SAND--81-2542

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Category UC-66c

HIGH-TEMPERATURE GEOTHERMAL CABLEHEADS

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ABSTRACT

Two high-temperature, corrosion-resistant logging cable-heads which use metal seals and a stable fluid to achieve proper electrical terminations and cable-sonde interfacing are described. A tensile bar provides a calibrated yield point, and a cone assembly anchors the cable armor to the head. Electrical problems of the sort generally ascribable to the cable-sonde interface were absent during demonstration hostile-environment loggings in which these cableheads were used.

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INTRODUCTION

The data generated by a downhole logging sonde is communicated to the surface through an electromechanical logging cable. The cable is typically comprised of one or more insulated conductors surrounded by a double, contra-helically wound layer of high-strength wire (the armor). The armor is the strength member of the cable and supports the weight of the entire downhole package. The strength of the armor is great enough to allow for additional pulling should the sonde become lodged in the well. The interfacing of both the mechanical strength and the electrical conduction paths between the cable and the sonde is provided by the cablehead.

In geothermal wells, hostile conditions related to temperature, pressure, and corrosive chemicals are encountered. Insulation of the electrical conductors throughout the length of the cable and at the cable-sonde interface is essential for reliable data acquisition. The design of two cableheads capable of operating at 275°C at 20,000 psi in corrosive brine solutions for more than 250 hours is reported herein.

Design Considerations

As part of the overall Geothermal Logging Instrumentation Development Program*, Sandia worked with Gearhart Owen Wire-

*This work sponsored by the U.S. Department of Energy.

line Services to develop single-conductor and seven-conductor cableheads for use by the geothermal industry at temperatures up to 275°C and pressures to 20,000 psi in corrosive brine fluids. A basic guideline was the modeling of the cableheads after existing designs used by well-logging service companies in their low-temperature work.

Problems which have been identified with the existing low temperature heads are: 1) elastomeric O-ring seals that have low reliability in hostile geothermal wells, 2) light-weight greases used as a fluid barrier at the point of electrical termination, and 3) the use of materials that are not corrosion resistant in hot brines. At high geothermal temperatures the elastomeric materials generally lost mechanical strength and thus sealing ability; the greases melt and are displaced by well fluids which results in high electrical leakage and limited, if any, data acquisition; and the standard metals lose tensile strength and become brittle.

The problem with the O-ring seals was solved by using metal gasket seals; there are many metal seals capable of sealing against pressures of 20,000 psi at temperatures considerably above 275°C. However, the sealing configurations that must be employed with metal gaskets are different than with elastomeric O-rings. Stretching of the gasket to get it into position is not possible and rotation of sealing surfaces on the sealing device is not allowable with metal seals. In addition, the natural cleaning action on the elastomeric O-ring cannot be obtained with a metal sealing

device. Although the use of metal seals leads to some incompatibility with existing service company tool housings, the resulting reliability is more desirable.

The problem with the lightweight greases was resolved by the use of an insulating fluid (KrytoxTM, a fluorinated oil manufactured by Dupont) that has almost twice the density of pure water, is chemically stable at high temperature, does not readily absorb water, and has good wetting characteristics to both the cablehead and the feedthrough materials.

The bulk of each cablehead is made of a corrosion resistant alloy (K-monel) which is capable of withstanding temperatures greater than 350°C in brine solutions for extended periods of time without becoming embrittled or losing mechanical strength. The electrical feedthroughs, made of nickel-plated Kovar and ceramic, are rated to better than 500°C.

The design of each cablehead incorporates a tensile bar configuration to provide for a calibrated breaking strength. By changing to a different tensile bar, which provides the mechanical connection of the lower section of the cablehead to the upper section, the breaking strength of the cablehead can be altered. Electrical termination of the cable conductors is provided in the lower section of the cablehead while all of the cable armor wires are terminated to the head in its upper section using a cone clamping configuration.

The Single-Conductor Cablehead

Figure 1 shows the basic sections of the single-conductor cablehead. The upper section has 45° beveled edges for a streamlined geometry and a stinger at the top that is easily grippable by fishing tools. This top stinger would be used for fishing purposes if the cable were to break and the cable and sonde were lost in the hole. Just below the top stinger is the mechanical termination point. The cable anchor assembly is composed of a pair of cones and an outer body. As seen in Figure 2, there are two layers of armor wire, one of which is sandwiched between the surfaces of the outer body and the larger cone, and the other is sandwiched between the large and small cones. As pull on the cable increases, the cones are pulled into the outer body and securely grip the armor wires. The outer body rests against the walls of the upper section and transmits the load-carrying capability of the cable to the cablehead. At this point, the full breaking strength of the cable is still available.

The tensile bar, which connects the upper stinger to the lower stinger, serves as the weak point in the head. The bar is milled to a point where it has a calibrated breaking strength which is less than the breaking strength of the cable. Should the lower section of the head or tool sonde become lodged in the hole, the cable and upper section can be removed from the well by pulling hard enough to break the tensile bar, thereby releasing the upper section from the lower section. The lower stinger can subsequently be gripped

Figure 1. Single-Conductor Cablehead

Figure 2. Cable Anchor Assembly

by fishing equipment in order to remove the tool. (Since wirelines used in fishing efforts have much higher breaking strengths than do logging cables they are considerably more effective in dislodging a stuck tool.)

An anti-rotating key, shown in Figure 3, is used to prevent the top stinger from rotating relative to the lower stinger. This prevents separation of the two parts due to unscrewing of the tensile bar--it also prevents the tensile bar from being screwed up tight enough to be damaged or broken due to excess torque. In addition, to prevent damage to the tensile bar due to excess compression between upper and lower sections of the cablehead, an anti-compression block is used between the end crossbars of the tensile bar. This anti-compression block is shown in Figure 4. Compression of the cablehead assembly is necessary during the seating of the metal gaskets used and excess compression could also be incurred if an obstruction or the bottom of the well were encountered at high speeds.

The single conductor passes through the upper stinger, the tensile bar, the lower stinger and into the termination cavity. Sufficient insulation is stripped away to make a solder joint between the nickel-plated Kovar conductor and the terminal assembly. A 309°C eutectic solder (1.5 to 2.5% Ag) is used for reliability and ease of application. The terminal assembly is slipped over the high-pressure feedthrough and screwed into place ensuring a good electrical connection.

Figure 3. Anti-Rotation Provisions

Figure 4. Anti-Compression Block

Provision must be made to seal out the wellbore fluid from the exposed portions of the conductors, since its presence would result in the shorting of the conductor to the cablehead and armor which are acting as the ground return path for the sonde instrumentation. A filler hole and path are provided as shown in Figure 3 so that an insulating fluid with the required properties can be injected at the bottom of the termination cavity. Enough fluid is injected to cover the terminal assembly, but, to prevent unnecessary loss due to thermal expansion, not enough to fill the cavity. Typically, a small quantity of fresh oil is injected prior to each logging run.

The final step in making up the head is to secure the high-pressure bulkhead. The hydraulic unit, seen in Figure 5, is used to properly install the metal seal. To prevent the bulkhead from rotating on the seal, an anti-rotation pin is used. Care must be taken that all sealing surfaces are clean and not marred. The cablehead is complete when the seal has been set with the proper compressional force and the seal retaining collar tightened.

When attaching a sonde to the head, the hydraulic unit is once again used to set a final metal seal to protect the head-sonde interface area from fluid incursion, and the quick change nut is used to mechanically connect the sonde to the head.

Figure 5. Hydraulic Unit for Metal Seal Installation

The Seven-Conductor Head

Although the same basic design needs exist for the multi-conductor head as for the single-conductor head, the actual geometry of the head is different, as seen in Figure 6. Tools using the seven-conductor cable are, in general, heavier tools used in noncased wells. Because of the increase in weight, a stress-relief spring is used to reduce the chance of cable damage at the head during uphole handling. The spring is tapered and the cone housing is beveled to streamline the head. This streamlining helps prevent the head from becoming lodged in the well due to sidewall irregularities or abrupt changes in the casing profile.

Termination of the cable armor is accomplished within the cone housing. Each layer of armor wire is securely gripped by the clamping action of a cone against a second cone wall. Due to the geometry an increased pull on the cable results in greater wedging forces between the cones and wires. The full breaking strength of the cable is guaranteed at this termination when the armor wires and cones are wedged into position. The cone tightening sub is provided to prevent the cone assembly from backing off during the initial head assembly. This "backing off" will not occur once the assembly has been set. The setting is usually accomplished during a verification pull test on the head after the assembly is complete. To prevent the cone housing and tightening sub from backing off and separating, a cap screw is installed as indicated in Figure 6.

Figure 6. Multi-Conductor Cablehead

The cone tightening sub is connected to the stress bar which in turn is connected to the connector sleeve via the tensile bar. Torque damage is prevented by the locking sleeve due to its hexagonal geometry which prevents rotation of the two sections. A spring pit is used to prevent the locking sleeve from riding up and leaving the connector sleeve free to rotate. The flexure strength of the upper section of the head is provided by the outer sleeve which spans from the cone housing, past the tensile bar, to the connector sleeve. Since the outer sleeve is secured to only the lower section of the head, the upper section of the head could be removed from the well should the tensile bar break. Fishing grooves are provided as an aid in gripping and removing the cablehead section and connected sonde from the well.

The cable conductors are passed through the cablehead sections, around the tensile bar and into the termination cavity. Each conductor has just enough insulation removed so that it may be soldered to a threaded connector. This threaded connector construction allows for easy removal of conductors from the high-pressure bulkhead. The bulkhead has seven metal and ceramic high-temperature feedthroughs, and is sealed to the connecting sleeve with a metal seal. This metal seal is set with the aid of a hydraulic compression unit and then a retaining collar is screwed into place to secure the seal. An anti-rotation pin is incorporated to protect the metal seal from scarring due to seal surface rotation.

Another metal seal makes up the final cablehead-sonde interface. The hydraulic compression unit is used to set the seal in place. Again, a guide key prevents rotation, and a quick change nut secures the seal and the sonde. With the system assembled, Krytox oil or any other fluid with the necessary properties is injected into the termination cavity through the filler hole. A path is provided so the fluid fills the cavity from the bottom of the bulkhead feedthroughs upward. Enough fluid is used to cover the uninsulated section of the feedthroughs and cable conductors, with sufficient space being left to allow for thermal expansion without excessive loss of the insulating fluid.

CONCLUSIONS

Four prototype heads of both types have been fabricated. Pull tests on the armor gripping cone sections and tensile bars have been performed to verify the designs. The KrytoxTM oil has been tested in geothermal brine at 275°C and 1000 psi for over 300 hours with no evidence of chemical or physical change. Figure 7 shows the isolation resistance decreases as a function of time for the monocable configuration with a reduced conductor-to-conductor gap. These data indicate that the usefulness of the head may be extended for up to 178 days before the insulation resistance of the termination becomes a problem. The monocable head has been used for five logging runs with no problems being encountered. The

KRYTOX® STABILITY TEST IN BRINE SOLUTION

Figure 7. Insulating Fluid Resistance Change as a Function of Time

runs included one hour at 300°C, 1-1/2 hours at 275°C, 18 hours at 240°C and two continuous runs reaching 230°C. Fresh KrytoxTM was injected prior to each run to ensure proper insulation properties.

Shorting of the conductor occurred when a sonde was taken out of the well and laid down. When the tool was returned to the upright position, proper electrical communication was restored. The KrytoxTM, thus, demonstrated a good ability to displace well fluids. In addition, the KrytoxTM proved to be sufficiently viscous at temperature to reduce its loss from the termination cavity while the head was held in a horizontal position. However, preferred practice is to keep the head vertical as much as possible after injecting the KrytoxTM.

The metal seals have been used to make up more than 15 seals, with half of these being accomplished in the field. No seal failures have been detected either by use of a leak check system, or while making an actual logging run with pressures as high as 3500 psi. The hydraulic makeup system has proved to be easy to use and results in quick makeup of the metal seals. Removal of one sonde from the head and the makeup of another can be performed in less than 15 minutes. The monocable head can be removed and a new head assembly performed in 30 to 40 minutes. This means that even if head problems are encountered, the service company can be ready to start a fresh log within an hour after removing the troubled assembly from the well.

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