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MONITORING OF CASING INTEGRITY IN GEOTHERMAL WELLS

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ABSTRACT

In order to gain an early warning of potential casing problems in geothermal wells, an electromagnetic instrument has been designed to log the casing condition. The Hot Hole Casing Corrosion (HHCC) instrument is capable of operation in real time in the harsh geothermal environment, at temperatures up to 320°C and at pressures up to 200 bar.

The HHCC tool's operation enables the accurate monitoring of both internal and external casing condition in the well's natural state without quenching. A major advantage that this instrument offers is the capability to detect corrosion on the external wall of the casing.

A programme of regular checks on casing condition has been instigated in several geothermal fields in New Zealand. This has proven useful in monitoring the casing integrity of geothermal wells and satisfying the operator's requirements for proving the safety of wells.

1. INTRODUCTION

The production casing string in a geothermal well can be subject to internal and external corrosion from the production or reinjection fluid on the inside of the casing and from the reservoir fluid on the outside of the casing. The casing could also be damaged by mechanical wear, particularly if the production casing is deviated from vertical, from rotating drill string in the well during drilling or workovers.

Century Drilling and Energy Services has designed and built a Hot Hole Casing Corrosion measuring tool (HHCC) which is capable of operating at 300°C for several hours. This enables the accurate monitoring of both internal and external casing condition in geothermal wells without the expense and risk associated with quenching wells as required with other corrosion logging tools.

A significant advantage of this casing evaluation technique is that the HHCC tool operates in a well's natural hot state avoiding the high cost of quenching remote wells. Possible accelerated casing corrosion, due to contact with cold oxygenated water from the quenching operation or mechanical failure caused by thermal shock is no longer a constraint on a casing monitoring programme.

The major advantage this type of tool offers over other types of casing evaluation tools is the capability to detect corrosion on the external wall of the casing. Early detection of external corrosion enables preventative measures to be taken prior to a hole developing in the casing, which could lead to a well blow out. Early detection may also enable redesign of casing materials or cement grouts for future wells in a steamfield.

The Hot Hole Casing Corrosion (HHCC) tool is an electromagnetic instrument operating at low frequency which gives a qualitative measure of casing thickness. The instrument is unaffected by scale on the walls of the casing. While the HHCC log is suitable for qualitative interpretation, if baseline surveys are made at well completion, then repeat surveys can give a quantitative estimate of any metal loss.

The instrument is capable of operation at temperatures up to 320°C and at pressures up to 200 bar.

2. OPERATIONS

The HHCC instrument runs on monoconductor cable and uses 6 coils with 3 magnetic fields to measure well casing corrosion. The three magnetic fields are produced simultaneously and utilise different frequencies for optimum response. The instrument is held central in the well by the three arm roller centralisers to ensure equal recording sensitivity in all directions. At less than 200kg and 4m long the tool is easily mobilised, and is suitable for use with a small crane in remote locations.

2.1 Phase Shift

The lowest frequency uses phase shift to measure mass of metal. For this measurement the transmitter and receiver coils are spaced sufficiently far apart to ensure the main coupling between them is via the metal of the casing. The phase shift between the source and receiving coil is compared. By measuring reductions in phase shift reductions in casing wall thickness can be estimated. Both the received amplitude and the phase delay, caused by eddy currents in the casing, are measured to determine the casing thickness. The frequency of the phase shift detector is low enough for the magnetic field to investigate beyond the production casing and into the anchor casing. Phase shift is measured from 0° to 360° and plotted on the graphs (Figures 3-5) with decreasing phase and therefore metal loss to the left, and increase in metal mass to the right.

2.2 Differential Caliper

The differential caliper is an internal diameter proximity sensor that measures the casing internal diameter with a technique similar to conventional metal detectors where the presence of metal alters the resonance of a tuned circuit. The tuned circuit is driven at a constant frequency and the variation in amplification, which is proportional to the casing internal diameter, is measured. The differential output is the average internal diameter of the casing over a small interval, typically 100mm. The differential caliper is shown in Figures 1-3 with decreasing internal diameter to the left. Increasing diameter is to the right, and clearly shows the casing collars.

2.3 Roughness Indicator

The roughness indicator (RI) operates from a transmitting coil located centrally between two symmetrically placed receiver coils. The receiver coils are wired together out of phase to cancel out and only produce an output when there is a non-symmetrical magnetic coupling. This occurs when there is a break in the magnetic path due to a crack or joint in the casing. The RI is used to detect cracks, pitting, and drill string damage. Although the RI does not measure internal diameter it effectively examines the casing wall for small faults not detectable by the averaging of the differential caliper. The trace produced by the RI increases in width as the casing roughness increases.

External casing corrosion is inferred from the phase shift and the differential caliper. If the phase changes indicating a change in the mass of metal the differential caliper will show if the metal loss is from the internal diameter. If the metal loss is from external corrosion, then the differential caliper will remain constant showing the internal diameter of the casing has not changed.

The electronics are housed in a vacuum flask for temperature protection, while the sensors remain at the temperature and pressure of the geothermal environment. A low power microprocessor combined with a purpose built DC switch mode power supply keeps power consumption to a minimum giving an extended downhole time. The internal temperature of the electronics is monitored and available to the operator at the surface so that the tool can be powered down if internal heating is beyond acceptable limits.

3. CASING SIZES

A range of casing sizes can be logged using interchangeable coil sets. One set of coils is suitable for logging 7 $^{5}/_{8}$" to 9 $^{5}/_{8}$" casings and a second set of coils suitable for 10 ¾" to 13 $^{3}/_{8}$" casings. A 265mm coil set is available for casing diameters larger than 13 $^{3}/_{8}$" as a cold well option, for up to 200°C. The HHCC instrument is held central in each casing size by the adjustable three arm roller centralisers.

4. INTERPRETATION

In the following examples of actual HHCC logs the interpretation of the instrument output can be demonstrated.

Figure 3. The phase shift shows there is metal loss at 397m and 405m in the 9 $^{5}/_{8}$" production casing. On the phase trace the screwed collars show as a twin peak. Metal mass increases where the collar is screwed onto the casing. The double peak is caused when the transmit HHCC coil and then the receive coil passes through the region of increased metal. The caliper shows a decrease in internal diameter at 405m where the casing thinned by corrosion has been deflected inwards. The roughness indicator (RI) trace shows the width increasing as the casing roughness increases. Casing collars produce a characteristic tick in both directions as the coils pass over the gap between joints. The RI shows that the inside surface of the casing is pitted at both 397m and 405m.

The amplitude of the response indicates that that the casing is penetrated but not completely corroded away at 405m.

Figure 4. This example shows the 13 $^{3}/_{8}$" anchor casing set to 270m and 9 $^{5}/_{8}$" production casing. The log from 225m to 270m is the sum of the anchor casing plus the production casing. Metal loss in the dual string is evident between 247m and 251m. The lack of significant change in internal diameter, and no change in roughness indicated from the RI, allows us to infer that the corrosion is on the outside of the anchor casing. There is the possibility that the corrosion is between the casing strings, but this is unlikely given that the strings are cemented together and corrosion would have to penetrate beyond the anchor casing first.

Figure 5. This is an example of casing damage in a 9 $^{5}/_{8}$" production casing, between 782m and 785m. The decrease in phase shift shows a split casing collar that has developed in the well after completion and could have been the result of an earthquake or from stress during heating of the well. This well has been previously logged and so comparisons can be made. A phase response that is much lower than previous logs and double differential calliper response shows a radially split casing collar, but the casing joint has not completely pulled apart.

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Figure 1. HHCC Tool at wellhead.

Table 1. HHCC Tool Specifications

	HHCC		
Casing Size	**Diameter (mm)**	**Length (m)**	**Weight (kg)**
7 $^5/_8$" to 9 $^5/_8$"	140	3.96	182
10 ¾" to 13 $^3/_8$"	215	4.05	186
Over 13 $^3/_8$"	265	4.05	188

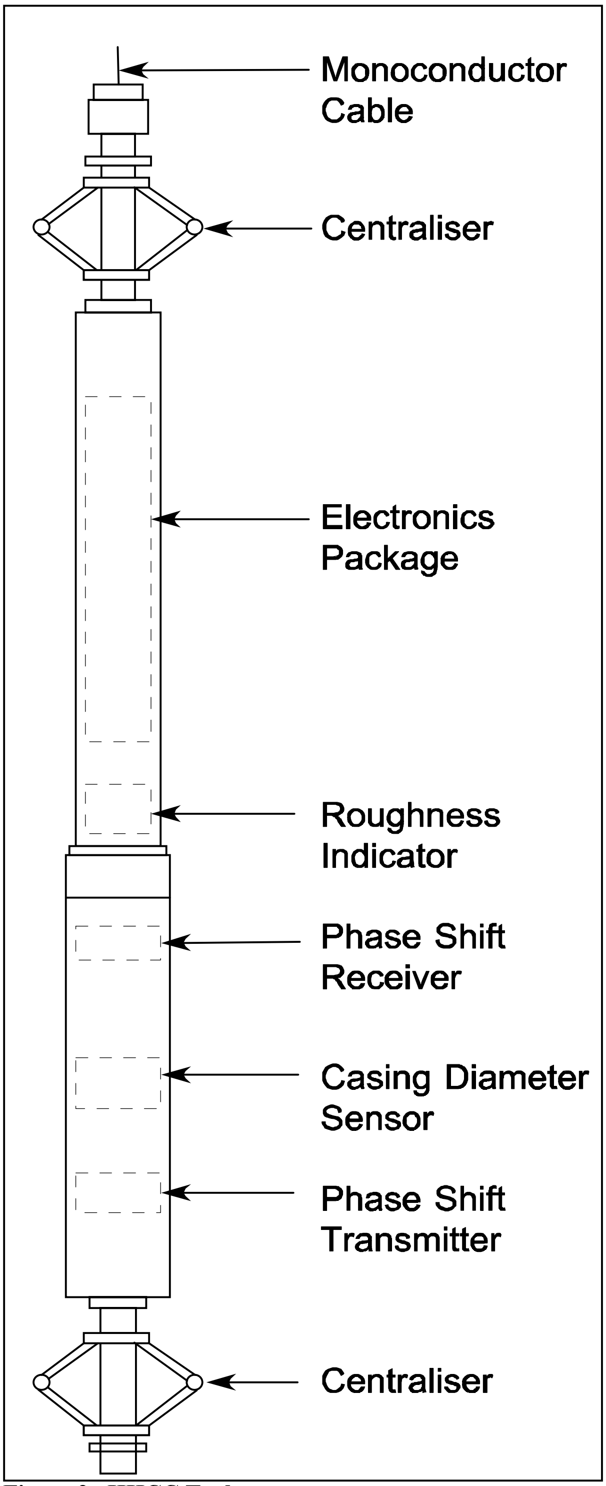

Figure 2. HHCC Tool

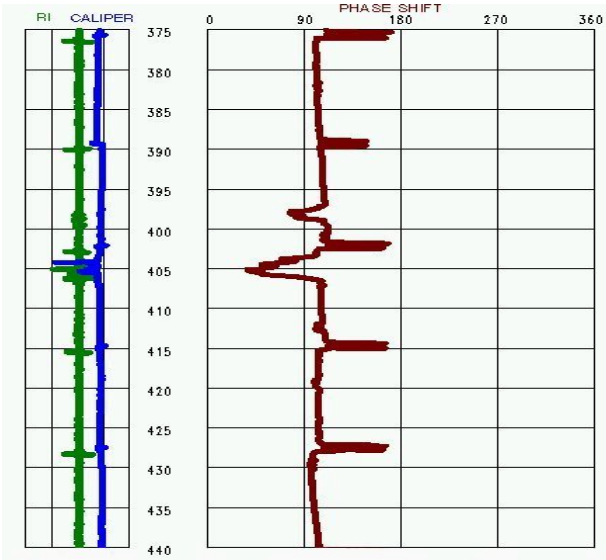

Figure 3. Metal loss in 9 $^5/_8$" production casing

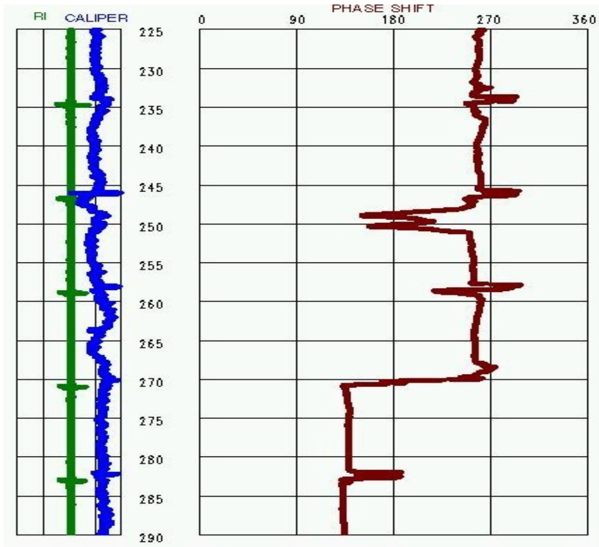

Figure 4. Metal loss in 13 $^3/_8$" anchor casing

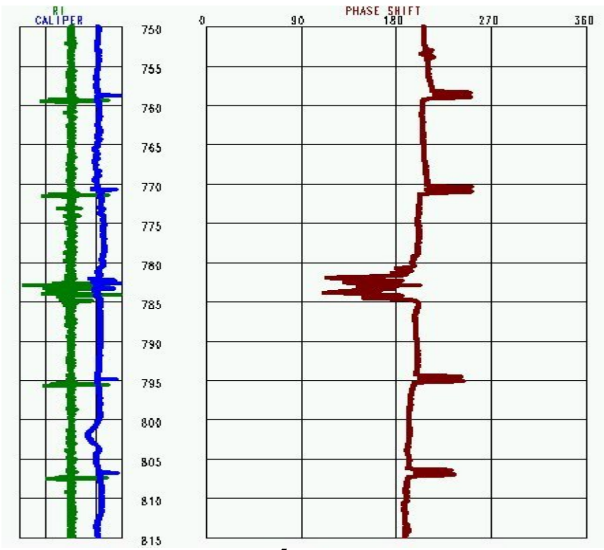

Figure 5. Split collar in 9 $^5/_8$" production casing