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TEMPERATURE MEASUREMENT IN LIQUID METAL

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1. INTRODUCTION

The knowledge of liquid metal temperature is essential for production and quality control of steel, cast iron and non-ferrous alloys.

Molten metal temperature must be within strict limits determined and required by the metallurgical and quality department, before the heat or melt may be tapped or cast. These acceptance limits are the best compromise between various conflicting factors. A too low temperature gives raise to casting problems. A too high temperature results in extra energy consumption, increased refractory wear, decrease of eutectic cells in iron, different casting problems (break-through, various surface defects, etc.) and time losses due to holding or cooling down the molten metal.

Hence, accuracy, reproducibility and reliability of molten metal temperature measurements directly influence the quality of the end product as well as the productivity of the plant.

To control whether the desired temperature is reached, different techniques are used. Amongst the best-known methods we cite optical temperature measurement and thermoelectric temperature measurement.

Because of the influence of slag, fumes and various border conditions, optical temperature measurement of molten metal is a relatively rough method that cannot guarantee the high accuracy mostly required. Moreover, this method only measures the temperature at the metal surface.

Thermoelectric temperature measurements with noble metal thermocouples dipped in the molten metal bath actually provide the best solution. Nowadays, expendable thermocouples such as shown in fig.1 are the most economical and effective way to fulfil the required accuracy, reproducibility and reliability.

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2. PRINCIPLE OF THERMOELECTRIC TEMPERATURE MEASUREMENT

The thermoelectric effect can be explained by the theory that when warming up a metal wire at one side, the outer electrons of the metal atoms will be released and will move to the colder end. By this, the hot side of the wire will become positively loaded because of a surplus of ions, and the cold side will become negatively loaded because of a surplus of electrons (fig.2).
Already in 1821, Seebeck described the thermoelectric effect of a thermocouple consisting of two different metals warmed up at their junction point (hot junction). This discovery allowed to convert a temperature measurement into an electric measurement. Indeed, if two different metal wires are joined together at one extremity and kept at a temperature T1, an electric tension will be generated between their open extremities kept at a temperature T2 (fig.3). The so generated electric tension depends on the nature of the wires and the temperature difference between T1 and T2, and is independent from the diameter and length of the wires. If T2 (cold junction) is kept constant at a well-known stable and reproducible temperature (e.g. the temperature of a mixture of ice and water at atmospheric pressure), the generated electric tension is proportional to the temperature of the hot junction. The so obtained electric tension is a very precise measure for the temperature at the hot junction T1.

In modern digital temperature measuring instruments this electric tension is converted into pulses whose number is completely independent from the mains voltage and the ambient temperature. These modern temperature measuring instruments include an automatic cold junction temperature compensation for temperatures between 0 and 50 °C.

3. THERMOCOUPLE ALLOYS

In 1885, Henri Le Chatellier introduced the platinum / platinum-rhodium thermocouple in the steel industry. The positive wire consisted of 90 % platinum and 10 % rhodium, and the negative wire consisted of pure platinum. This composition is still used on a very large scale.

Later, different other thermocouple combinations have been introduced and normalized.

Following thermocouples are commonly used for bath temperature measurement in foundries and steel plants:

Positive leg	Negative leg	ANSI-type	Temp. range
PtRh10%	Pt	S	- 50 to 1767 °C
PtRh13%	Pt	R	- 50 to 1767 °C
PtRh30%	PtRh6%	B	0 to 1820 °C

The choice amongst these depends on the temperature to be measured, the calibration of the measuring instrument and the available compensating wires.

The chemical composition of compensating wires is such that at temperatures below 200 °C the same thermoelectric voltage is generated as the related thermocouple. Compensating wires are used to reduce the length of expensive noble metal thermocouples to the strict minimum.
For type S and R thermocouples, compensation wires made of copper (positive leg) and copper-nickel (negative leg) are used. For type B thermocouples, compensation wires made of copper are sufficient.

A typical thermoelectric temperature measuring circuit is shown in fig.4.

4. POSITHERM EXPENDABLE THERMOCOUPLES

Fig.5 shows a cut-away view of a standard Positherm immersion thermocouple.

It consists of:

- thermocouple wires, which are rigorously selected in order to guarantee an accuracy of 0 to + 3 °C at 1554 °C (Pd melting point). Positherm thermocouples are available in type S, R or B calibrations.

- a quartz tube, protecting and positioning the thermocouple wires.

- a compensated connector, assuring good contact between the thermocouple and the contact block mounted on the immersion lance.

- a ceramic housing, protecting the thermocouple assembly.

- refractory cement, insulating the thermocouple wires and the cold junction so that its temperature remains below 200 °C during the measurement.

- a metal cap, which protects the quartz tube during transport and avoids that slag may adhere to the quartz tube when passing through the possible slag layer on top of the molten metal. This cap is made of steel for application in steel melts. For application in low temperature steel, cast iron and aluminium alloys, it is made of aluminium. A copper cap is used for measurements in copper alloys.

- a cardboard tube, protecting the contact block, probe holder and compensated inner cable during the measurement. Cardboard tubes are available in different lengths to suit different applications.

5. DIFFERENT TYPES OF POSITHERM THERMOCOUPLES

For particular applications other variants of the Positherm immersion thermocouple are available:

- Positherm Non-Splash thermocouples (fig.6) have a supplementary non-splash layer around the cardboard tube to protect the operator against metal splashes caused by the inevitable humidity in the cardboard tube. Positherm Non-Splash is recommended for these applications where the operator is close to the liquid metal, e.g. when measuring in small furnaces and ladles.

- Multi-Stik and Maxi-Stik (fig.7) are specially designed for multiple readings in slag free ferrous and non-ferrous metals. A refractory fibre sleeve insulates and protects the internal components of the probe. It is splash free for maximum safety.

- Positherm Multi-Immersion thermocouples (fig.8) are designed for multiple readings in small, slag free melts in which it is desirable for metallurgical reasons to dip nothing into the melt but the quartz tube. For that reason, they have an extra long U-bent quartz tube protecting the thermocouple.

6. THE THERMOELECTRIC MEASURING CIRCUIT

Besides the thermocouple, following elements form part of the thermoelectric measuring circuit :

- the immersion lance (fig.9) used to dip the thermocouple into the molten metal. It consists of :
    - a contact block assuring electrical contact between the thermocouple insert and the compensated cable in the lance
    - a probe holder to support the thermocouple
    - a lance body of an appropriate length depending on the application
    - a compensated (for type S and R thermocouples) heat resisting inner cable to make the connection between the contact block and the back of the lance
    - a handle enabling manipulation of the lance and incorporating a juction box for connecting the inner cable to the extension cable

- the compensated extension cable (for type S and R thermocouples), connecting the immersion lance to the measuring instrument

- the temperature measuring instrument, for evaluating the measuring signal and displaying the molten metal temperature value

7. TEMPERATURE MEASURING INSTRUMENTS

Nowadays, molten metal temperature measurement is done by means of digital instruments equipped with a system for automatic cold junction compensation. As said before, thermoelectric temperature measurement compares the electric tension generated at the hot junction of the thermocouple with the electric tension generated by a well-known stable and reproducible temperature (0 °C) at the cold junction. Therefore, temperature measuring instruments are equipped with sensors that measure the ambient temperature at the cold junction and automatically compensate for its deviation from 0 °C. Compared to the former analogue instruments, the accuracy is improved and the measured temperature is displayed by means of large, easy to read digits.

Fig.10 shows Heraeus Electro-Nite's Digitemp-E for high precision molten metal temperature measurement. It is specially designed to work under tough conditions, such as encountered in foundries. The measuring sequence is clearly displayed with 3 signal lights indicating "ready to measure", "measuring" and "end of measurement". The instrument has a TTY 20 mA-output to transmit measurement information to a remote printer, display or computer.

For small melting furnaces and ladles, Heraeus Electro-Nite offers the portable temperature measuring instrument Digilance III (fig.11), powered by a rechargeable battery. The measured temperature value remains displayed for one minute, after which the instrument automatically switches off to save the battery. All Positherm thermocouples up to a length of 400 mm can be used with this instrument. If Positherm Multi-Immersion thermocouples are used, it is recommended to protect the probe holder by means of a cardboard sleeve.

Besides these basic instruments, Heraeus Electro-Nite offers a variety of different combined measuring instruments, e.g. molten metal temperature and thermal analysis, temperature and active oxygen, temperature and liquidus temperature (steel), etc.

7. CONCLUSIONS

Nowadays, molten metal temperature measurement is almost exclusively done by means of expendable thermocouples in combination with appropriate hardware and digital temperature measuring instruments. The measurement is easy and requires no special skill. The temperature result is obtained within ca. 6 sec with an accuracy in the order of 0 to + 3 °C.

A variety of different thermocouples, lances, cables and measuring instruments is offered by Heraeus Electro-Nite to suit different applications.

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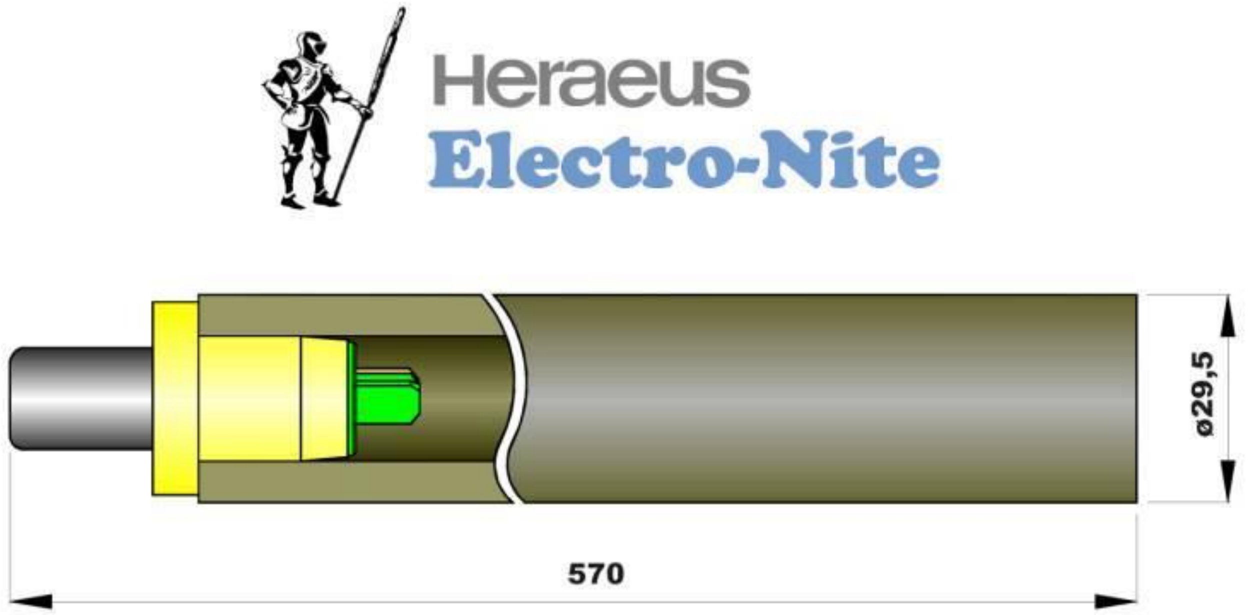
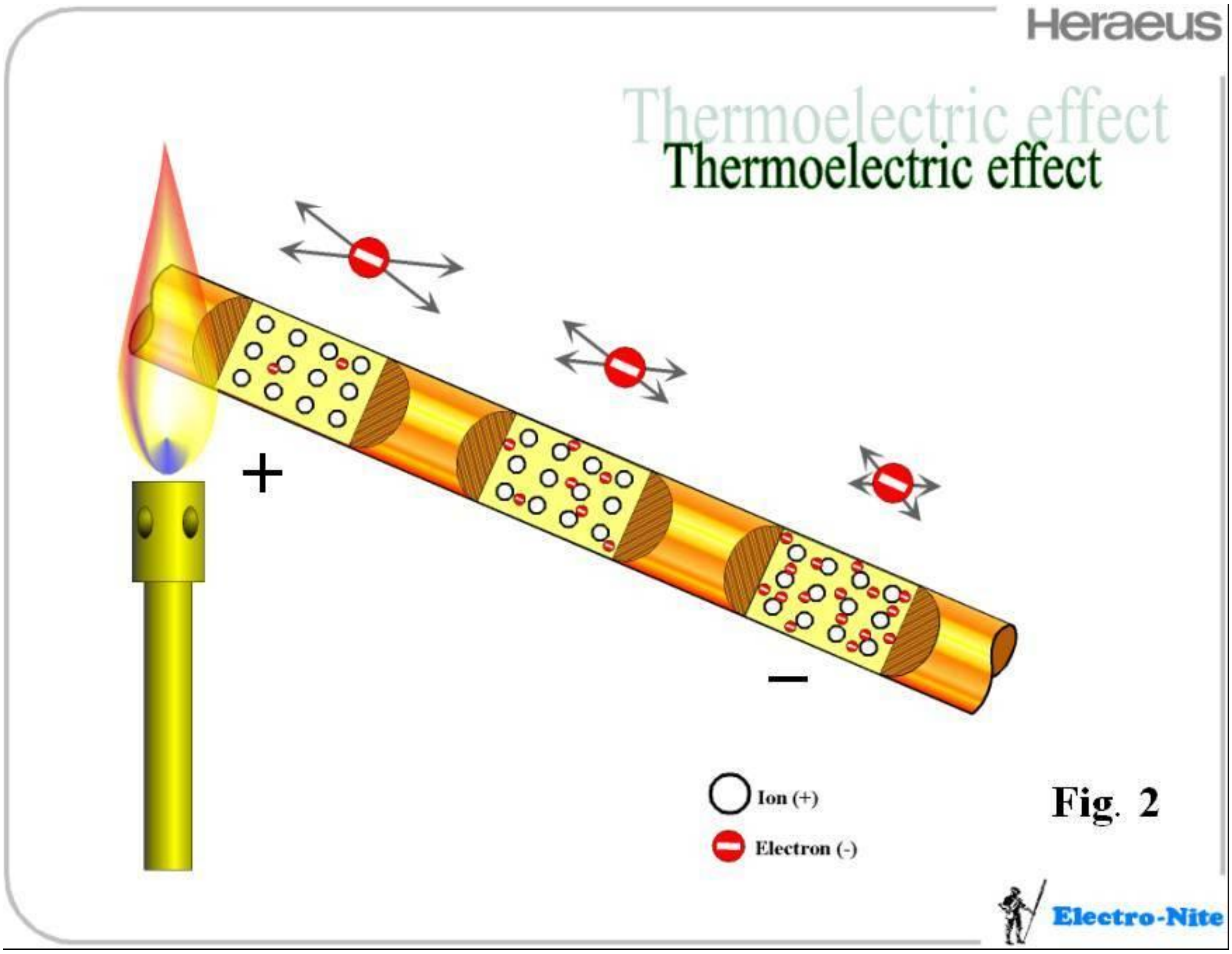
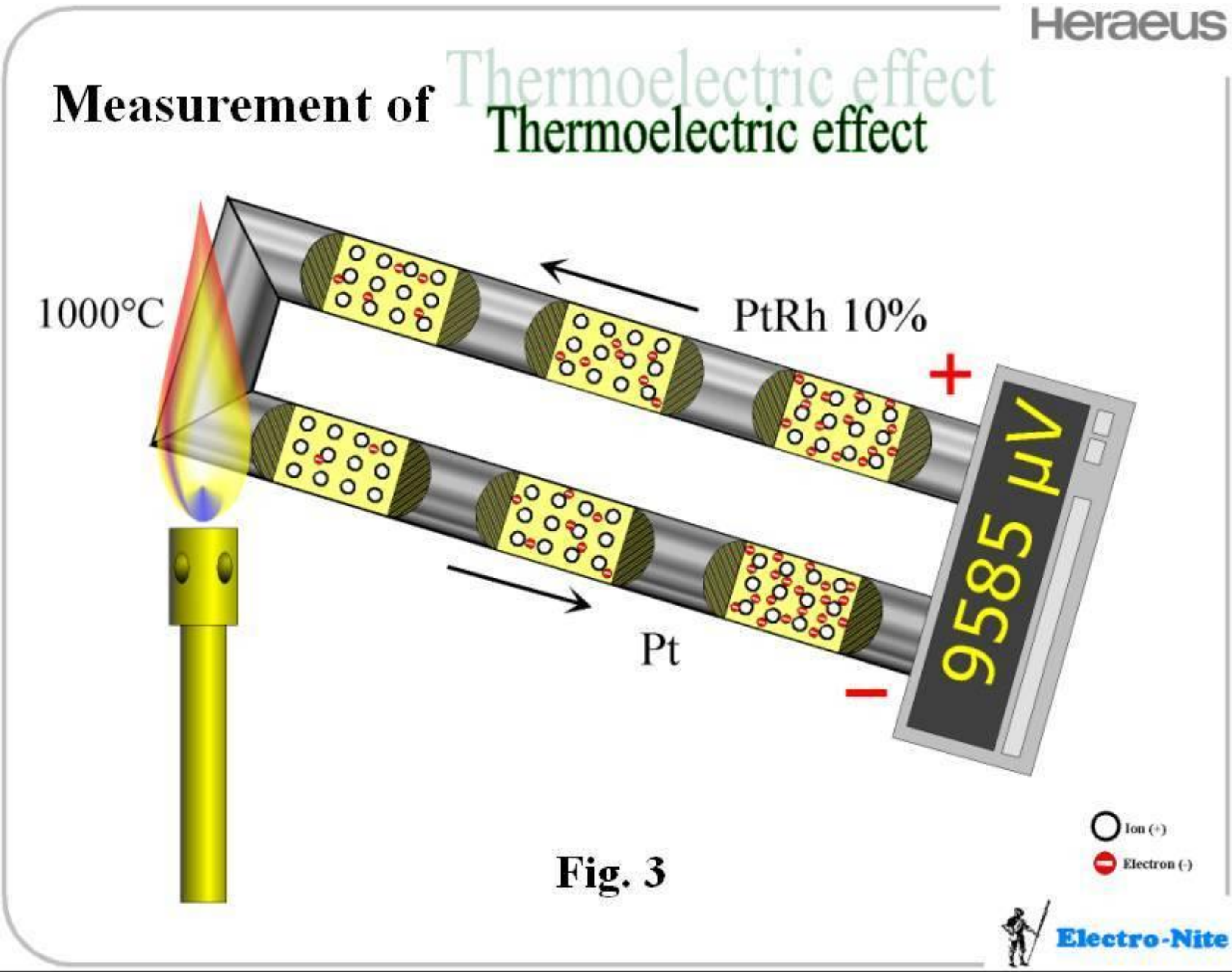


Positherm thermocouple

Fig. 1


Heraeus
Thermoelectric effect
+
–
Ion (+)
Electron (-)
Fig. 2
Electro-Nite


Heraeus
Measurement of
Thermoelectric effect
1000°C
PtRh 10%
+
9585 µV
Pt
−
Ion (+)
Electron (-)
Electro-Nite
Fig. 3

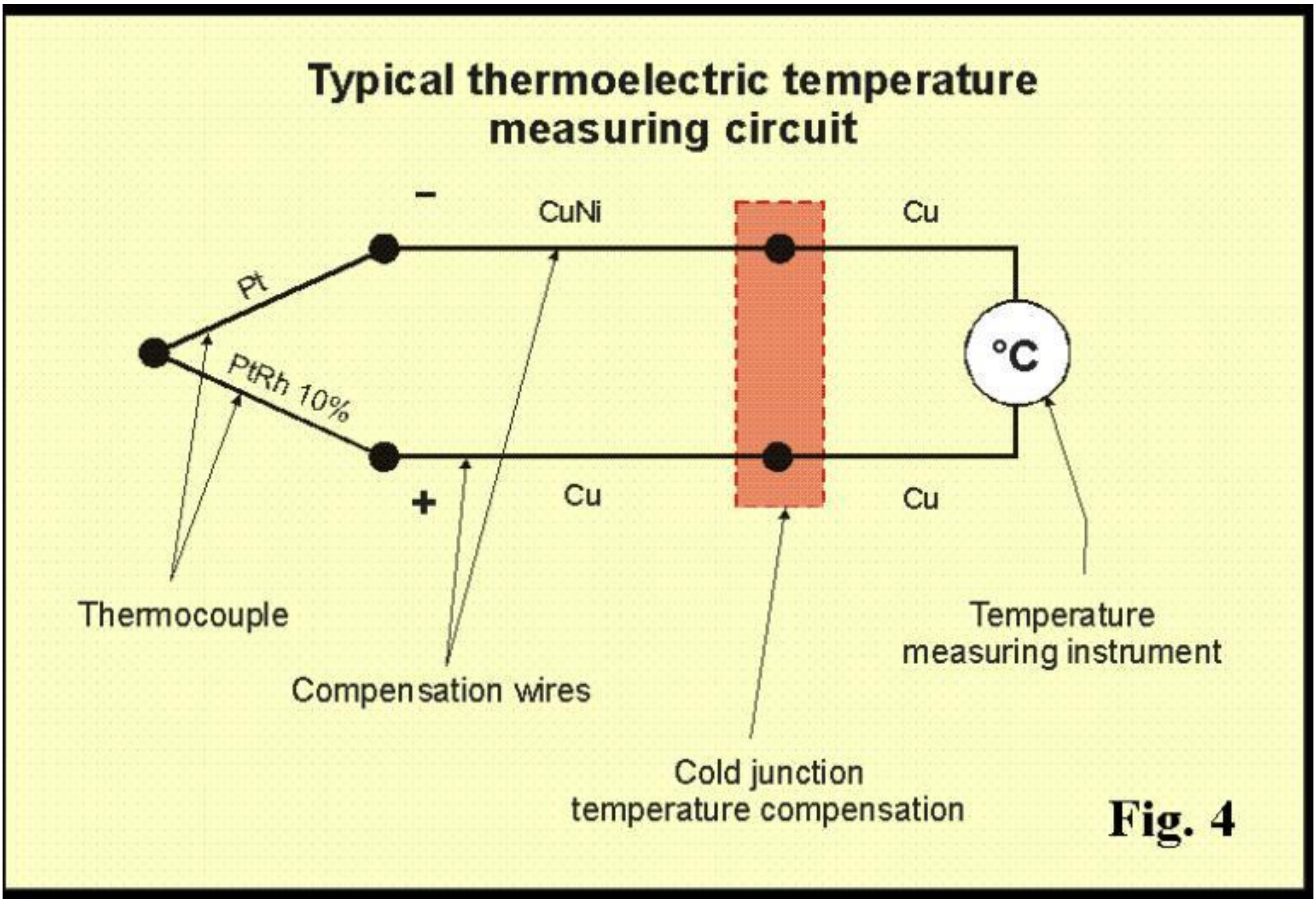

Typical thermoelectric temperature measuring circuit
–
CuNi
Cu
Pt
PtRh 10%
°C
+
Cu
Cu
Thermocouple
Temperature
measuring instrument
Compensation wires
Cold junction
temperature compensation

Fig. 4

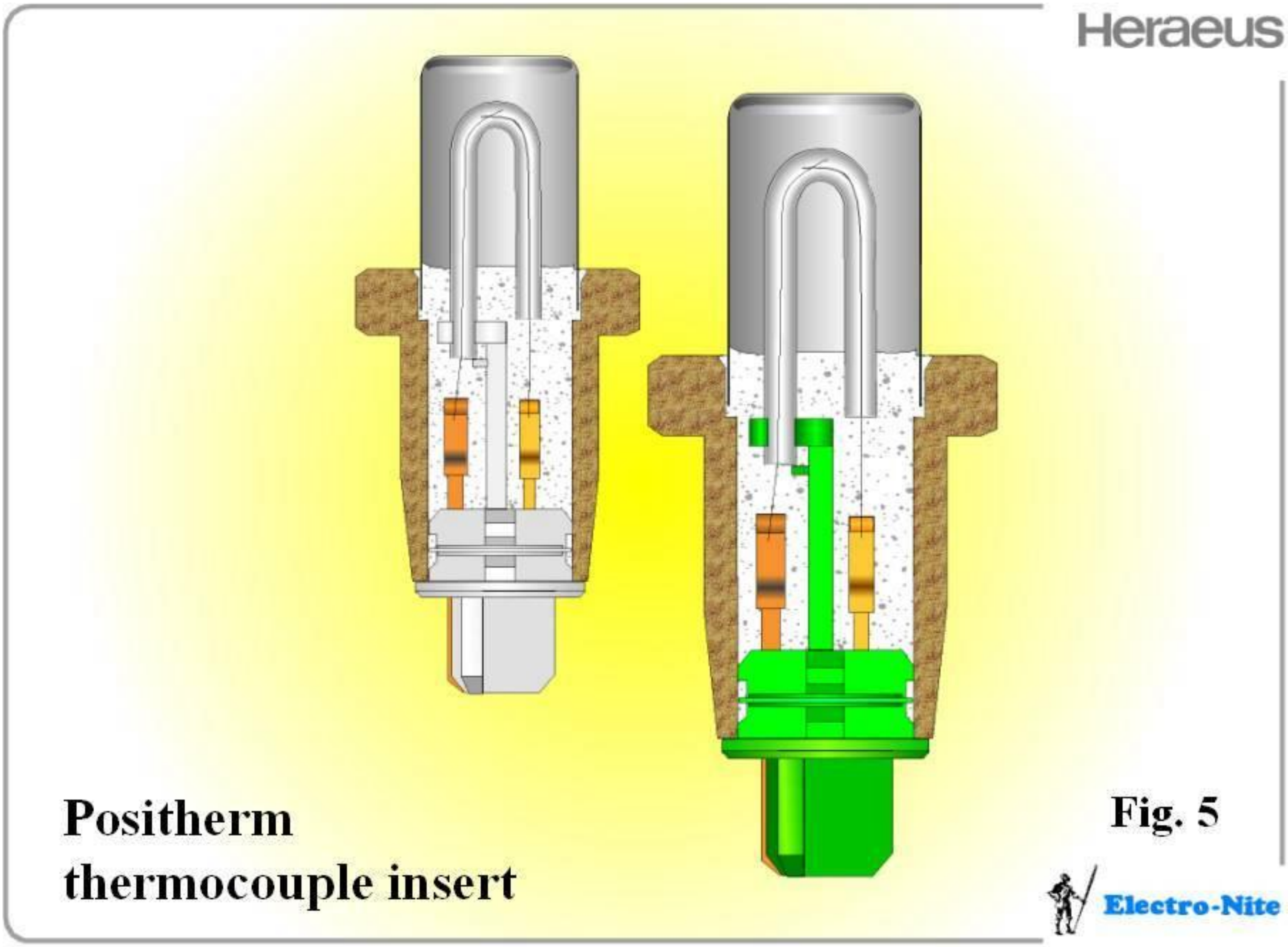
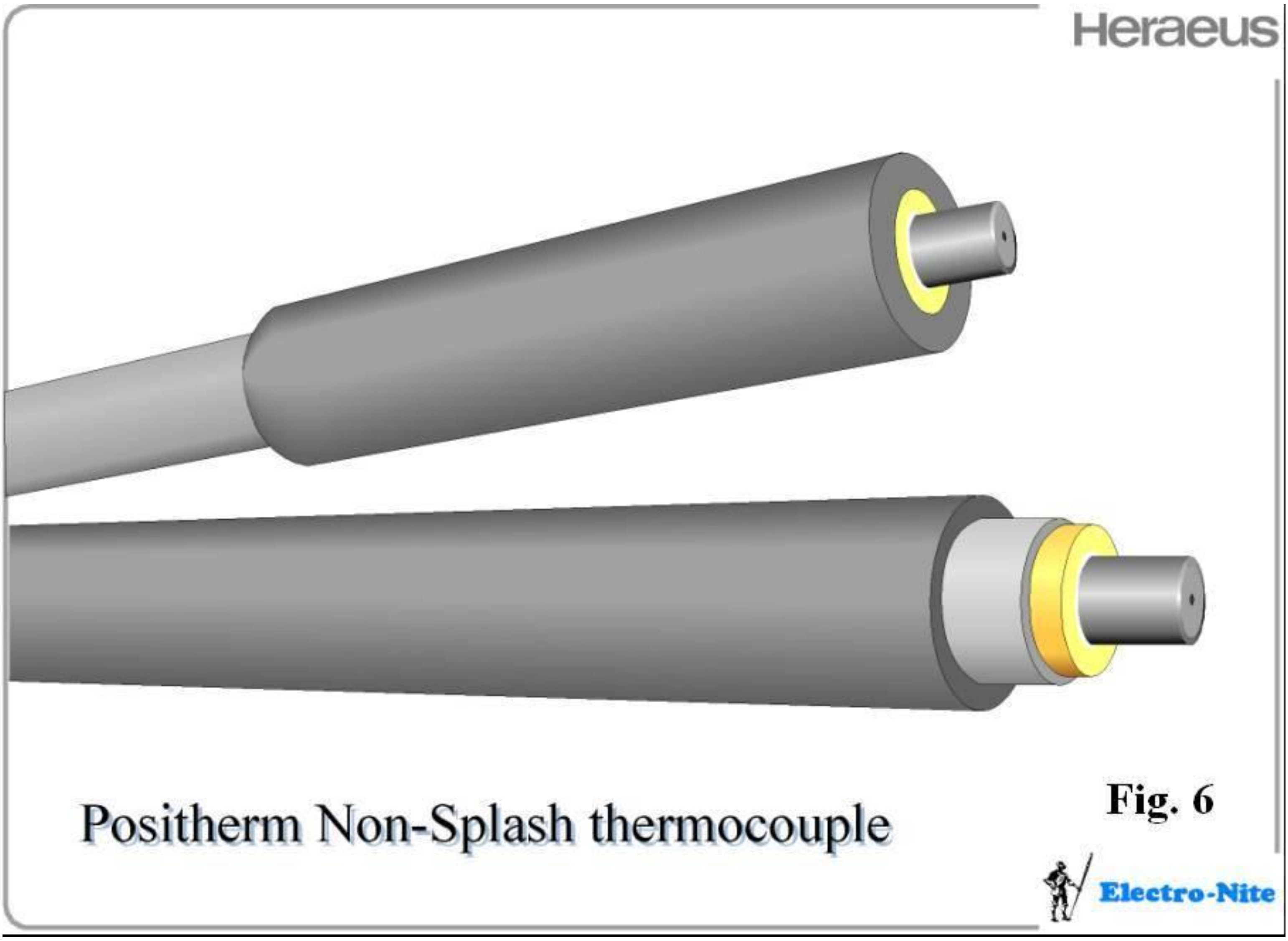


Fig. 5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Positherm Non-Splash thermocouple
Fig. 6
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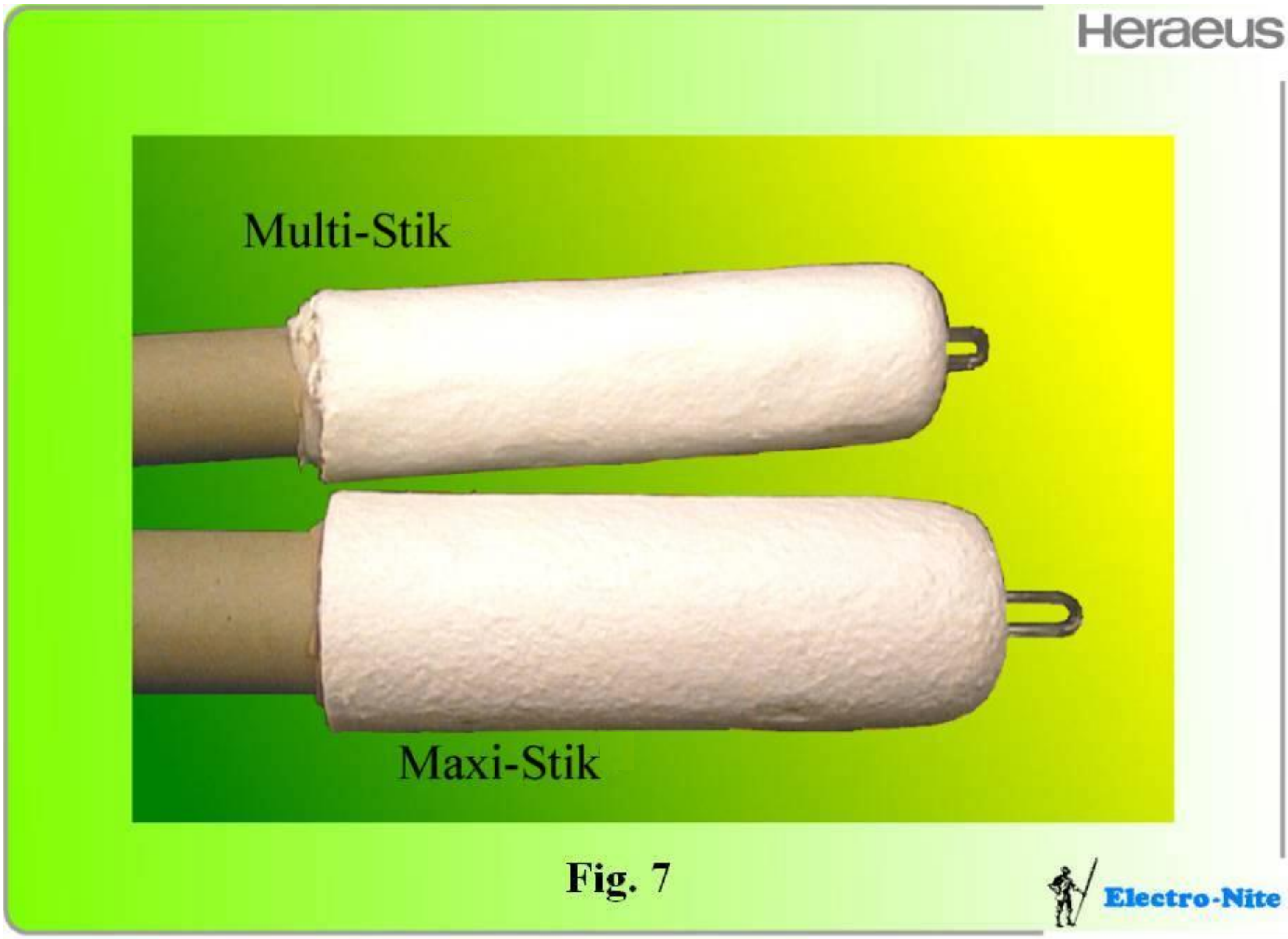

Fig. 7

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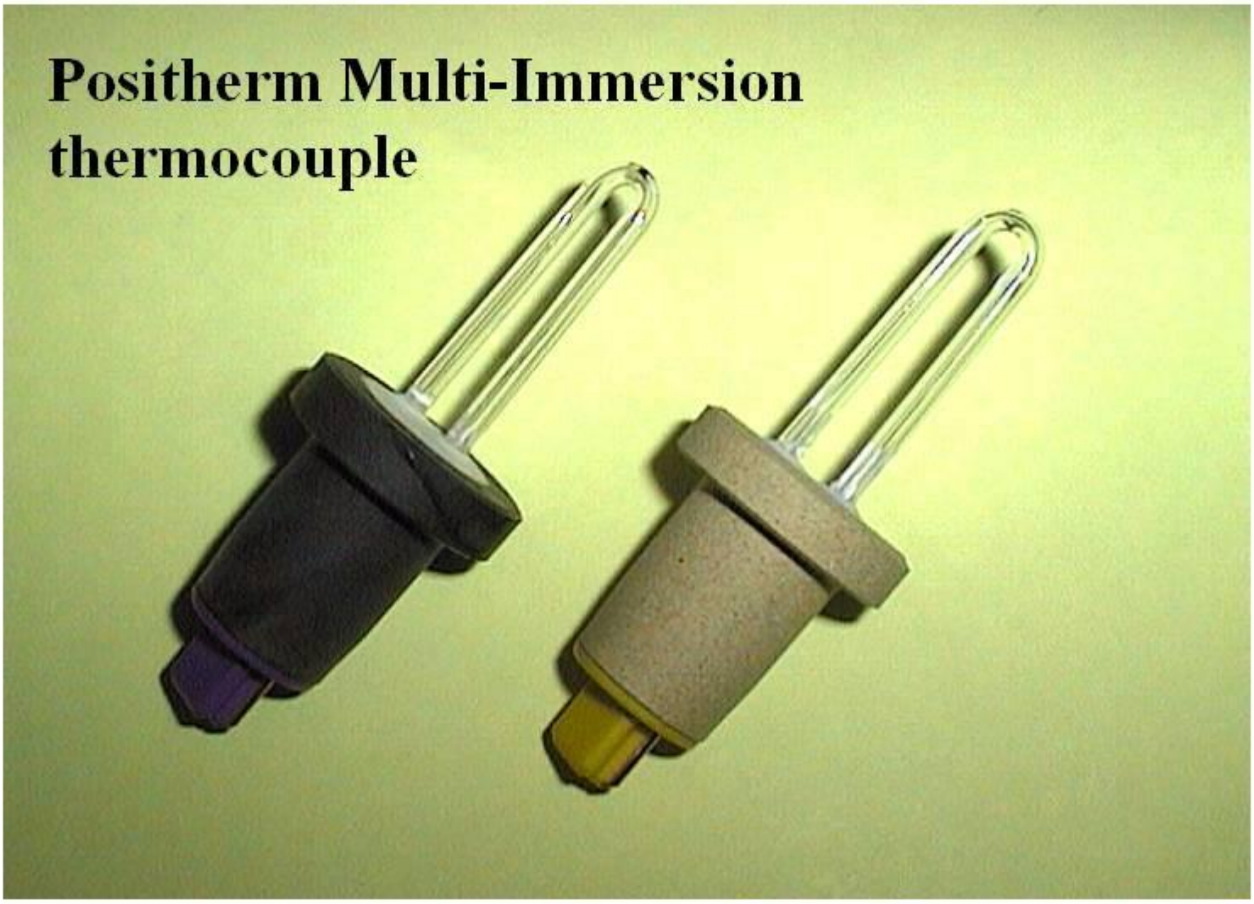

Fig. 8

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NOTE: SEE H. E-N INSTRUCTIONS FOR CRITICAL ▽ CHARACTERISTICS

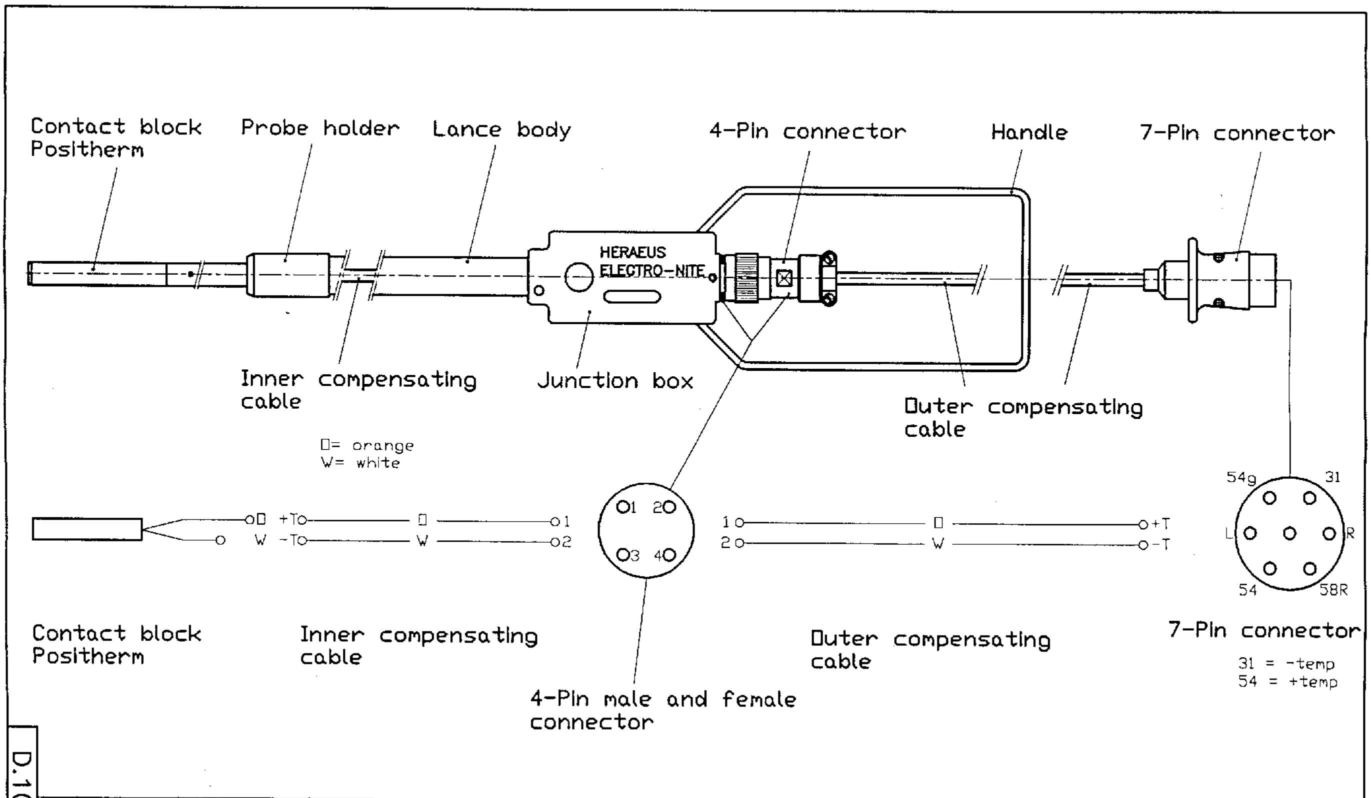

Fig. 9

REV	DATE	N°	DRAWN	APPROV.

Heraeus Electro-Nite INTERNATIONAL N.V.

Drawn	HV	Positherm Immersion Lance
Check.	WVDP	16/10/00 D.1054.R B
Appr.	AT	

Digitemp-E

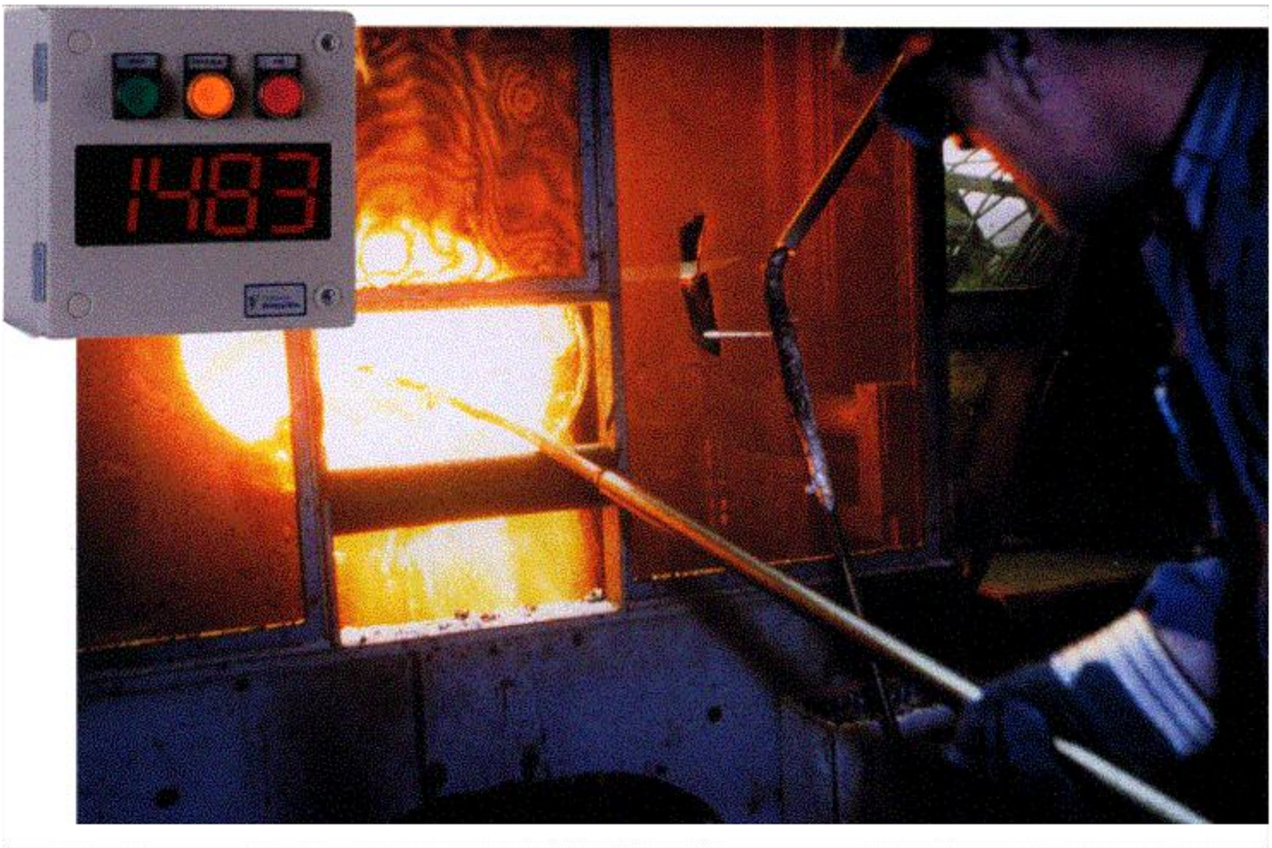

Fig. 10

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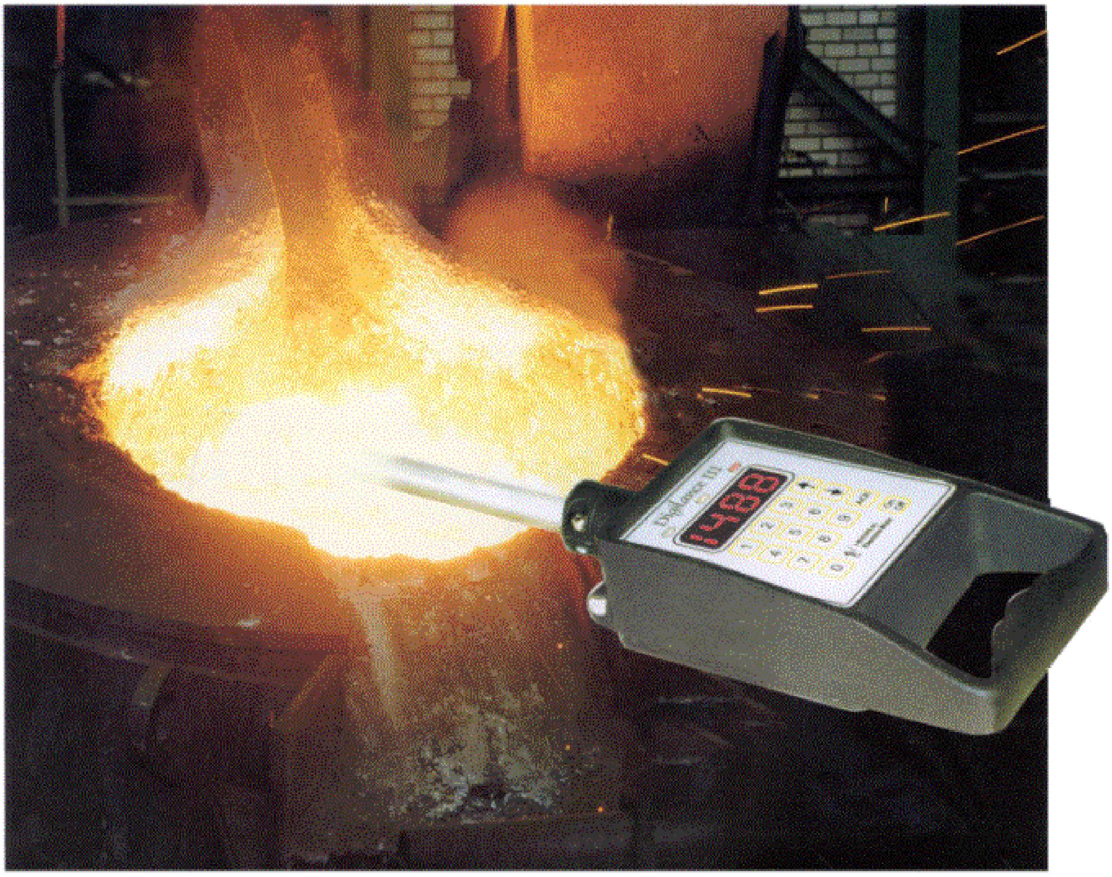

Fig. 11

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