INNOVATIVE SYSTEM FOR THE MEASUREMENT OF TEMPERURE AND PRESSURE IN GEOTHERMAL WELLS

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ABSTRACT

An innovative system for temperature and pressure measurements in geothermal wells is described. It was developed by ENEL and CISE with the aim to operate contemporary and real-time well logging.
The system, named HELIUM 48 (Hostile Environment Light Instrumentation for Underground Measurements), can also be used inside of the drilling rods. It is based on a suitable "HostEn" (Hostile Environment) seven conductors cable in order to fulfil the following operating conditions:

- maximum depth: 4000 m
- maximum pressure: 50 MPa
- maximum temperature: 400 °C

No dewar nor other thermal shiels are employed for the probe; so it hasn't any time limit for its in-well work.
The technical features of the main components of this high performant and cost-effective system are described and the operation results are reported.

1. INTRODUCTION

The exploitation of geothermal resources with increasingly higher reservoir temperatures requires a continuous improvement both of drilling techniques and of measure systems of different physical parameters in the well.
Geothermal electrical instrumentation, commercially available for real-time well-logging, presents working limits of about 260 "C (exceptionally 300 "C) mainly due to the plastic compounds used for geothermal cable electric insulation.
These circumstances led ENEL and CISE to develop a system for contemporaneous and real-time temperature and pressure measurement, having a maximum working temperature of 400 "C, as required by operating needs of ENEL geothermal exploitation programs.

The system was developed considering the following requirement priority:

- contemporaneous and real-time temperature and pressure measure obtained by electrical transducers direct current fed, capable to operate with the foreseen working temperatures without employing dewar or other thermal shiel devices;
- limited weight and size of components to optimize the system operations with a reduced number of operators;
- measurements execution inside of the drill rod by assuming 48 mm the maximum transversal size of the components to be lowered in the well.

On the basis of these requirements and of the foresen working conditions, each system component was the object of specific investigations.
After a preliminary research on the innovating materials of interest, the different component of the system, and in particular the cable and the probes, has been designed.
The study of the innovating solutions was accompained by laboratory and field tests in order to check the success of different solutions. During the development of the system, many solutions have been modified and adjusted to reach the required performances, in order to assure the greatest reliability and to reduce working and maintenance time and costs.
In particular, the realization of the geothermal cable required equipment able to execute longitudinal plasma weldings on Incoloy or Hastelloy or stainless steel cable external sheath, without any failure for lenght up to 5000 m and not damaging the underlying insulating conductor material.
The whole system, as it is, has been carefully tested and is currently used by ENEL in high temperature geothermal logs.
The system is composed as follows:

- a cable with 7 electrical conductors, fiberglass insulated, protected inside a metallic sheath assuring a total seal from the geothermal fluid;
- a TP48 probe, equipped with a resistance thermometer and a strain-gauge pressure transducer, and with a TA48 cable-head for the connection to the cable;
- surface devices (stuffing-box, top pulley, etc.);
- a van provided with a winch for the cable lowering and rising in the well, and with a computerized equipment for the probe electrical feeding and signals acquisition and handling.

2. HOSTEN GEOTHERMAL CABLE

The HostEn (Hostile Environment) cable consists of 7 electrical conductors made of nickel-plated copper, fiberglass insulated, closed within a metal sheath having an overall diameter of 6.35 mm, 0.6 mm thick (Fig. 1)

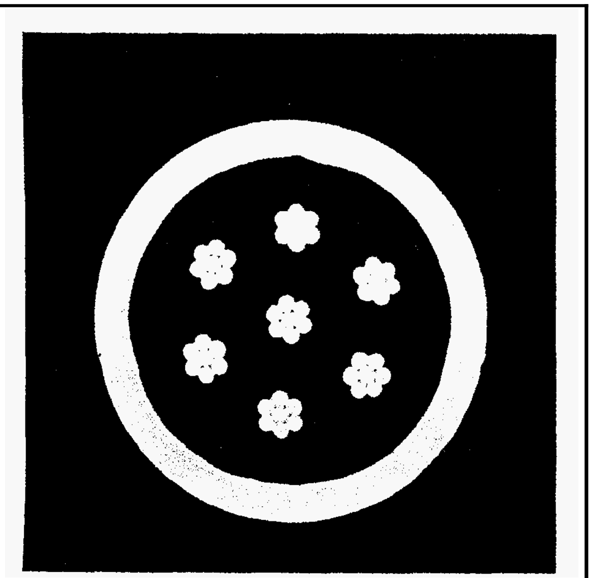

Figure 1. HostEn cable cross-section

The metal sheath is obtained **from** a ribbon through a continuous (patented) process of longitudinal moulding and welding. Besides isolating the conductors from the geothermal fluid, the sheath acts also the mechanical support of the cable and of the cable-head and probe assembly.
From the production of the metal sheath, high nickel content alloys are used. Incoloy825 is suitably used because of its mechanical characteristics and high corrosion resistance. The cable is pressurized with helium at a pressure of 10 bars.
The spool winch and the surface pulleys have a diameter of 800 mm in order to limit the bending stress on the metal sheath.
In Figure 2, we can see the fatigue characteristic of the metal sheath obtained with differet loads. by repetitive cycles of cable winding and unwinding on 2 pulleys. each with a diameter of 800 mm.
Considering the weight of the cable (1315 N/km) and of the cable-head and probe assembly (about 100 N). the minimum number of complete cycles of in-well cable operations. in relation to the well depth. is the following:

Well depth (meters)	# of cycles before failure
3000	*5750*
3500	*3700*
4000	*700*

This evaluation was carried out presuming the absence of geothermal liquid in the well. on the contrary, the hydrostatic thrust (≈ 300 N/km) determines an appreciable increase in the life of the cable
In case of a probe lock in the well, before cable recovery. **the** helium pressure inside the cable sheath is

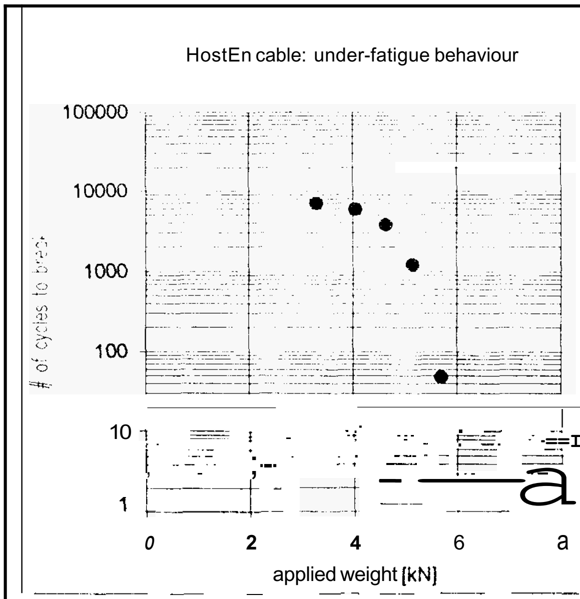

Figure 2. # of cycles to break *vs* applied weight

increased up to 200 bar, in order to prevent --or at least to delay-- **the** penetration of geothermal fluid inside the cable.
In Figure 3, we can note the influence of the operation temperature on the insulation resistance of the cable.

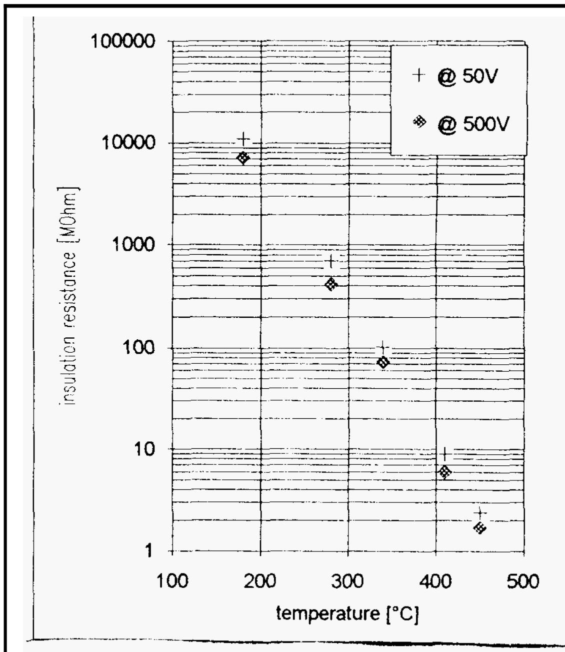

Figure 3. insulation test on a 200 m long sample

These values were obtained from tests. carried out on a cable sample 200 m long, in a temperature range from **20 up** to *500* °C. The insulation resistance is higher than **2** MOhm at **a** temperature of 400 °C and decrcascs to 340 kOhm at *500* °C.

The cable can also transniit signals in frequency. In Figure **4,** we can note the characteristic impedance of the cable, for frequencies from 0.1 to 100 kHz.

For the same frequency range, Figure **5** indicates the trend of the attenuation and of the phase, measured at room temperture on a cable, **3800** meters long, terminated with its characteristic inipedancc

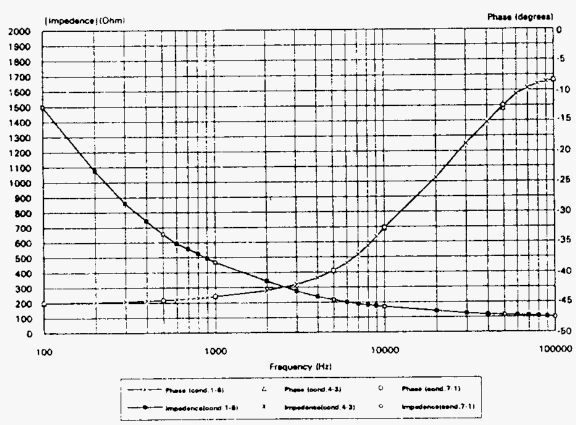

Figure 4. Characteristic Impedance of HostEn cable

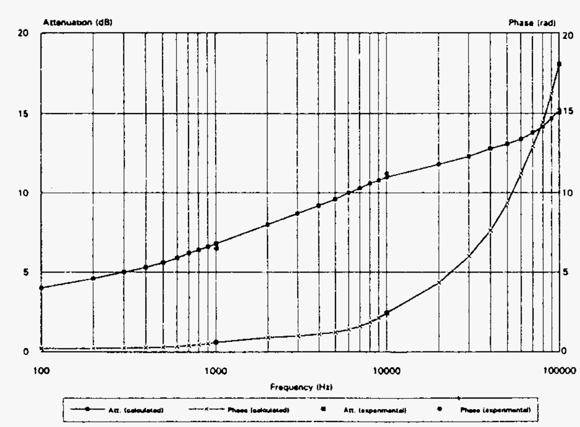

Figure 5. Attenuation and Phase of HostEn cable

3. TP48 PROBE AND ITS CABLE-HEAD

The probe is made of stainless steel **ASTM A297** gr.HT (17.4 PH), age hardened, assembled by means of laser welding in order to reduce the deformations and the areas thermally altered which are more susceptible of corrosion due to the geothermal fluid.

The probe has the following size and weight:

- Maximum external diameter: 48 mm
- Length: 593 mm
- Weight: 50 N

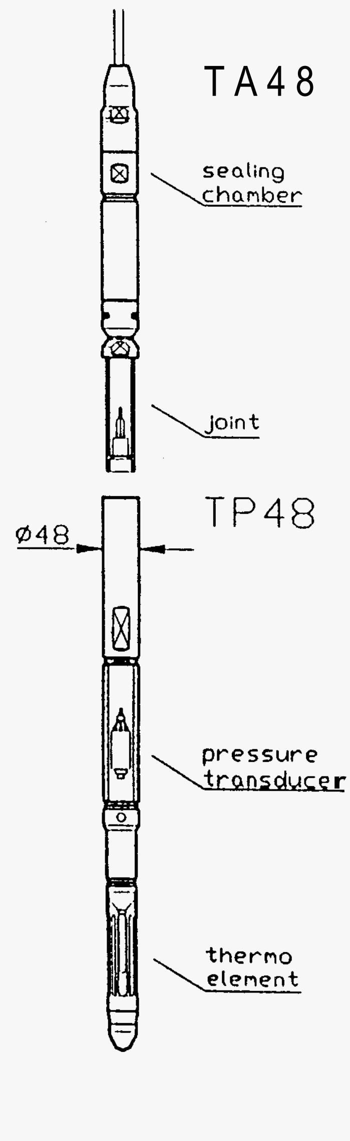

Figure 6. **TA48** - TP48 assembly sketch

It is equipped (see Figure 6) with a PT25 thermo-element and with a strain-gauge pressure transducer.
Electrical connections inside the probe are shown in Figure 7; they were designed to allow contemporaneous measurements of pressure and temperature.

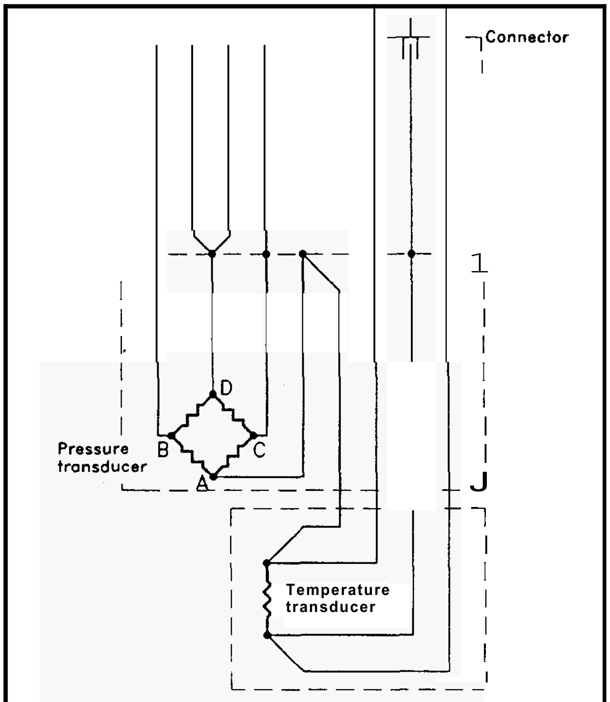

Figure 7. Electrical circuit

Different commercial pressure transducers are used in connetion with the probe maximum working temperature (up to 400 °C).
The probe is connected to the cable by means of a stainless steel ASTM A297 gr.HT cable-head, with the following size and weight:

- Maximum external diamneter: 48 mm
- Length: 593 mm
- Weight: 50 N

The cable, the cable-head and the probe are fully tight toward the geothermal fluid. Therefore, the connections between the cable sheath and the cable-head and between the cable-head and the probe are equipped with double-stage seals and with a gathering chamber (housed in the cable-head) where the geothermal fluid leakages through the first seal stage are picked-up.
The grafite gaskets, housed in the cable-head, are bounded on the cable sheath in order to seal the geothermal fluid and to obtain, by friction, the requested locking of the cable to the cable-head. The cable-head release load can be adjusted using different graphite seal length. Being the insides of the cable, of the cable-head and the probe held pressurized with helium at a pressure of 10 bar, geothermal fluid infiltration through the second stage of the seal is possible only if the gathering chamber pressure becomes higher than the helium pressure.
Disk springs were adopted in order to mantein at the correct value the graphite seals compression, taking into account the differential thermal dilatation among graphite seals and the relevant seats.
The same sealing system used between the cable sheath and the cable-head is used also between the cable-head and the probe; the geothermal fluid which gets over the first sealing stage is diverted in the same before described gatherig chamber.
The chamber, having a volume of 110 cm^3, must be emptied, typically, every 200 hours of in-well logging work.
The electrical coupling between the pins of the cable-head and of the probe connectors is frontal, with contact coil springs.

4. SURFACE TOOLS

They include:

- a hydraulically operated stuffing-box equipped with an extender pipe and a preventervalve;
- a top pulley unit driving the cable into the stuffing-box; the unit is equipped with two load celles which allow to measure the cable load without taking into account the slope of the cable between the winch and the top pulley;
- a lower pulley unit.

5. INFLUENCE OF ELECTRIC INSULATION ON THE MEASUREMENT ERRORS

Since the values of the temperature and the pressure in the well are obtained from the voltage and current measurements performd by the surface data acquisition unit, the electrical insulation of the geothermal cable plays a very important role on the log accuracy.
Taking into account that the cable insulation resistance is mainly affected by the temperature in the well, a laboratory investigation was carried out on a cable sample, 200 m long, in the temperature range from 125 up to 500 °C.
Figure 8 shows a plot of the errors in measuring voltage, current and electrical resistane, versus the cable temperature.
In the Figure, experimental data and errors calculated on a "concentrated parameters" (insulation and conductor resistances) mathematical model of the cable, are also compared.
With this model, assuming a cable length of 4000 meters with a temperature linerly increasing from 0 to 400 °C at the end connected to the probe, and assuming for the insulation and the conductor resistances the values obtained from the laboratory tests on the 200 meters sample, the errors introduced by the electrical insulation decreasing due to the cable temperature,

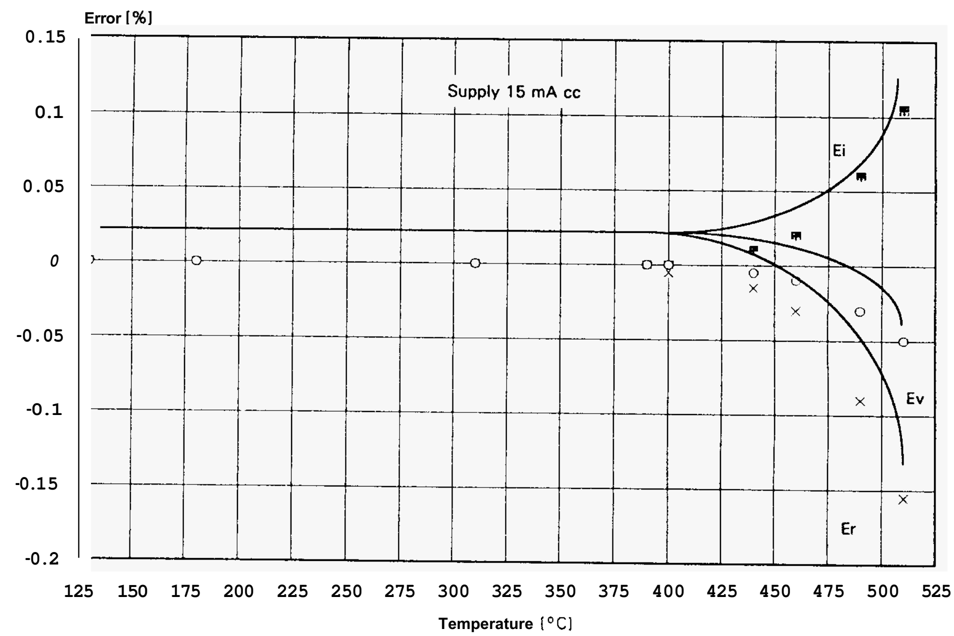

Figure 8. Experimented and calculated errors in electrical quantities niesurenients vs temperature

appear to be as follows:

- 0.2 "C for the temperature;
- 0.07 bar for the pressure. using a 500 bar full-scale pressure transducer.

6. WORKING PERFORMANCES

Before put HELIUM **48** systeni at work. more than 20 test-logs in geothermal wells were perfornied. with temperatures up to 300 "C. pressures up to 216 bar and depths of almost 2500 meters. In sum. the probe worked in-well about 600 hours.
During that in-well operation, many tests on the system were carried out. as electrical insulation. micrographical analysis on the cable sheth. volume measure of the geothermal fluid accumulated in the gathering chamber, and others.
They showed:

- a good corrosion resistance of the metallic sheath: stress-corrosion processes did not occur; rarely we saw light corrosion for pitting with a maximum depth of 0.06 mm (1/10 of tlic sheath thickness);
- **a** modest abrasive sheath process caused by the contact with the **well** walls (longitudinal scuffing with a maximum depth of 0.04 nim);
- a complete efficency of the scalings. that also provided no reduction in electric insulation at room temperature of the cable. after all the well logging test.

After the testings. the system begun working in 1994

7. CONCLUSIONS

HELIUM **48** system appears of great interest in geothernial logging for temperatures above 250 °C and in particular in the range from 300 to 400 "C.
The original solutions developed in order to:

- prevent any geothermal fuid inlet towards the cable and probe electrical circuits (double stage grafite gaskets. gathering chamber, helium pressurization of the cable and probe);
- perform, at **a** definit load, the cable-head release in case of probe locking in the well allowing the cable recovery;
- obtain also at highest working temperatures **a** stady contact between thepins of the elctrical connectors housed in the probe and in the cable-head.

have been field-tested and they assure, even at the maximum working conditions. high reliability and accuracy of the system
The use of TP48 probe inside the drilling rod, the contemporary and real-time temperature and pressure measurement which allows a log management during its execution (i.e. with a more frequent measurement in the fracture region of the well). the low weights of cable and probe make the HELIUM **48 a** very easy-to-use and a cost effective systeni for geothermal logging.