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EMPIR JRP 18RPT03 MetForTC

WORKSHOP – Novel devices and methods for verification of thermocouple performance

Novel devices and methods for in-situ testing of thermocouple drift

Danijel Šestan

FSB
Sveučilište u Zagrebu
Fakultet strojarstva i brodogradnje
University of Zagreb
Faculty of Mechanical Engineering and Naval Architecture

LPM
Laboratorij za procesna mjerenja
Laboratory for Process Measurement
Ivana Lučića 5, 10000 Zagreb, Hrvatska
Tel: +385 1 6168330
e-mail: lpm@fsb.hr, www.fsb.hr

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Thermocouple drift

- thermocouples (TCs) are temperature sensors that are widely used in many industrial processes requiring temperature control
- inaccurate temperature measurement in industry can cause higher energy consumption or increased production time leading to increase in product price or decrease of its quality
- accuracy of temperature measurement is influenced by drift
- drift is a departure of the voltage–temperature relationship from the one determined through calibration, or a rapid excursion from manufacturer's tolerances
- drift rate depends on the thermocouple type and thermal conditions it is exposed to
- drift magnitudes range from several °C to a few tens of °C
- thermocouples are more prone to drift at high temperatures, but drift can not be neglected at lower temperatures either
- industrial users requiring temperature measurements of high accuracy tend to replace thermocouples regularly as a precautionary measure
- without means for tracking the thermocouple drift those replacements can be done too early as well as too late

Dual-type thermometers concept

- to alleviate the problems related to thermocouple drift, consortium consisting of national metrology institutes of **Turkey, Hungary, Bulgaria, Romania, Czech Republic, Bosnia and Herzegovina, Norway, Republic of Moldova, Montenegro, and Croatia** has developed the new concept of dual-type thermometers
- the work is performed within the framework of the EMPIR Research Potential Project “Developing Traceable Measurement Capabilities for Monitoring Thermocouple Performance” (MetForTC), which launched in June 2019

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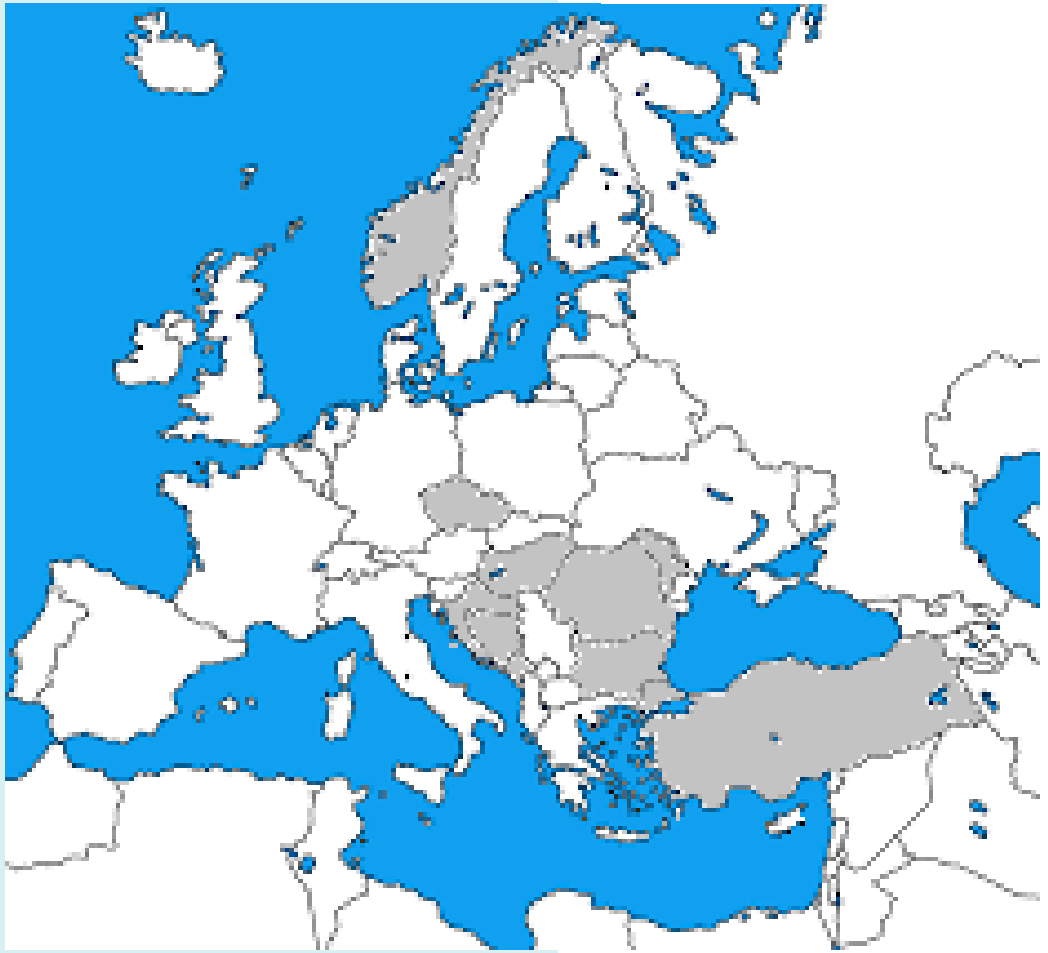
- the concept aims to provide thermocouple users a relatively cheap and simple solution for in-situ monitoring its drift, including environments with varying temperatures



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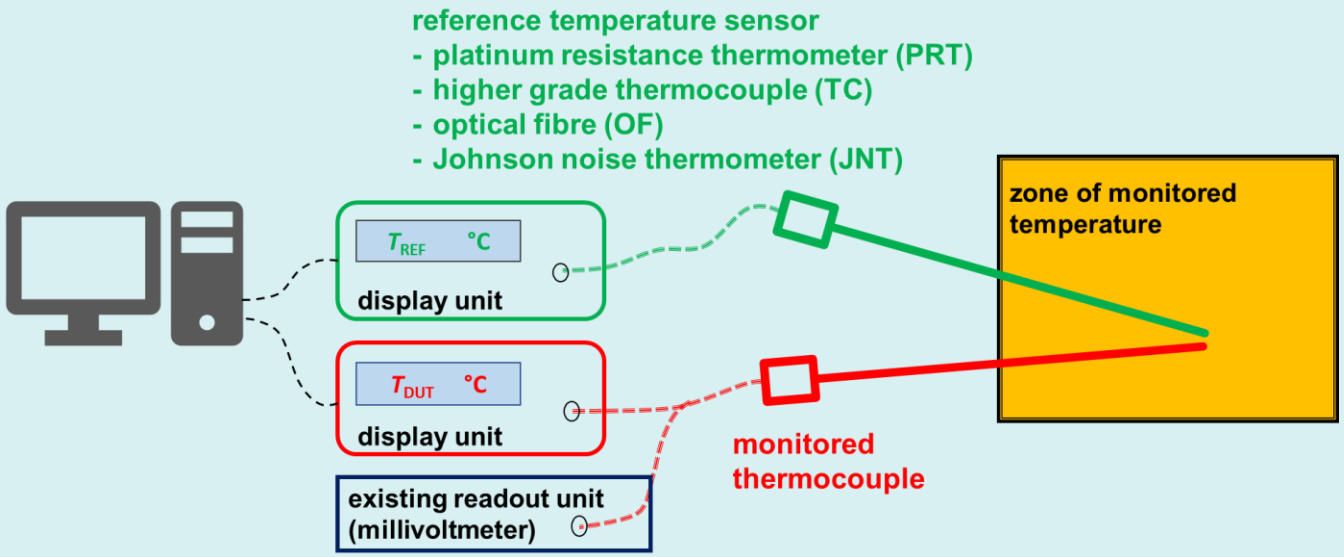
Dual-type thermometers concept

The basic idea behind the concept of dual-type thermometers is that a drift of a thermocouple can be determined by monitoring the difference in its temperature readings and the readings of an additional (reference) thermometer, where the reference sensor experiences a lower drift than the thermocouple under test.

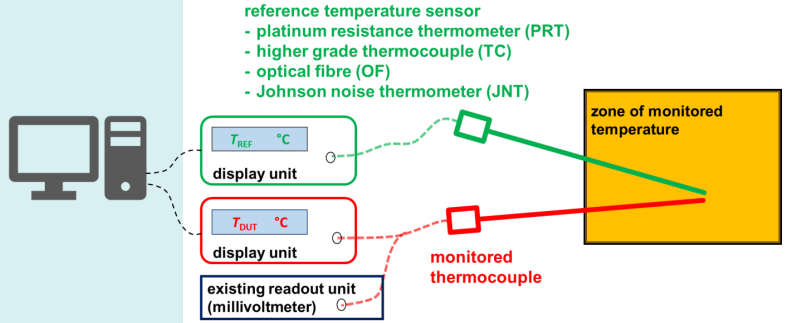


Using the shown setup, the drift of the thermocouple under test can be continuously monitored by tracking the difference in temperature readings of reference sensor (T_{REF}) and monitored thermocouple (T_{DUT}):

$$T_{REF}\text{-}T_{DUT}$$

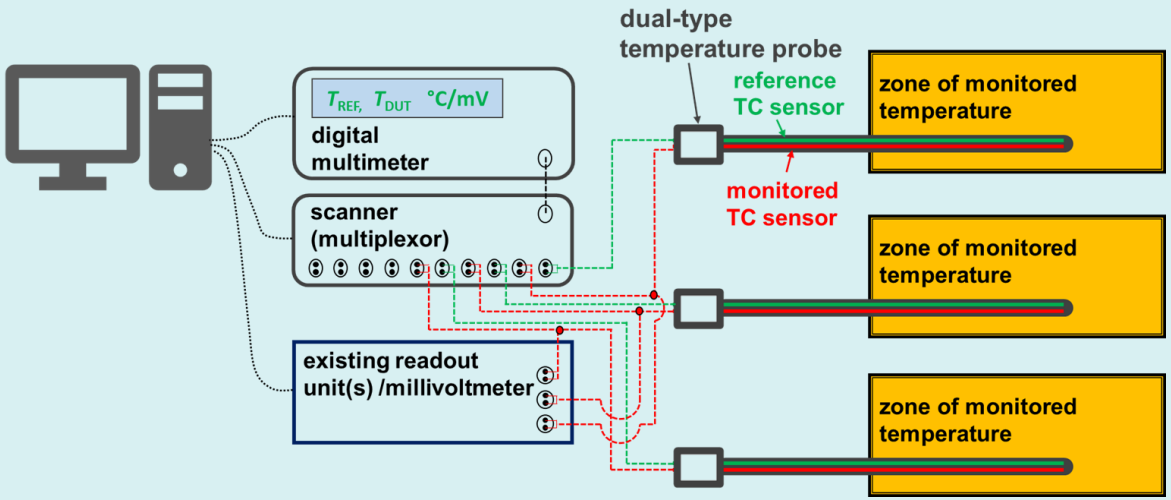
Dual-type thermometers concept

- method relies on measurement of differences in readings of two temperature sensors and their calibration is, therefore, not mandatory for drift determination
- three types of temperature sensors were considered as a reference sensors: higher grade thermocouple, platinum resistance temperature sensor and fibre optics with pyrometer
- shown setup can be used for in-situ drift monitoring but there are three main advantages of having both temperature sensors placed within the same protective sheath (i.e., having a dual-type temperature sensor):
  - the influence of temperature gradients in the measurement zone on the difference of temperatures measured by two thermometers (T_{REF}-T_{DUT}) could be greatly reduced with reduction of the spatial distance between the corresponding sensors, leading to better precision in the drift determination
  - the price of manufacturing one probe should be lower than for two separate probes
  - mounting the second (reference) probe would be hardly feasible in some measurement setups



Utilizing thermocouples as a reference sensors

Thermocouples are considered as the reference temperature sensors in the temperature range between 0 °C and 1084 °C, which is their main advantage in comparison with platinum resistance and fiber-optic reference sensors.

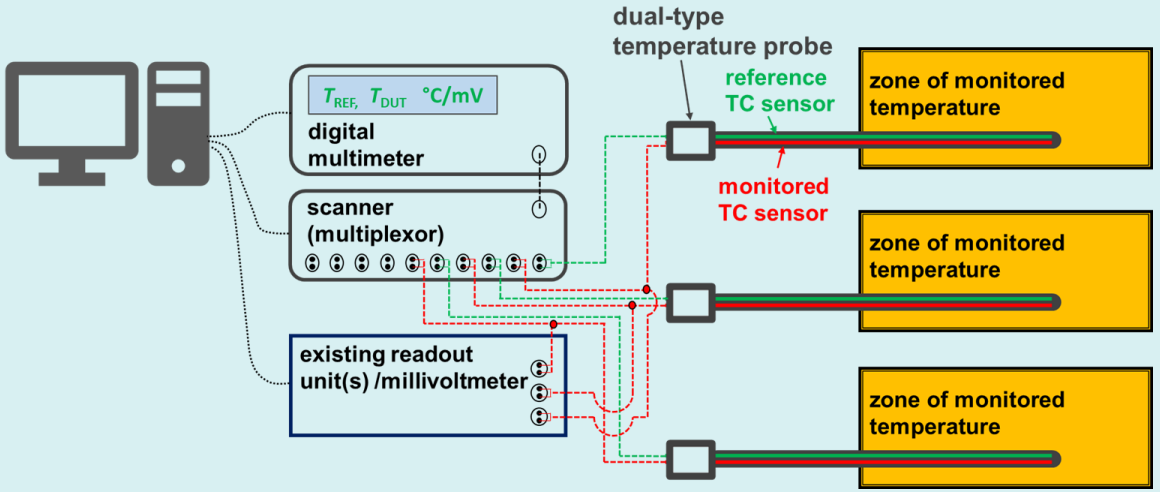


In such setup, a higher-grade thermocouples are used as a reference temperature sensors, e.g., drift of thermocouples type K or N is monitored using thermocouple type S reference sensor and thermocouple type S can be monitored with the thermocouple type R with a greater wires' diameter.

Monitored thermocouples are simultaneously connected to the multimeter and the input channel of their existing readout unit, which is possible with multimeters having high input resistance.

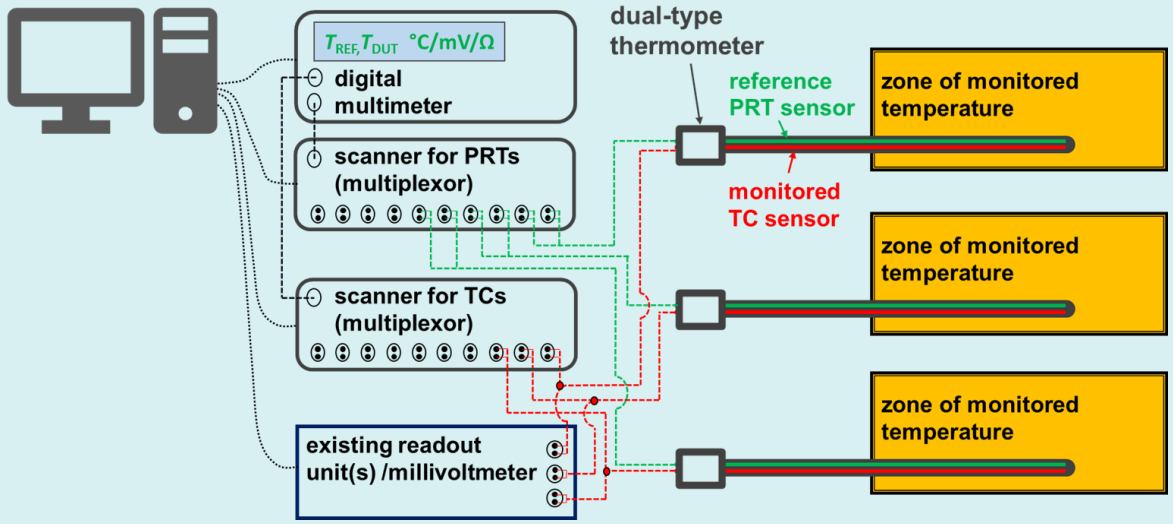
Utilizing thermocouples as a reference sensors

- possible to track the drift of the existing millivoltmeter by tracking the difference in readings obtained through the existing and the additional millivoltmeter
- if it is possible to connect the existing readout unit to a PC, and record readings at a sufficient rate, connection to additional multimeter is not mandatory
    - the advantage of such setup is the ability to monitor twice as many dual-type temperature sensors with any given scanner
- separate scanner is not required for monitoring one or two thermocouples
- scanner is also not required if the existing digital multimeter has two channels and only one dual-type temperature sensor is used



Utilizing platinum resistance sensor as a reference

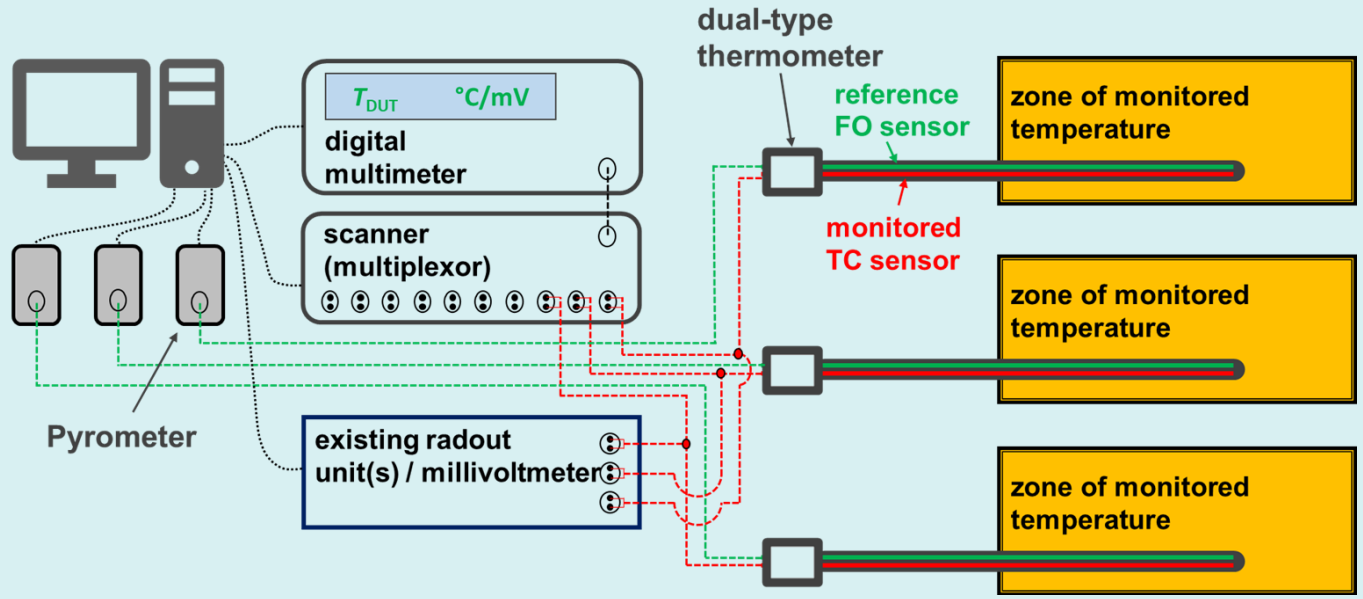
Platinum resistance temperature sensors (PRTs) are considered as reference sensors in the temperature range between -50 °C and 600 °C. Despite the narrower range, PRTs in general experience lower drift than thermocouples.



- the number of dual-type sensors that can be simultaneously connected to the system depends on the number of available scanner channels
- setup enables tracking of the drift of the existing millivoltmeter if monitored thermocouples are connected to both, the existing and additional multimeters
- if the existing readout unit can be connected to a PC, and record readings at a sufficient rate, a thermometry resistance bridge could be used instead of a multimeter

Utilizing fiber-optic sensor as a reference sensor

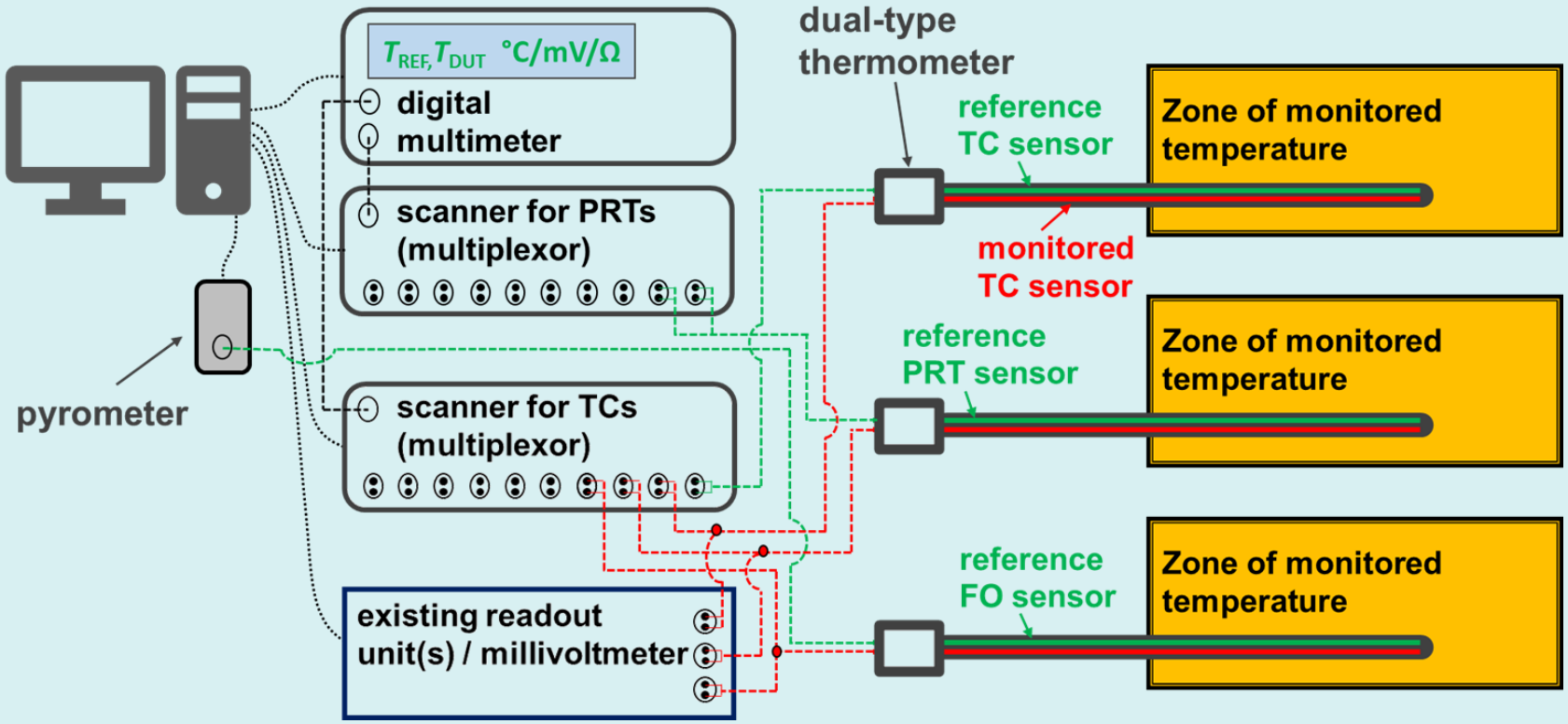
Fiber-optic temperature sensors are considered as reference sensors in the temperature range between 500 °C and 1000 °C. However, an actual upper-temperature limit could be higher, which would be the subject for future investigation.



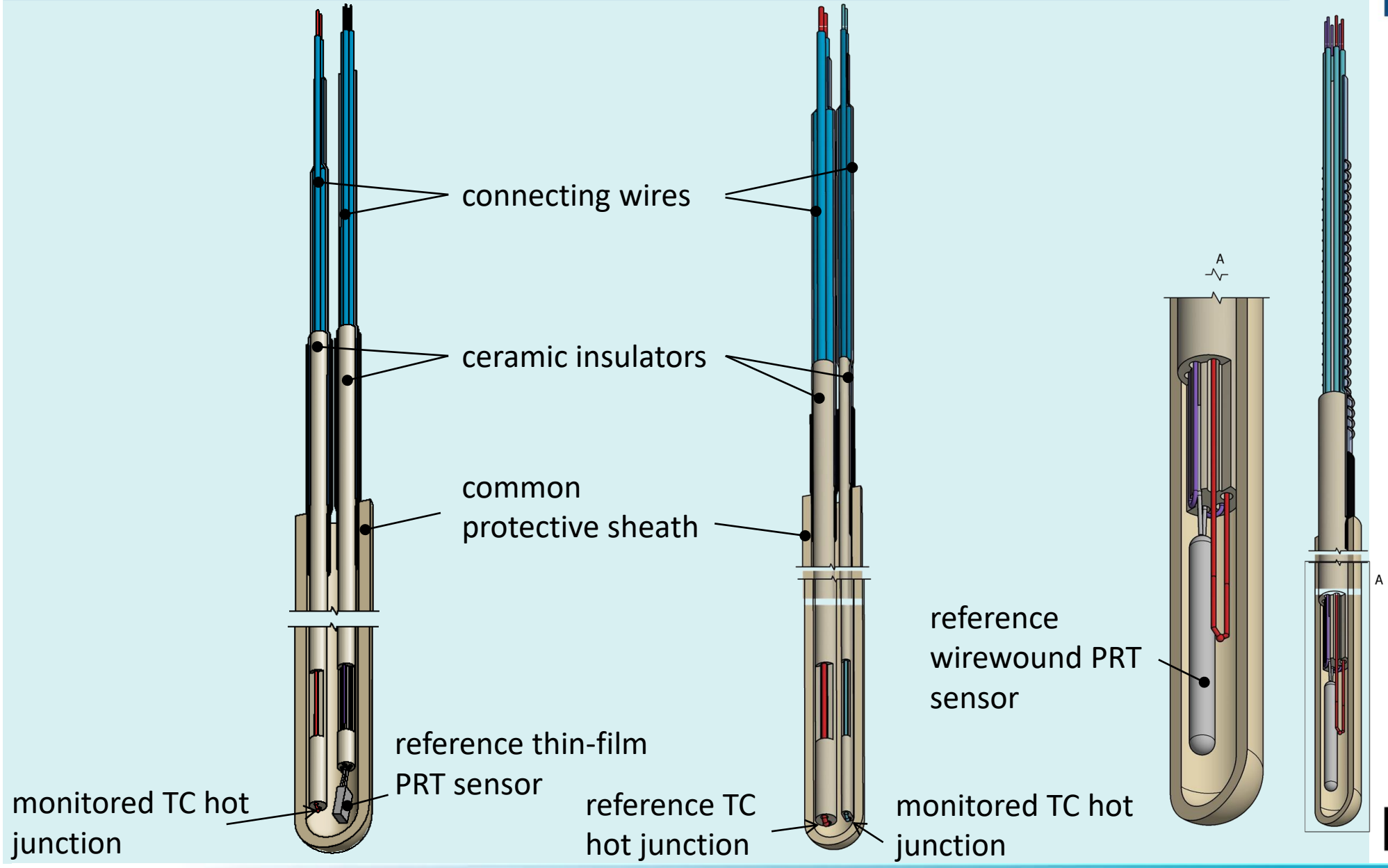
- the higher price of multiple pyrometers could be justified by the possibility of monitoring drift of the noble metal thermocouples

Combination of dual-type thermometers utilizing different types of reference sensor

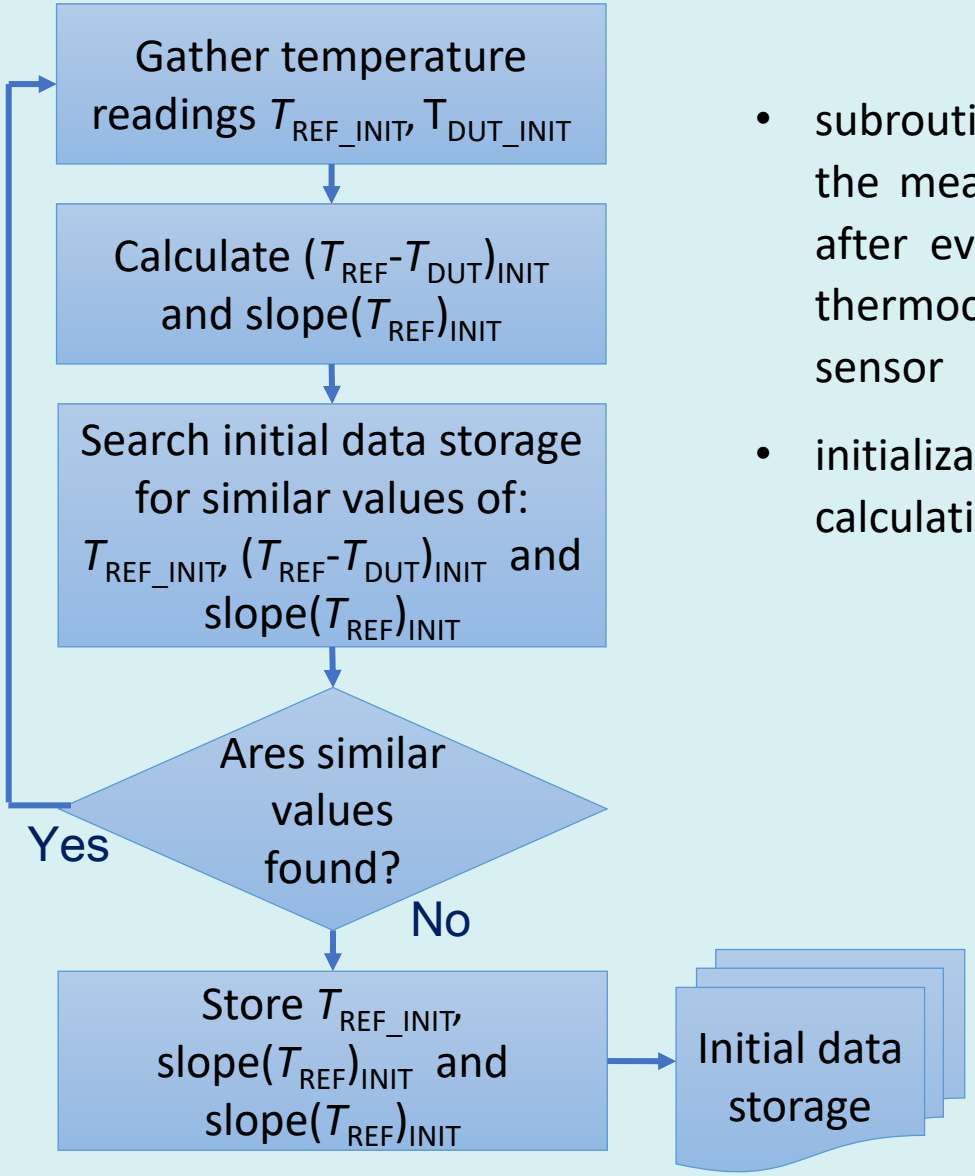
Measurement setups shown previously can be combined for monitoring the drift of multiple thermocouples operating in different temperature ranges.



Dual-type temperature probe designs



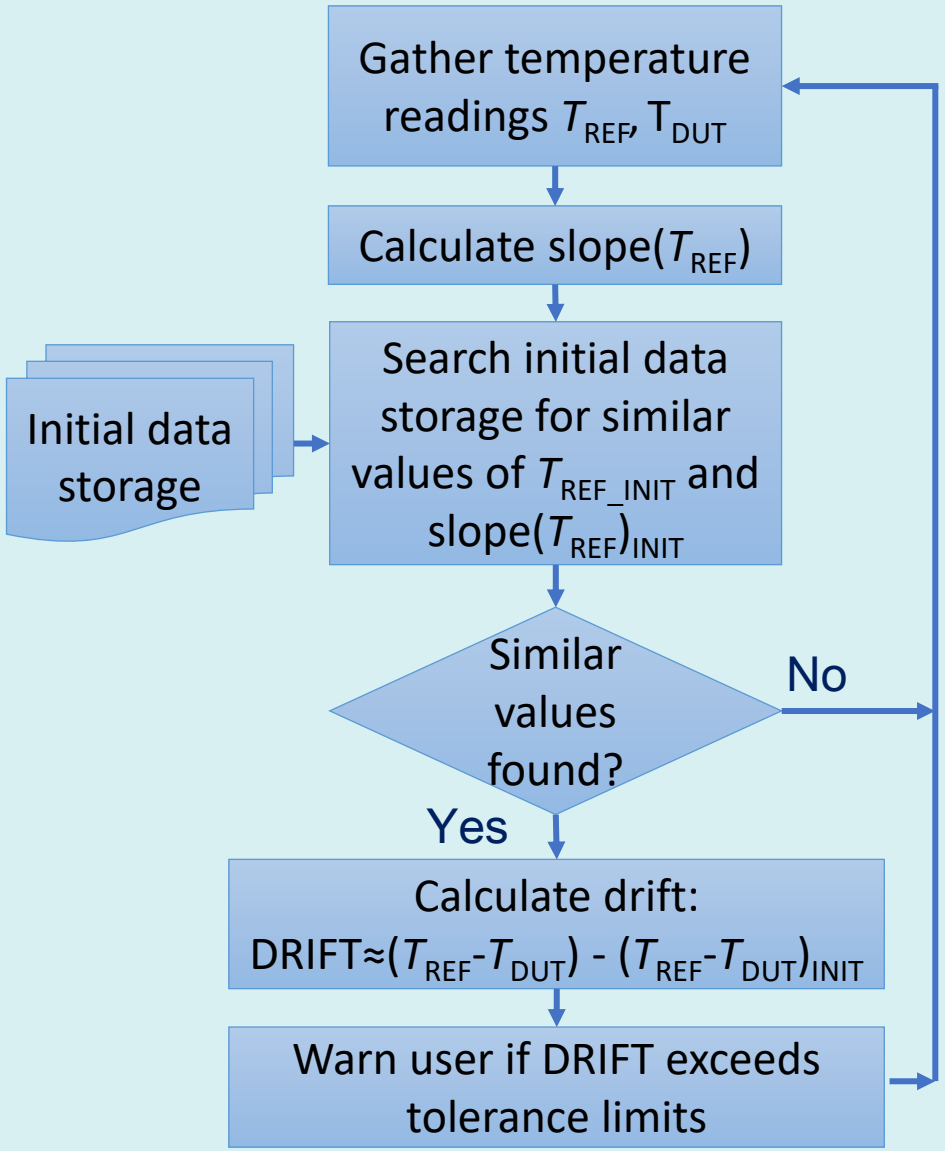
Drift determination algorithm



Initialization subroutine

- subroutine starts immediately after putting the measurement system in operation and after every replacement of the monitored thermocouple or reference temperature sensor
- initialization period and period for slope calculation are user adjustable

Drift determination algorithm



Drift monitoring subroutine

- the degree of required similarity, i.e. maximal allowable differences

  $|T_{REF,\,CURRENT}-T_{REF,INIT}|$ and
  $|slope(T_{REF,CURRENT})- slope(T_{REF,INIT})|$

  are user adjustable as well as conditions which are not suitable for drift calculation (e.g. too high slope)

- searching algorithm can be made more efficient by excluding initial data, taken during the periods with too large temperature slopes, from the storage

Checking the reference temperature sensor

- assuming that a newly installed monitored thermocouple operates within the specified tolerances, its readings during the initial period can be used for checking the drift of the reference temperature sensor
- check can be performed after every replacement of monitored thermocouple by comparing difference in readings of two thermometers with initial differences recorded during previous replacements, under the similar conditions, i.e. similar T_{REF} and $slope(T_{REF})$

Intermittent drift checks

- dual-type temperature sensors can be designed in a way enabling independent removal of monitored and reference temperature sensors from the common protective sheath
- drift can be checked occasionally by insertion of the reference temperature sensor in the common protective sheath, and comparing the difference in temperature readings T_{REF}-T_{DUT} with the ones obtained in previous checks, under the similar conditions

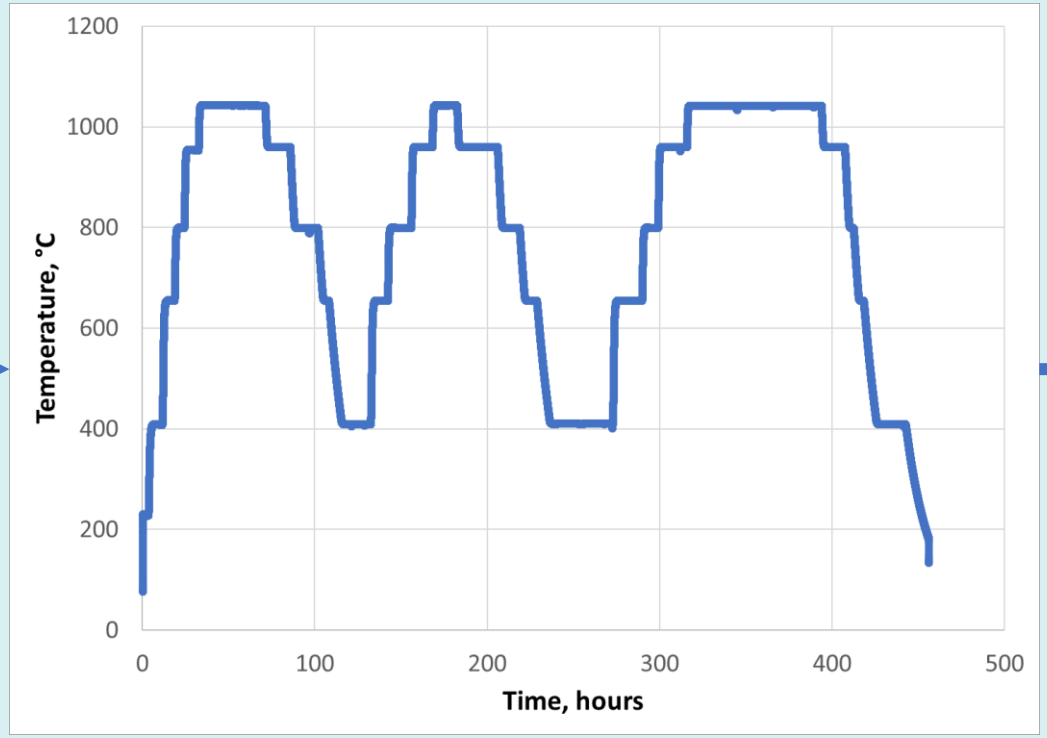
Advantages

- one reference sensor can be used for checking the drift of several thermocouples
- no need for a scanner or multiple pyrometers
- reference sensor will last longer since it will be not continuously exposed to high temperatures

Performance testing method

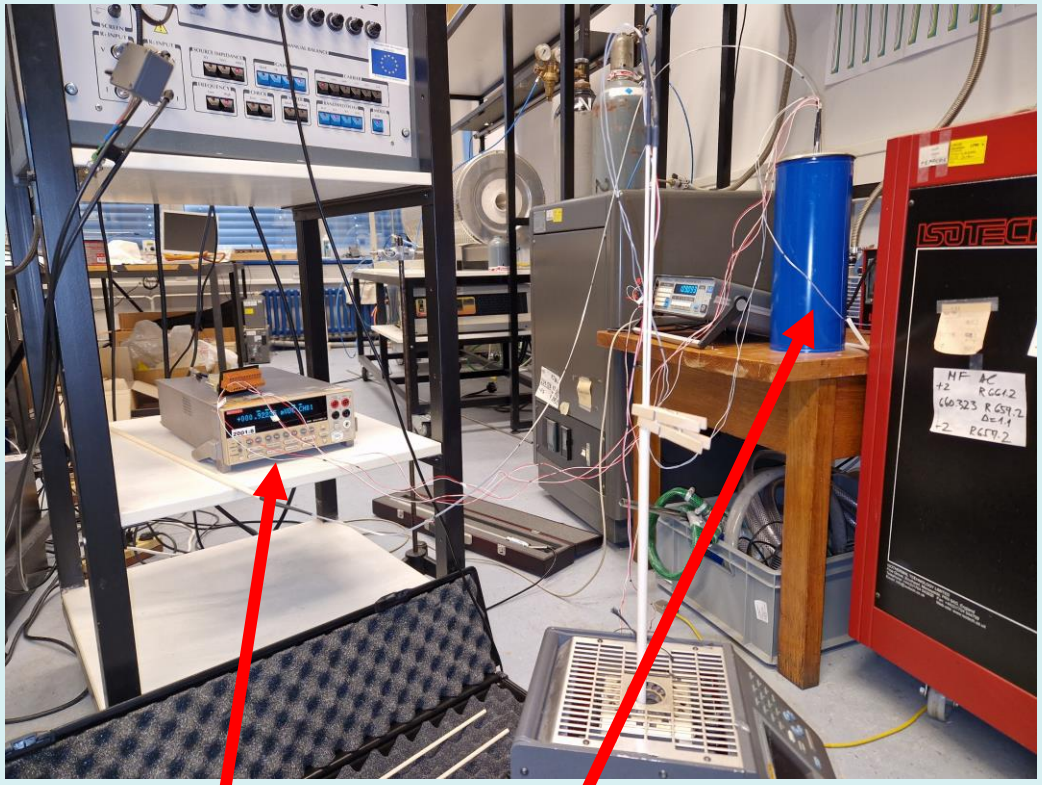
1. calibration of monitored and reference sensors as a separate instruments
2. placing both sensors in a same protective sheath (forming a dual type probe)
3. heating and cooling dual type temperature probe from one calibration temperature to another
4. repeating calibration

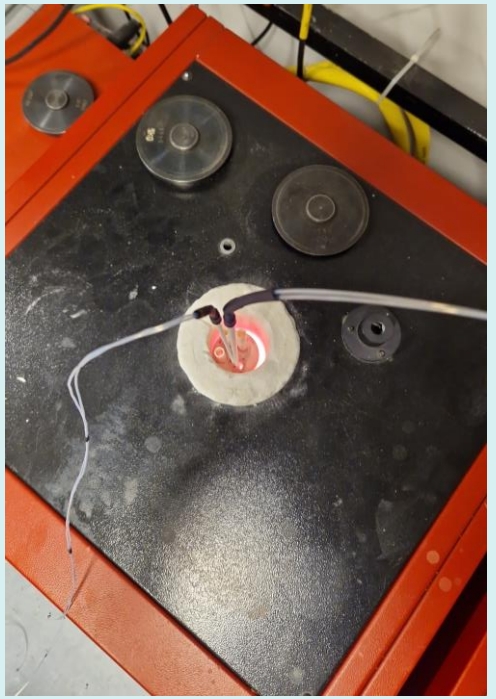
Calibration 1

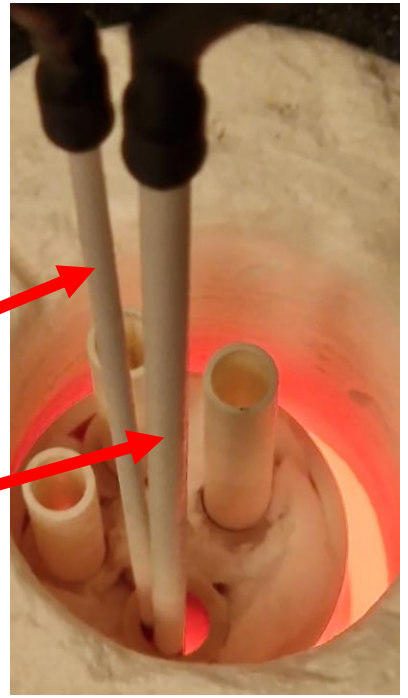


Calibration 2

Measurement setup – FSB-LPM Croatia

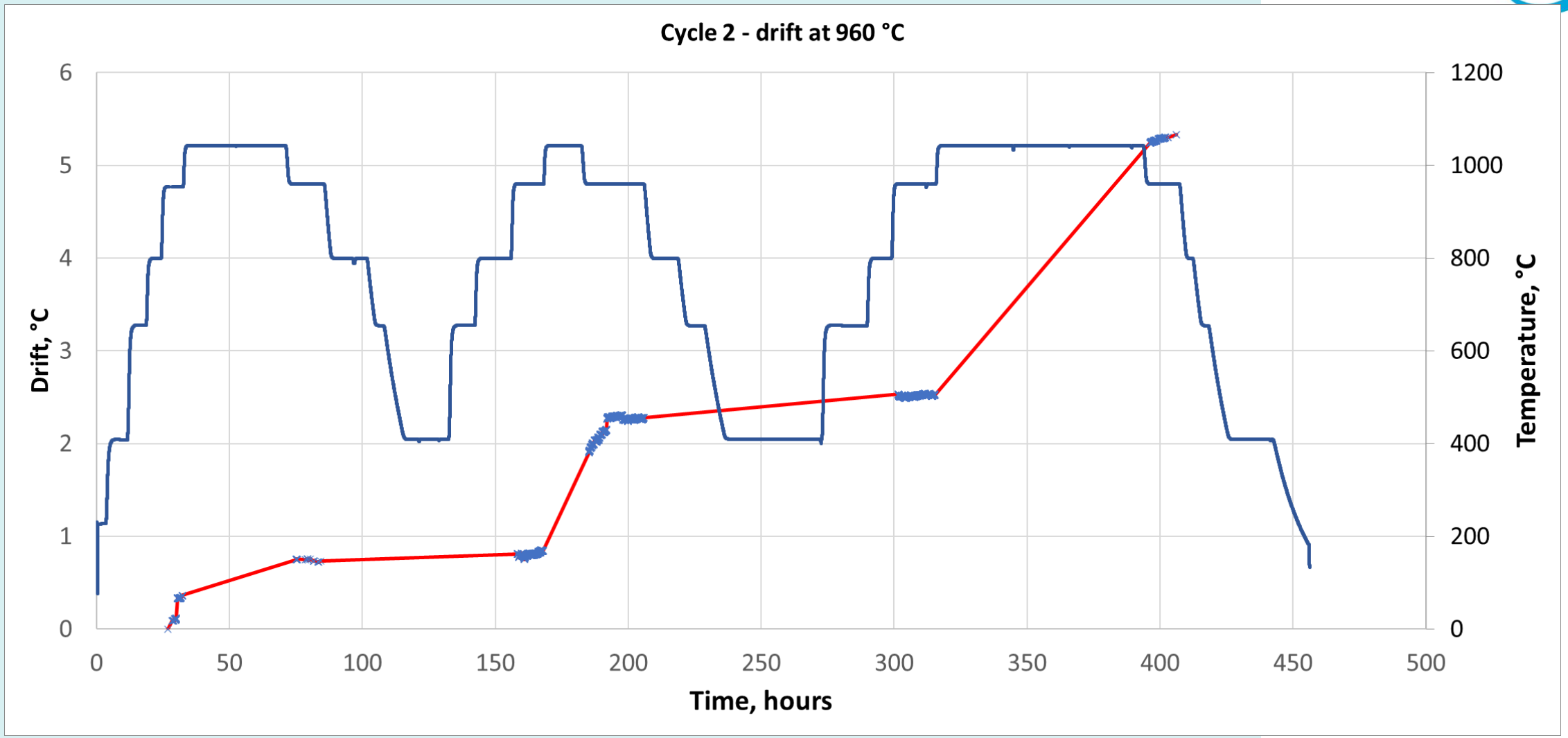






Voltmeter: Keithley 2001
Cold junctions: Ice bath
Reference thermocouple: type S (Ø=0.35 mm)
Monitored thermocouple: type K (Ø=1.0 mm)

Measurement results – FSB-LPM Croatia



Measurement results – FSB-LPM Croatia

Nominal temperature, °C	960	800	660	410	230
Drift determined by calibration (ref.)	5.4	3.6	1.8	1.1	3.3
Drift determined by DTT	5.33	3.36	1.81	1.25	-0.01
Difference between DTT and CALIBRATION	**0.0**	**-0.3**	**0.0**	**0.2**	**-3.3**

Conclusion

- novel concept of dual-type temperature sensors has been developed within the framework of the ongoing project EMPIR Research Potential Project “Developing Traceable Measurement Capabilities for Monitoring Thermocouple Performance” (MetForTC)
- concept aims to provide a relatively simple and cheap solution for in-situ monitoring of thermocouple drift
- testing results obtained by FSB-LPM for DTT consisting of monitored thermocouple type K and reference thermocouple type S indicate that concept works
- dual-type thermometers were tested in all national metrology institutes participating in this project
- progress can be tracked through the project website: **www.metfortc.org**

Acknowledgement

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Thank you for your attention!