NEW DEVELOPMENTS IN GEOTHERMAL INSTRUMENTATION : THE OVERCOMING OF THE THERMAL BARRIERS

N. Adorni, A. Parmeggiani *
L. Ceppatelli and P. Rosselli +

* CISE Spa, Segrate, Italy
+ ENEL-Unità Nazionale Geotermica, Italy

ABSTRACT

The possibilities of utilization of electric probes developed for oil research in geothermal well logging are limited by high temperatures. The paper identifies two types of limits and the ways of overcoming them. A few solutions are presented and some of the probes constructed are shortly described. The maximum utilization temperature for the electric probes (as well as for the cable of connection with surface) seems to be, however, 400°C. To overcome this limit, use is proposed of optical transducers and cables permitting temperatures up to 500°C.

INTRODUCTION

Electrical well logging has been used in oil research for about half a century now. The electric instruments for well logging are particularly valuable because:

- the values to be measured are supplied only during logging so that they can direct its course;
- these instruments are the most accurate available.

Mechanical instruments are, however, still widely used thanks to their roughness, cheapness and simplicity. Conversely, they supply the results only after the lifting from the well and they are much less accurate. All available types of oil instrumentation have been used for geothermal well logging and, when required, the necessary and possible modifications, but the temperature increase in the course of geothermal research has led to the development of new instruments specially designed for this purpose. As a matter of fact, two limiting temperatures constitute the barriers to the use of electric probes. The first, at about 125-150°C prevents the use of electronics in the probes; the second, at about 260-280°C prevents the use of plastic insulating materials (FEP, PTFE, PFA) both in the probes and in the cable of connection with the surface instruments for the data acquisition. Instead, the temperature does not constitute such a strong limit for the mechanical instruments as for the electrical ones, though it requires some changes in their design and in the materials used. However, as previously mentioned, despite further improvements, the mechanical instruments are unable to supply the same accurate measurement values and real time information. For the above reasons, such instruments will be disregarded in this paper.

OVERCOMING THE FIRST THERMAL BARRIER

The objective can be achieved in three ways:

2.1 Protection from high temperatures of the probe electronics by means of Dewars. This solution may be satisfactory, though it only applies to short time well logging. It is, therefore, impossible to perform temperature surveys and well interference tests, characteristic of geothermal researhh which requires long periods inside the well.

2.2 Development of electronic high temperature components. Research is being carried out by some component producers whose results would broaden the investigation field in high temperature wells (televiewers, ultrasonic techniques, geophysical logs, etc.). Unfortunately, it will be some time before these instruments will become available.

2.3 No use of electronics in the probes. The most important instruments used in geothermal investigations can be constructed without electronic components in the probes but they are unable to perform the sophisticated geophysical logs needed in oil field investigations. Without electronic components, it is necessary to make use of direct current and analogic data transmission from the probe to the surface instrumentation. The single conductor cable cannot be used, whereas multiconductor cables must be adopted. The insulation resistances must be high enough, e.g. 1 MΩ could be an acceptable value for the cable probe set. CISE and ENEL have jointly designed and constructed various probes and related surface instrumentation using a 7-conductor cable. The whole system consists of a truck, endowed with power sources, depth gauge, winch with a 6000 m cable. On the truck is a small laboratory which houses the data acquisition system with computer and peripherals (magnetic tape unit, printer and plotter for direct log recording, etc.). The system has a few elements common to every kind of probe and a few plug-in modules, each of them specific for each probe: so that when a probe is substituted for another one the corresponding plug-in module must also be substituted. Fig. 1 shows the schematic representation of this system. The probe connection with the cable is obtained by means of a sealed coupling section 52 mm in diameter, 0.6 m long and 8.5 kg in weight. Fig. 2 shows a cutaway view of the coupling section.

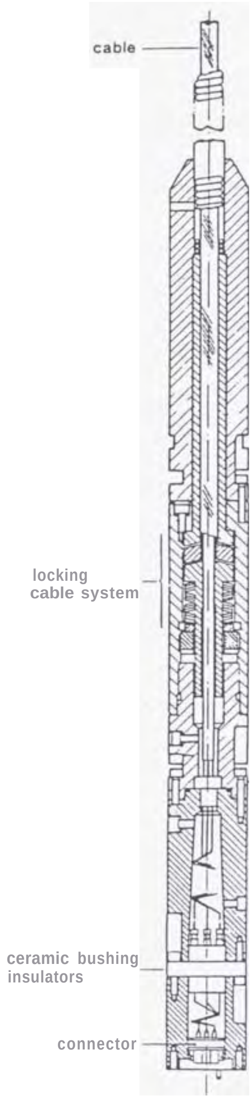
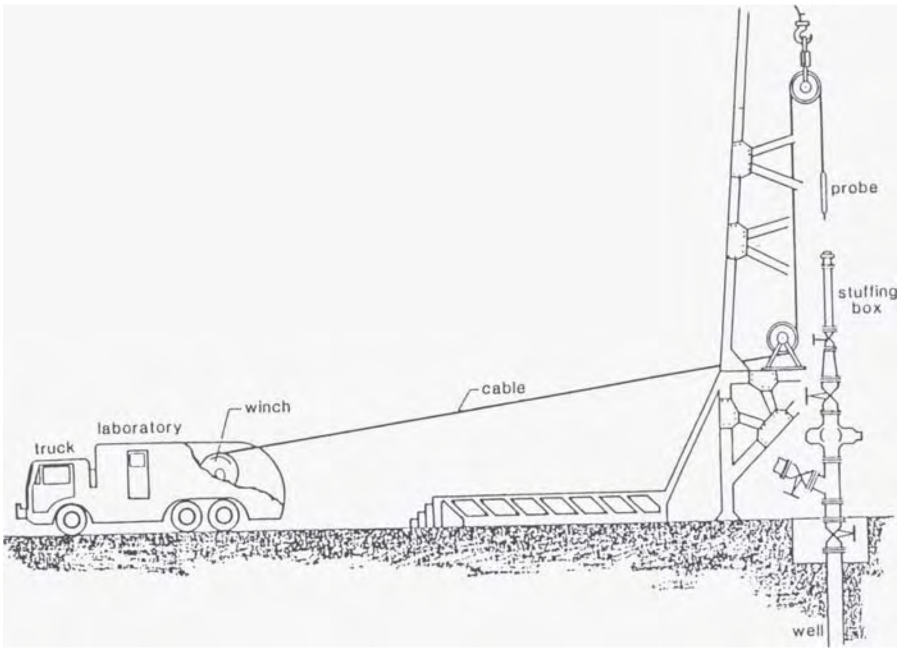


FIG. 2. Cutaway view of the coupling section.

FIG.1. Scheme of the measuring system in the field.



SHORT DESCRIPTION OF THE PROBES DESIGNED AND CONSTRUCTED

3.1 Probe for temperature and pressure measurement (TP probe)(Ref.1) The probe shown in Fig. 3 is 53 mm in diameter, 0.5 m in length and 4.5 kg in weight. Its characteristics are:

- maximum temperature 300°C;
- maximum pressure 50 MPa (500 bars) (in dependence on the transducer mounted in the probe);
- maximum depth 4000 m;
- temperature accuracy ±0.2°C;
- temperature resolution 0.01 "C;
- time sontant 6 s;
- pressure accuracy ± 0.3% of transducer capacity'
- pressure resolution 0.0004% of the transducer capacity.

The seven-conductor cable insulated with teflon, which at present connects the probe with the surface data acquisition system, restricts the probe performance to a maximum of **280°C.** The electric circuit, fed by direct current and shown in Fig.4, overcomes the electric resistance of the cable conductors and makes it possible to correct the pressure's temperature error. Since this error depends on various factors (resistance variation of the four Wheatstone bridge sides, Young module's variation of the transducer diaphragm, thermal expansion of the different transducer elements) the transducer has purposely been thermally insulated from the probe frame in order to get the same temperature as all the transducer elements. The electric circuit, endowed with the above mentioned expedient, is patented in Italy (foreign patents pending). The data acquisition system processes the signals and supplies the correct temperature and pressure values directly: in addition, it carries out the pericdical control of the insulation resistance of the whole electric circuit (including the cable) against earth. Using a voltmeter having input resistance higher than 100 kΩ, an insulation resistance of 1 MΩ

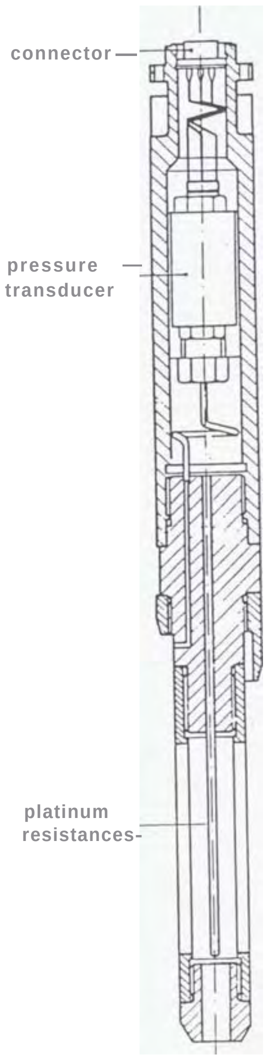


FIG.3. Probe for temperature and pressure measurement (TP probe)

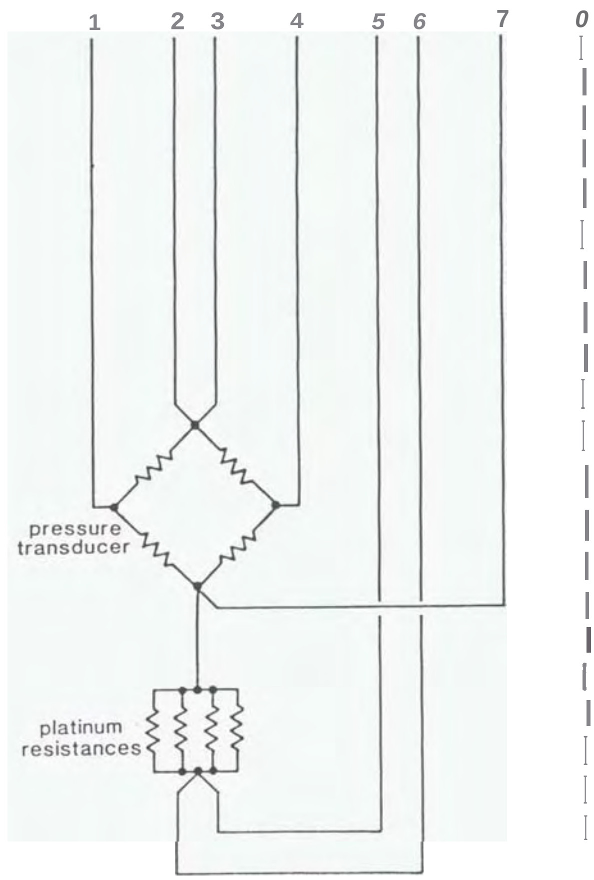


FIG.4. Measuring circuit of the TP probe

gives a 0.1% measurement error, which increases to 1% if the insulation resistance decreases to 0.1MΩ. As an example, Fig. 5. shows the automatic plot of the results obtained using this probe in an open well.

3.2 Caliper. The caliper, shown in Fig. 6, is 120 mm in diameter, 3 m in length and 160 kg in weight. It performs the simultaneous measurements of two orthogonal diameters of a borehole cross-section and of the velocity drift of the fluid emitted (during production tests) or injected (during injection tests). Its characteristics are:

- maximum temperature 250°C;
- maximum pressure 35 MPa (350 bars);
- maximum depth 4000 m;
- diameter measurements from 120 to 650 mm;
- diameter measurement accuracy ± 5 mm;
- fluid velocity accuracy ± 10%.

The diameter measurement is carried out by means of two pairs of orthogonal arms connected with two potentiometric transducers. The fluid velocity measurement is carried out using small turbines provided with three magnets that operate a reed relay. There are four small interchangeable turbines having vanes with different inclination angles for the different velocities. Fig. 7 shows the diagram of the electric circuit of the probe. The data acquisition system processes the signals and calculates:

- well cross-section area;
- flowrate.

The system is also capable of identifying the turbine rotation direction and, consequently, the flow direction. With the caliper, it is possible to identify the permeable formations crossed by the borehole.

3.3 Electric clinometer. The clinometer, shown in Fig. 8, is provided with a magnetic compass and carried out the measurement of borehole drift angles and their direction with reference to the geographic coordinates. Owing to the compass, it cannot be used in cased holes and is affected by the possible formation magnetisem. A second version with gyro-compass is being planned. The instrument is 4.4 m long and can be extended to 6.9 m, its weight is 65 kg. It is provided with three different interchangeable measurement equipments. Its characteristics are:

- maximum temperature 300°C;
- maximum pressure 50 MPa (500 bars);
- maximum depth 4000 m
- borehole diameters from 120 to 400 mm;
- drift angle measurements:

  0-15° with accuracy < ± 1°
  0-30° " " ± 1°
  0-60° " " ± 2°

- direction error ± 3°40'

Fig. 9 shows the diagram of the electric circuit of the probe. The measurement equipment can rotate around its axis so as to follow the drift direction. It is thus possible to get one drill signal instead of two orthogonal components necessary when the measurements equipment is fixed. This solution directly supplies the drift angle values, eliminates the gimballing errors and requires the minimum number of cable conductors, which is an advantage, inview of the future substitution of the magnetic compass by a gyro.

3.4. Bottom sampler. The tool, shown in Fig.10, collects fluid samples in the well at the wanted depth. It consists of a bottle and two valves, and is sent down the well with the two valves closed: when it reaches the wanted depth, an electric motor opens the two valves in order to let the fluid enter into the bottle and the air come out of it. When the bottle is filled, the same electric motor closes the two valves and the tool is lifted with the sample. The tool can be used at:

- maximum temperature 250°C;
- maximum pressure 25 MPa (250 bars).

3.5 Recovery electromagnets. These tools are used to pick up small steel objects fallen into the boreholes. In order to identify the objects, the electromagnets are provided with a load cell designed on purpose that can measure the object weight directly at the well bottom with consequent better accuracy. Four tools have been constructed having the following characteristics:

- diameter 116 mm - maximum liftable weight 600 N
- diameter 175 mm - " " " 900 N
- diameter 250 mm - " " " 1400 N
- diameter 400 mm - " " " 2000 N

Weight measurement accuracy better than ± 10%. The electric supply of the electromagnets is controlled from the surface and ranges from 0 to 300 mA. The tools can be used at:

- maximum temperature 300°C;
- maximum pressure 50 MPa (500 bars).

Figs. 11 and 12 show the 250 mm diameter tool and the diagram of the electric circuit, respectively.

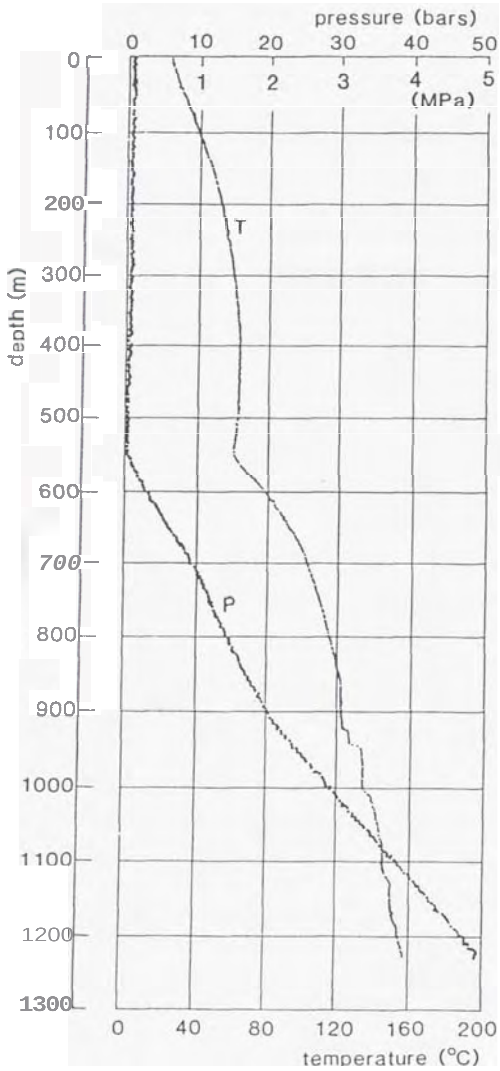
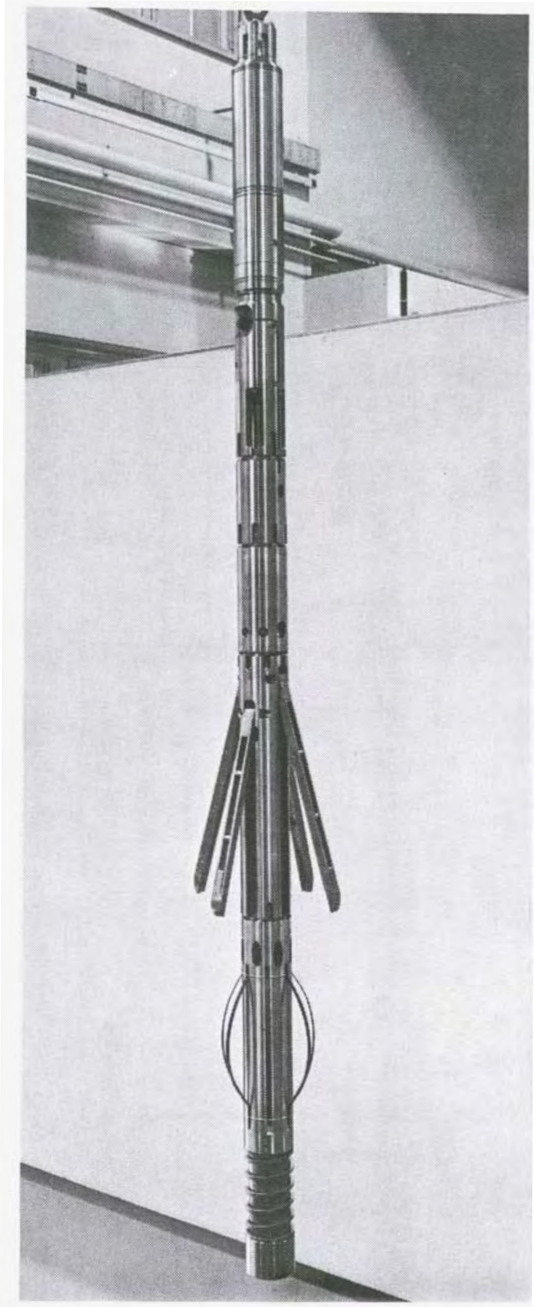


FIG.5. An example of TP log.

OVERCOMING THE SECOND THERMAL BARRIER

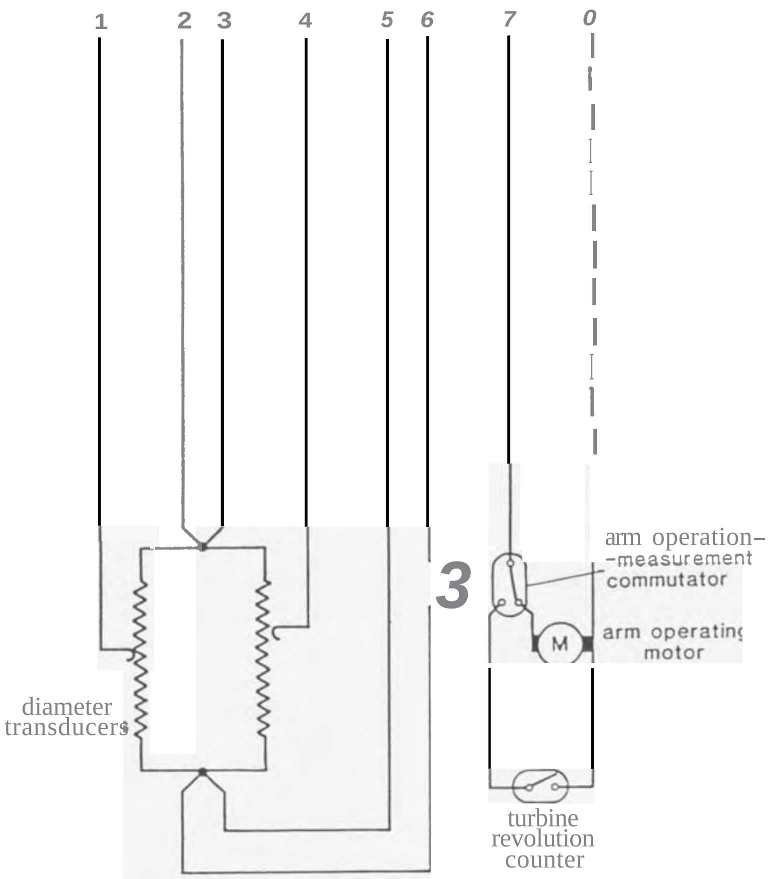
4.1 Some of the probes described so far could be already used at temperatures higher than 300°C, whereas some others could be used after the substitution of the electric insulating materials by ceramics. Unfortunately, this is not yet possible, owing to the cable available at present and to the sealed coupling section. It is, therefore, necessary to develop a watertight cable, resistant to the chemical well environment for use up to about 400°C and with sufficient insulation resistance. The insulating material cannot be other than mineral. Such a cable is under development at CISE and some hundred meters of it

FIG. *6.* Caliper



of it have already been constructed and tested. Thanks to its construction method, it can be long enough for use in the wells. It could withstand a temperature over 400°C, though with consequent decrease in the insulation resistance. This effect is, however, reversible. This cable shown in Fig 13, simplifies the design of the sealed coupling section and improves its temperature resistance. The connection is obtained using comnercial joints for tubes of the same diameter. Fig. 14 shows a macrophotograph of one of three elements of the cable.

FIG. 7. Electric circuit of the caliper



4.2. To overcome the temperature limits of the pressure transducer available at present, CISE, on ENEL comnitment, is developing thick film ceramic transducers. These transducers are also capable of supplying higher signals that, together with further possible improvement in the electric scheme, could lower the effect of the cable insulation resistance on the measurement accuracy. In our opinion, however, it seems almost impossible that electric probes can be used at temperatures over **400°C.**

INNOVATIVE INSTRUMENTATION FOR USE OVER 400°C AND UP TO 500°C

The word "transducer" is currently used to define a device giving an electric signal proportional to or at least correlated with the physical parameter to be measured. The performances of any electric transducer are strictly connected with the kind of the insulating material, which thermally speaking is the weakest component. This limitation could be overcome if a signal carrier different from electricity is used. Light can supply an interesting solution since it can be transmitted through glass or quartz optical fibre.

Since the electric insulation is not required in this case, and low loss quartz optical fibres are available on the market, a temperature of 500°C is undoubtedly achievable, provided a complete set of optical transducers for the various parameters of interest is available as well. An optical temperature probe, together with optical cable and surface electronics, is being developed at CISE. This instrument can be used up to 500°C and to a depth of 3500 m. On the frame of a financial agreement with EEC, a prototype will be tested on the field in the near future. Optical transducers for other physical parameters which can be used in geothermal investigations seem also to be feasible.

REFERENCES

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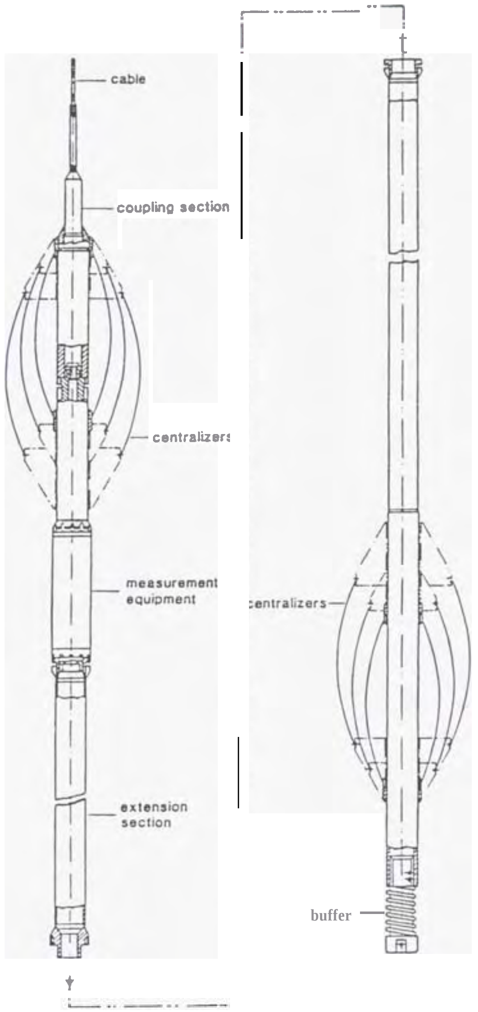

FIG. 8. Clinometer

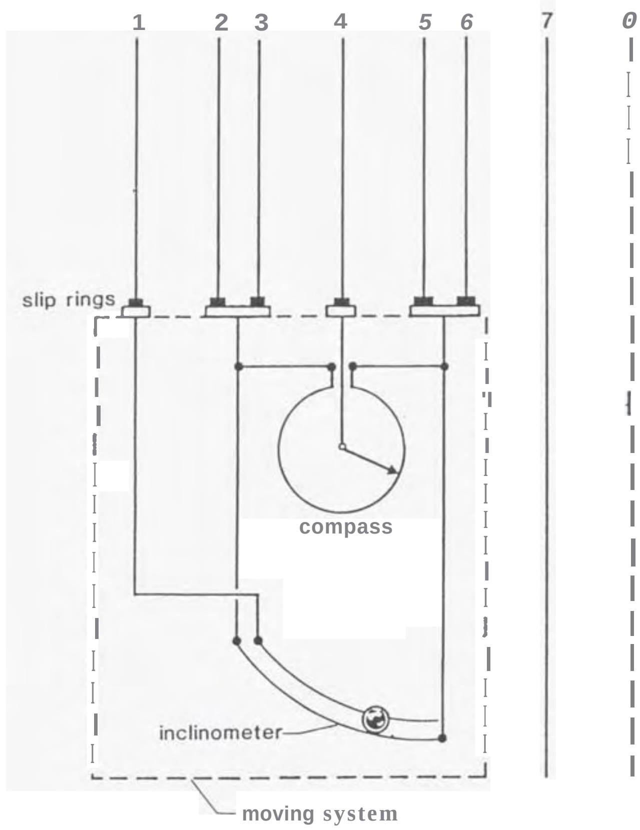

FIG. 9. Measuring circuit of the clinometer

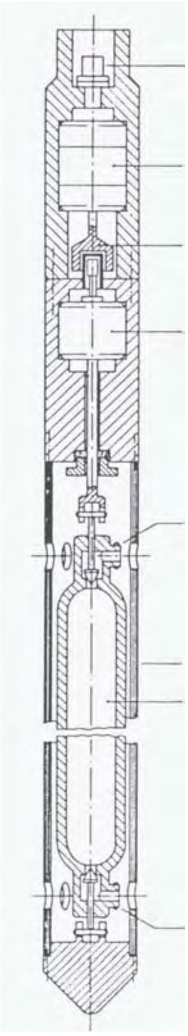

FIG. 10

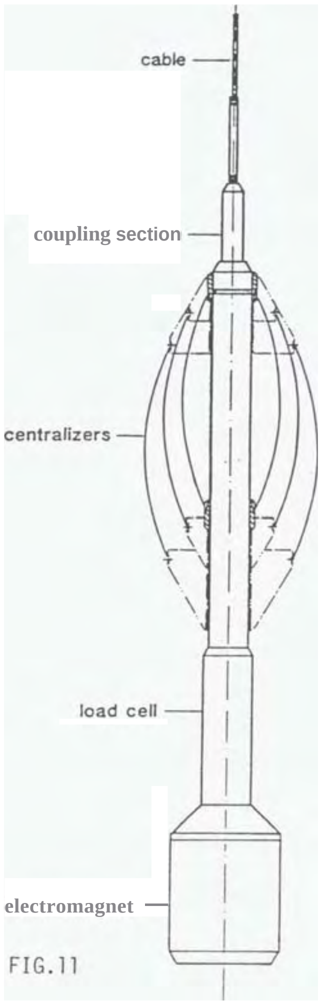

FIG.11

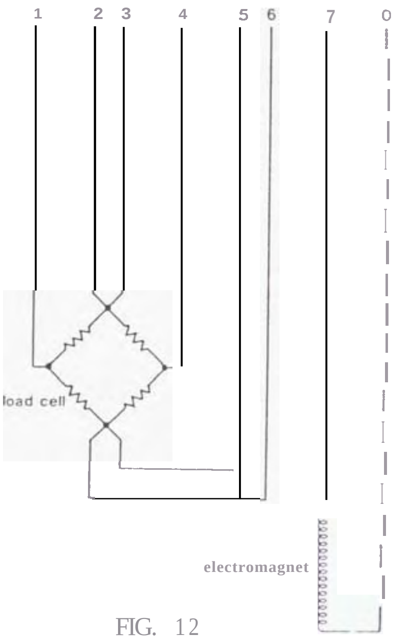

FIG. 12

FIG. 10: Bottom sampler.

FIG. 11: Recovery electromagnet 250 mm in diameter.

FIG. 12: Electric circuit of the recovery electromagnets.

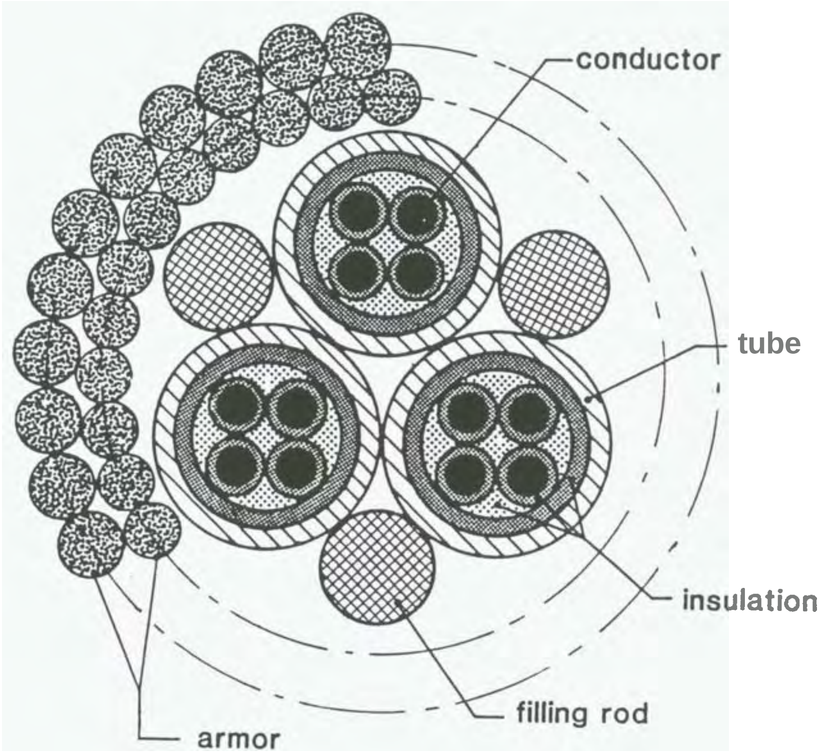

FIG. 13: **Electric cable** for 400° C.

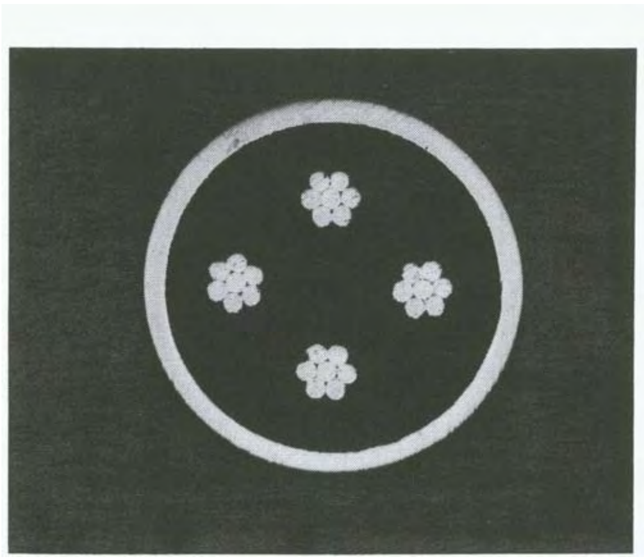

FIG. 14: **Macrophotograph** of **an element** of **the** 400° C **cable.**