EMPIR — The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

MetForTC

FSB — Sveučilište u Zagrebu Fakultet strojarstva i brodogradnje

EMPIR JRP 18RPT03 MetForTC

# WORKSHOP
# Temperature measurement by thermocouples

# Inhomogeneity of Thermocouples

**Prof.dr.Davor Zvizdic**

**Faculty of Mechanical Engineering and Naval Architecture, Laboratory for Process Measurement (FSB-LPM), East building, Blue room, Ivana Lučića 5,**

**Zagreb, Croatia, 27 February, 2020**

1

## Inhomogeneity of thermowires

In many cases the inhomogeneity of the thermowires is limiting the measurement uncertainty. For high precision calibration it is therefore necessary to test for inhomogeneity, using a method that involves locally changing the temperature profile along the length of the thermocouple, by heating or cooling, while maintaining the measuring and reference junctions at a constant temperature, such as 0 °C.

The region of heating or cooling is slowly moved along the length of the thermocouple, whereupon local inhomogeneities can be detected from changes in output.

Another possibility is to move the measuring junction in an environment with homogenous temperature distribution (e.g. a stirred liquid bath or a fixed point cell). In this procedure the region with the largest temperature gradient (surface of bath or furnace) will be in different positions of the thermowire, resulting in changes of the emf if the thermocouple is not homogeneous in the position of the thermal gradient.

2

## Inhomogeneity of thermowires

It is recommended to estimate the uncertainty contribution from the inhomogeneity as rectangular contribution, with a full width equivalent to the largest difference found for any two measurements during the test. If the test was only performed over a small length of the thermocouple, the largest difference in emf found in the measurement should be taken as half width of the rectangular distribution.

In cases where no individual measurement of the inhomogeneity is possible, it is recommended to take at least 20% of the Class 2 tolerance value for the corresponding type of thermocouple according to EN IEC 60584-2 [7] as contribution (k = 1) to the uncertainty .

For an estimation of the inhomogeneity at other temperatures than tested, it may be assumed that inhomogeneity can be expressed as a percentage of the total emf.

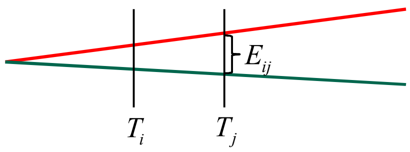
3

## Inhomogeneity

..it is abnormal change of Seebeck coefficient.

$$\sigma(t) = \lim_{\Delta T \to 0} \frac{\Delta E}{\Delta T}$$

In praxis we speak of average Seebeck coefficient of a wire segment:



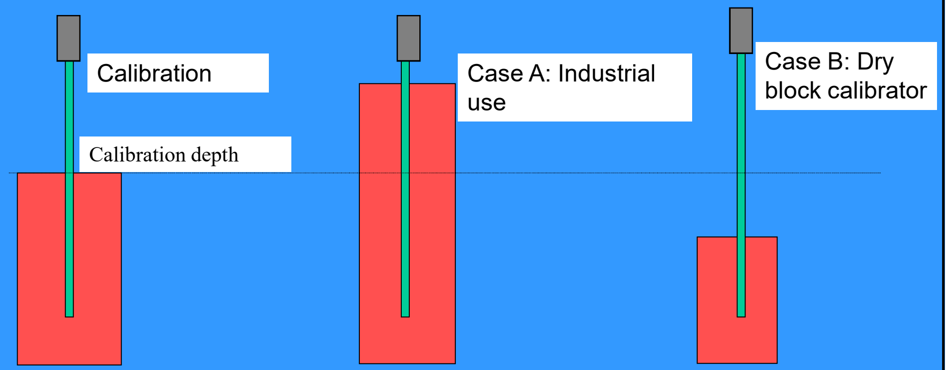

$$\sigma(T_m) = \frac{E_{ij}}{T_j - T_i}$$

Total emf which is measured at the end of the wires is the sum of all emf-s at all non-isothermal parts of the wire.

4

## Inhomogeneity?

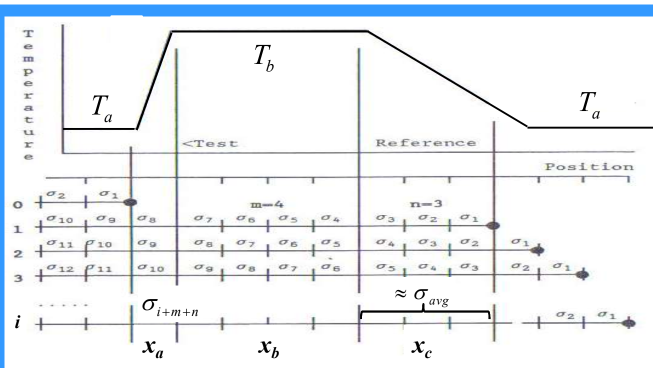
Calibration of the TC blindly believing in homogeneity of the wire may be waste of time and money, as inhomogeneity during use at elevated temperatures will inevitably occur.
Temperature profile during calibration may differ largely from the profile during regular use




5

## Dual temperature step test of the thermocouple wire

Emf measured at the end of the thermocouple during test is: Ei=Vo+(σ(i+m+n)-σ(avg)) ΔT
i.e. emf output from the segment on the entry step is compared to the approximate average several segments separated from the entry step.

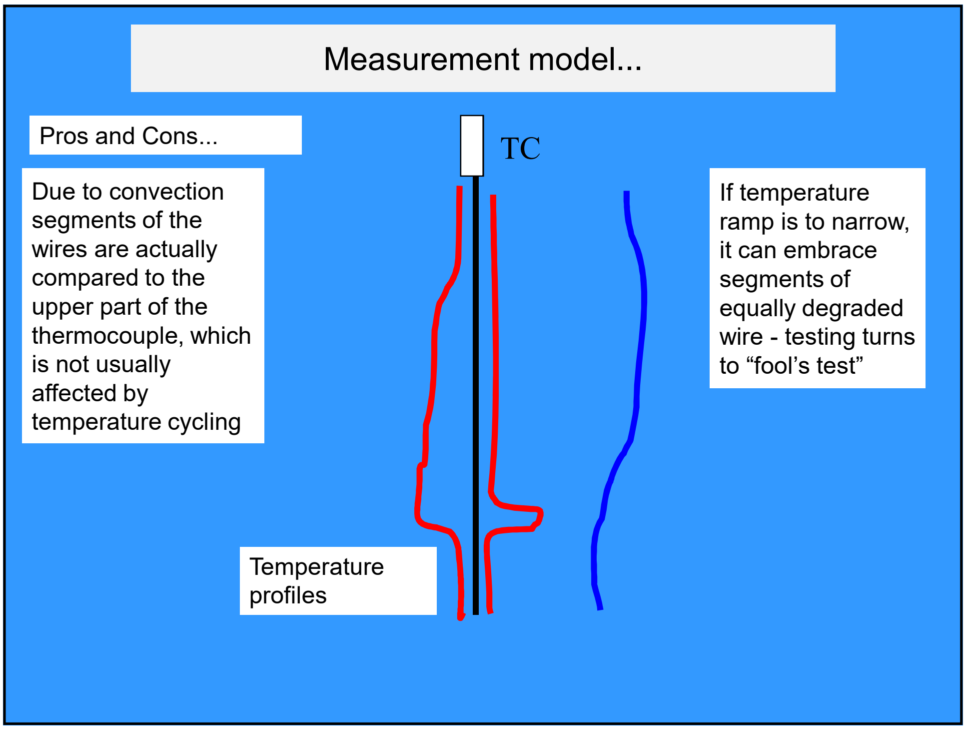



$$E_i = V_0 + \left(\sigma_{i+m+n} - \sigma_{avg}\right) \cdot \left(T_b - T_a\right)$$

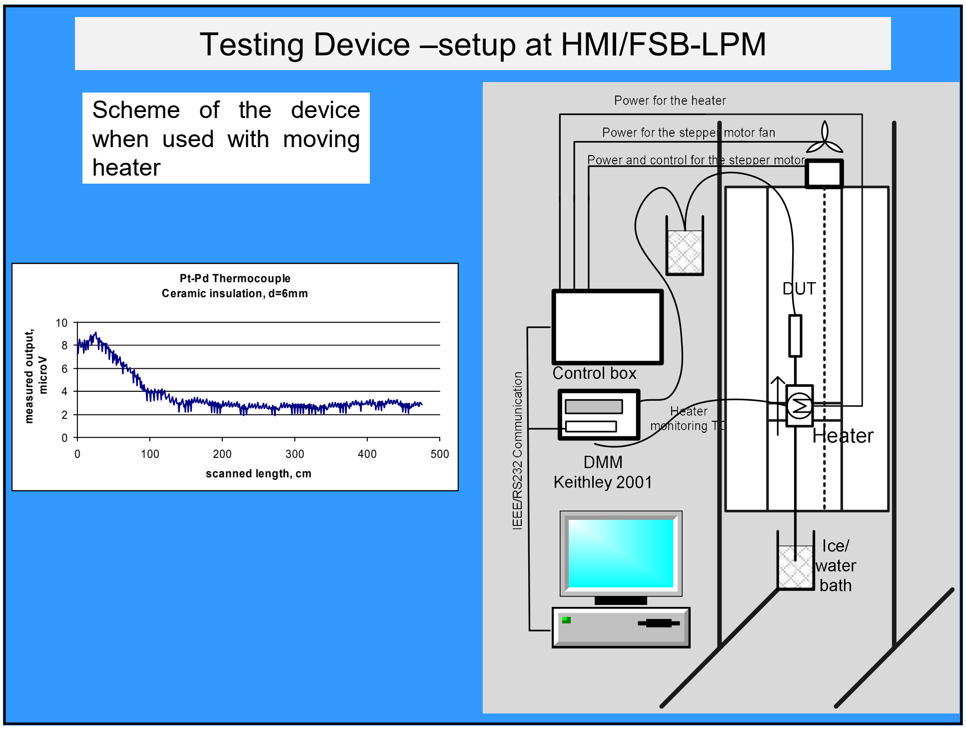
Deviation of the Seebeck coefficijent of the TC segment $X_a$ in relation to the average value

$V_0$ - The voltage we measure when both ends of the thermocouple are at the same temperature (due to voltmeter, parasitic voltages, and other errors)

6

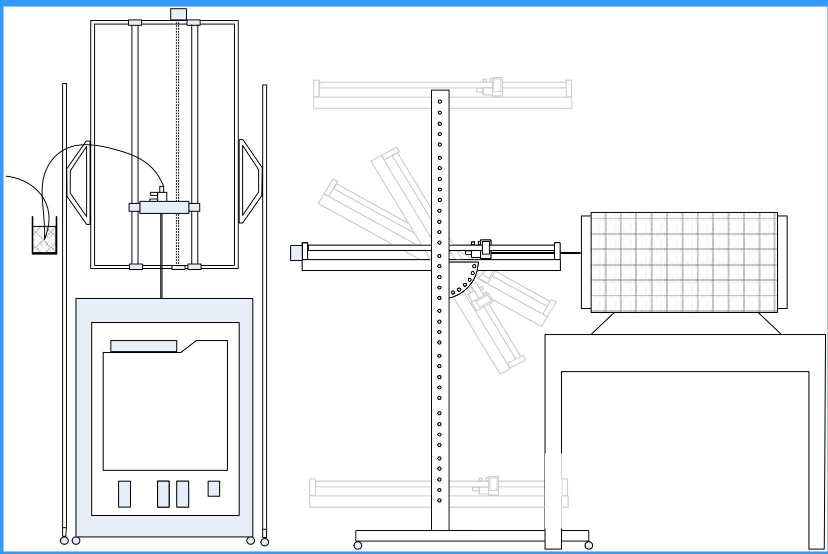

Measurement model...
Pros and Cons...
Due to convection segments of the wires are actually compared to the upper part of the thermocouple, which is not usually affected by temperature cycling
TC
If temperature ramp is to narrow, it can embrace segments of equally degraded wire - testing turns to “fool’s test”
Temperature profiles

7


Testing Device –setup at HMI/FSB-LPM
Scheme of the device when used with moving heater
Pt-Pd Thermocouple
Ceramic insulation, d=6mm
measured output, microV
scanned length, cm
Power for the heater
Power for the stepper motor fan
Power and control for the stepper motor
DUT
Control box
Heater monitoring TC
Heater
DMM
Keithley 2001
IEEE/RS232 Communication
Ice/ water bath

8

## Testing Device –setup at HMI/FSB-LPM



9

## Thermocouple can be classified in three categories

Depending on experimental results, thermocouple can be classified in three categories:

A - no inhomogeneity detected

B - inhomogeneity detected, its magnitude is used for estimation of inhomogeneity related calibration uncertainty

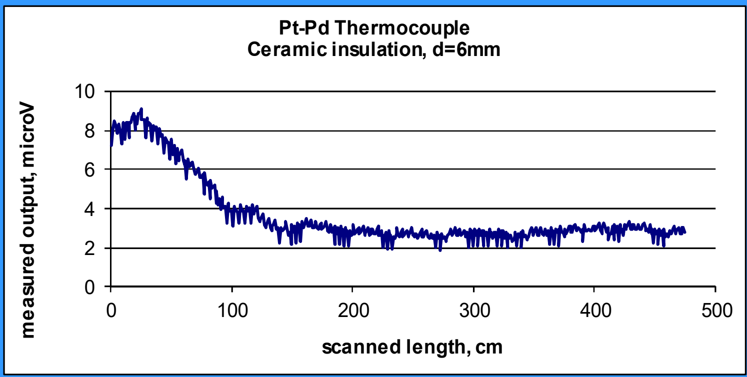
C - well, call the customer and tell the bad news

10

## Inhomogeneity Case 1

Class A – inhomogeneity detected less than 0.5 microV

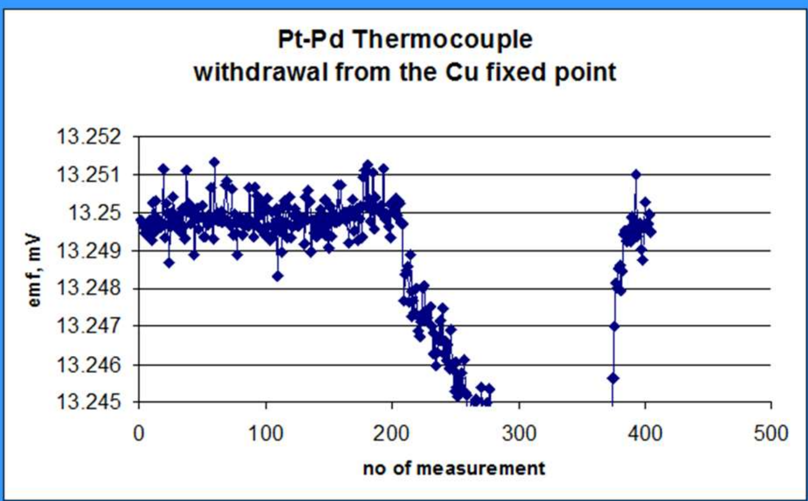
- Pt-Pd thermocouple, ceramic insulated, properly annealed and used only in recent Euromet intecoparison.
- Conduction effect at the tip and noise from step motor and AC heater




11

## Inhomogeneity Case 1 (Class A) continued

Additional test with gradual withdrawal from Cu fixed point, 20 cm in 3 cm steps



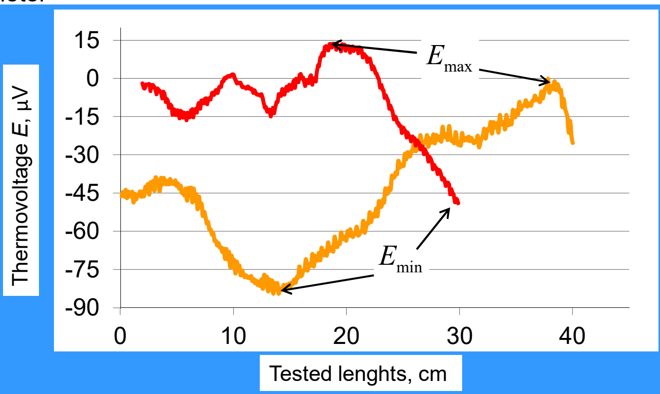

12

## Class B – inhomogeneity detected

Estimation of uncertainty due to inhomogeneity:

$$u(k=1)=(E_{max}-E_{min})\cdot\left[\frac{E(T_{in\ use})}{E(T_{heater})}\right]\cdot\frac{1}{2\sqrt{3}}$$

Results of two MIMS (Mineral Insulated Metal Sheath) thermocouples, 3mm diameter




13

## Results...interpretation

Calculation of inhomogeneity related uncertainties from measured results

- Emf is measured at the temperature of the heater approx. 300°C
- It has to be extrapolated to the temperature of the calibration
- Upper and lower level of measured Emf are taken as limits of rectangular distribution

Rule of the thumb:

u(k=1)=(Emf max-Emf min)*(EmfT/Emf Heater) *1/2*1/sqrt(3)

14

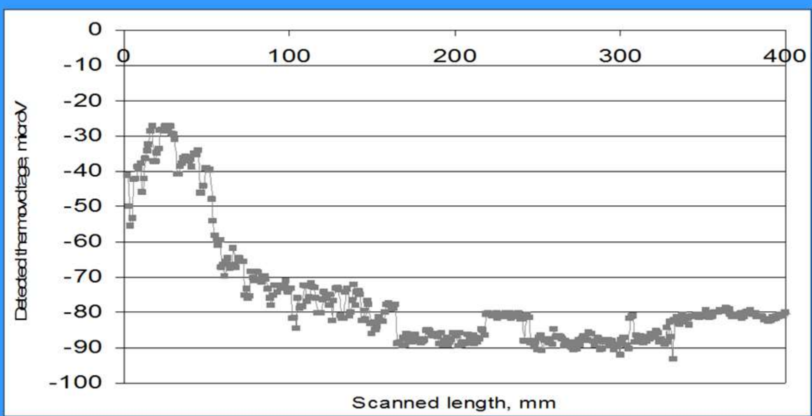
## Calibration uncertainty budget of one of the MIMS thermocouples

| DUT emf uncertainty budget | | | $t_{cal}$: | 658.6716 °C | | | |
|---|---|---|---|---|---|---|---|
| Type | Quantity | Symbol | Estimation | Uncertainty | Probability | Sensitivity coeff. | Contribution |
| A | DUT emf | $V_{iX}$ | 27.4350 | 0.00002 mV | normal (1σ) | 1.0 [ - ] | 0.02 µV |
| | DMM calibration | $\delta V_{iX1}$ | 0.00 µV | 2.19 µV | normal (2σ) | 1.0 [ - ] | 1.09 µV |
| | DMM resolution | $\delta V_{iX2}$ | 0.00 µV | 0.01 µV | rectangular | 1.0 [ - ] | 0.01 µV |
| | Parasitic voltages | $\delta V_R$ | 0.00 µV | 1.20 µV | rectangular | 1.0 [ - ] | 0.69 µV |
| B | **Inhomogeneity** | **$\delta V_H$** | **0.00 µV** | **50.00 µV** | **rectangular** | **1.0 [ - ]** | **28.87 µV** |
| | Comp\Ext cables | $\delta V_{LX}$ | 0.00 µV | 0.00 µV | rectangular | 1.0 [ - ] | 0.00 µV |
| | Ice/water bath | $\delta t_{0S}$ | 0.005 °C | 0.004 °C | rectangular | 39.5 µV/°C@0°C | 0.09 µV |
| | Temp. deviation | $\Delta t$ | 0.00 °C | 0.578 °C | normal (1σ) | 42.19 µV/°C@$t_{cal}$ | 24.41 µV |
| AB | DUT emf | $V_X$ | 27.43517 mV | | | Uncertainty (1σ) | 37.824 µV<br>0.897 °C |
| C | Interpolation | $\delta V_{int}$ | 0.00 µV | 12.088 µV | rectangular | 1.00 [ – ] | 6.98 µV |
| ABC | DUT emf | $V_X$ | 27.4352 mV | | | Uncertainty (1σ) | 38.462 µV<br>0.912 °C |

15

## Class C – bad news for the customer

- Thermocouple type S, ceramic insulated, heavily used in aggressive atmosphere
- Deviation from the reference function at 900°C more tha 15°C




16

## Conclusion

- In many cases the inhomogeneity of the thermowires is limiting the measurement uncertainty.
- In base metal thermocouples it is by far the largest uncertainty contribution.
- For high precision calibration it is therefore necessary to test for inhomogeneity, using a method that involves locally changing the temperature profile along the length of the thermocouple, by heating or cooling, while maintaining the measuring and reference junctions at a constant temperature, such as 0 °C.
- Another possibility is to move the measuring junction in an environment with homogenous temperature distribution (e.g. a stirred liquid bath or a fixed point cell).
- Estimate the uncertainty contribution from the inhomogeneity as rectangular contribution, with a full width equivalent to the largest difference found for any two measurements during the test.
- In cases where no individual measurement of the inhomogeneity is possible, it is recommended to take at least 20% of the Class 2 tolerance value for the corresponding type of thermocouple according to EN IEC 60584-2 as contribution (k = 1) to the uncertainty.
- For an estimation of the inhomogeneity at other temperatures than tested, it may be assumed that inhomogeneity can be expressed as a percentage of the total emf.

17

## Thank you for your attention!

18