs, unijunction transistors and bipolar transistors are all rated below 175°C. At higher temperatures, they all conduct high leakage currents and thus lose their transistor characteristics. Most commercial inductors, capacitors and resistors are also rated for low temperature operation, although some high temperature technologies do exist. The smallness of the market, however, precludes the high temperature components from massive production.

Through a careful selection procedure, one may find a transistor that has a higher operating temperature than the others. In addition, a negative voltage at the trigger terminal of an SCR before firing can increase its operating temperature by as much as 25°C. Nevertheless, the maximum operating temperature of a design based on the best available components is still limited to 200°C, well below the 275°C geothermal temperature.

In order to design a 275°C circuit, a project has been initiated at Sandia to develop a long operational life Sprytron switch-tube (Boettcher, 1972) for possible replacement of an SCR. Sprytrons operate at high voltage and are capable of transfering large currents for short time intervals. Figure 4 records the voltage and current through a Sprytron, starting from the second shot. (On the first shot, the voltage was 100 V and the current was too weak to be recorded.) The amount of current delivered through a Sprytron is quite comparable to that delivered through an SCR under the configuration of Figure 3. The Sprytron tube is vacuum exhausted at 600°C; thus, it works as well at 275°C as at ambient. The main deficiency is its limited life since it was not originally designed for continuous operation. The main challenge in the Sandia R&D effort is that of extending the operational life of the Sprytron tube; thus far, it has been possible to increase its life to 100,000 operations (or about 3 hours at a 10 pulse per second repetition rate) and it is expected eventually to reach 500,000 operations (about 15 hours at a 10 pps repetition rate).

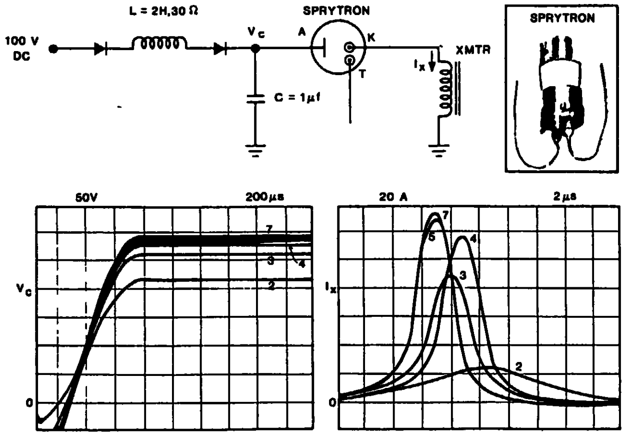

Figure 4. Sprytron and test circuit.

In addition to the development of a long life Sprytron, various commercial electronic components have been evaluated to determine their maximum operating temperatures. Some commercial products can operate at temperatures higher than their ratings. For example, some junction field effect transistors (JFETs) are rated at 200°C, but can actually operate at 275°C without significant leakage current. Some existing electronic technologies have high temperature capability, but are not off-the-shelf products. For example, mica capacitors can withstand high temperatures and high voltages, but high capacitance mica capacitors have to be specially ordered. Table 1 shows examples of some high temperature commercial products that will be used in Sandia's design for high temperature circuits for the acoustic CBL tools. A more complete list will be published by Sandia as part of a high temperature component handbook.

Company	Item	Maximum Temperature
	Resistors	
Caddock Electronics	Power Film	275°C
Cermalloy	Thick Film Inks	500°C
	Capacitors	
Philips (MEPCO)	Solid Aluminum Electrolytic	300°C
Custom Electronics	Mica Capacitors	300°C
Sprague	Thin Film SiO_2	300°C
KD Components	Mica Capacitors	300°C
	Transformers	
General Magnetics	Transformers	500°C
	Conductors	
Permalustre	Anodized Aluminum Wire	500°C
Hy-Temp Transducers	Ceramic Coated Copper Wire	500°C
Cermalloy	Conductor Inks	300°C
	Solder	
DuPont	High Temperature Paste	300°C
	Epoxy	
Ablestick	Conductor or Dielectric	300°C
	Transistors	
T.I.	JFET	275°C
	P.C. Board	
DuPont	Polyimide	300°C
	Packages	
Tekform	Metal Packages	350°C
3M	Ceramic packages	350°C

Table 1. Maximum operating temperature for some commercial products.

It is planned to use a magnetostrictive transmitter and a piezoelectric receiver in the logging tool design. Magnetostrictive materials usually have high Curie temperatures. For example, the Curie temperature of 2V Permendur from Arnold Engineering Company is 940°C. Not much of a problem is expected in operating at 275°C. As far as the receiver is concerned, piezoelectric materials are favored because of higher sensitivity. Both Channel 5800 (Curie temperature >300°C) from Channel Industries and K-95 modified lead titanate (Curie temperature ≈ 500°C) from Keramos, are being studied to determine which one will perform better in the geothermal environment. Kalrez perfluoroelastomer from DuPont will be considered for use as an O-ring material. Kalrez is rated at 260-288°C.

SUMMARY

In summary, an acoustic instrument capable of operating at high temperatures is essential for accurate evaluation of the cement bond condition in a geothermal well. Sandia is developing various high temperature component technologies for use in the design of an acoustic CBL instrument for operation up to 275°C. Critical portions of the 275°C CBL instrument have been built and tested in the laboratory. Test results suggest that the instrument can operate at 275°C but that the lifetime of the output switching device is not yet satisfactory. Work, already underway, is expected to yield the desired 15-hour lifetime.

REFERENCES

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