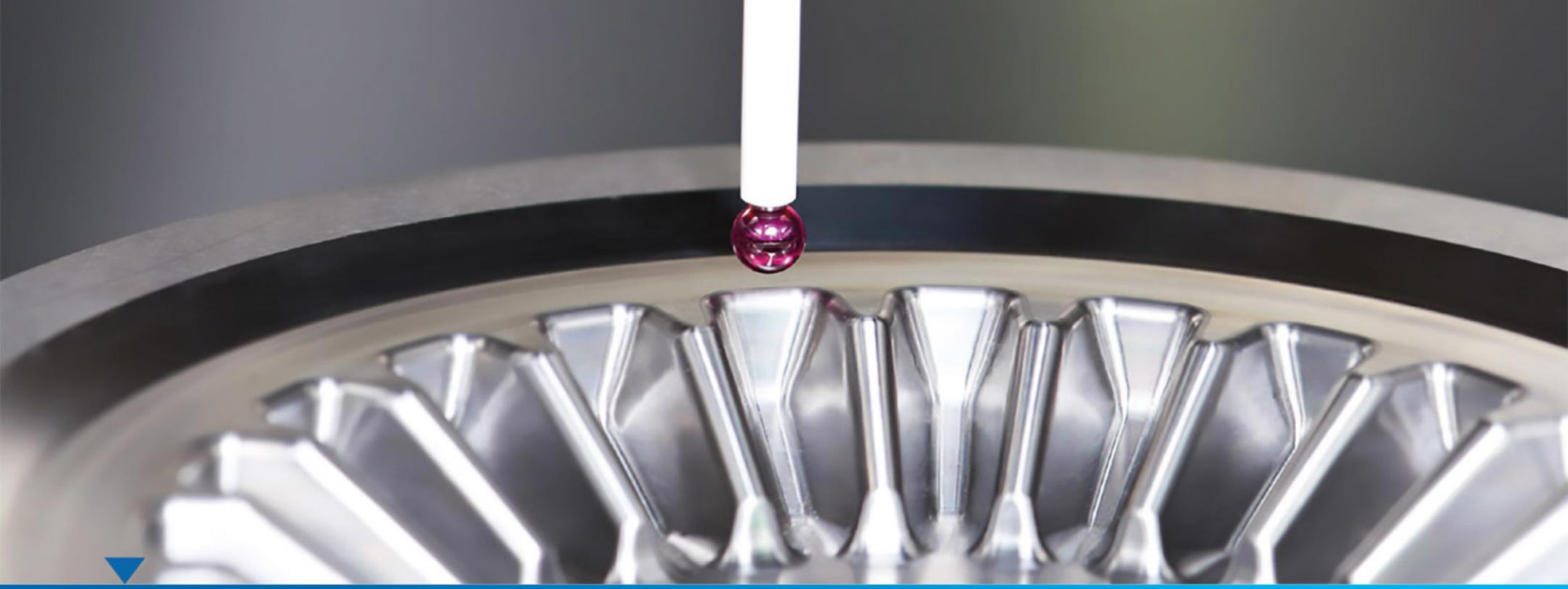


Good practice guide on selection, preparation and calibration of temperature sensors to be used in HTGHP

ČESKÝ METROLOGICKÝ INSTITUT

SIB52 THERMO

Metrology for thermal protection materials

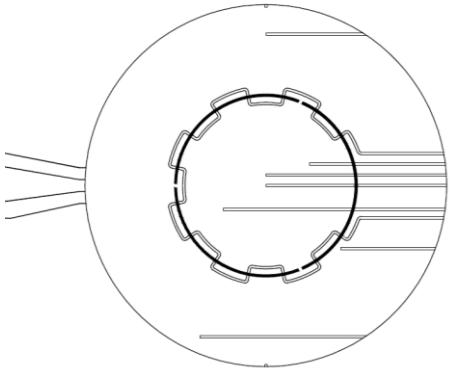
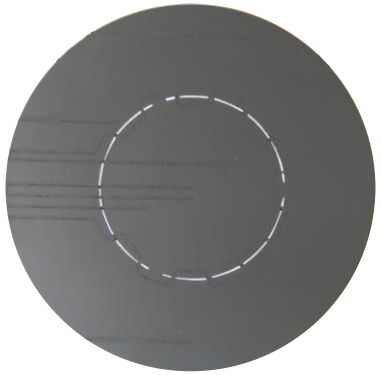
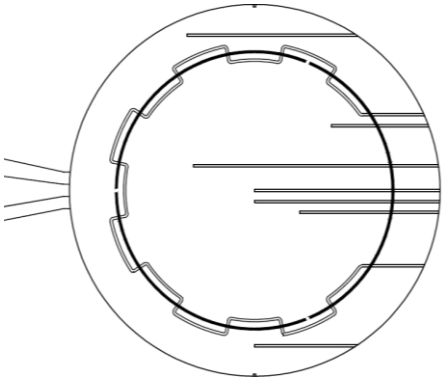
EURAMET

Content

- Introduction
- Temperature measurement
- Evaluation of sensors
- Uncertainty of measurements
- Summary

Temperature measurement

- Range to 850 °C
- Because of range – thermocouples are selected
- Requirements and limitations
  - High accuracy, precision and long-term stability at upper temperature limit
  - Minimal disruption of temperature profile
  - A small as possible x drift -> Thermocouples 1-2 mm

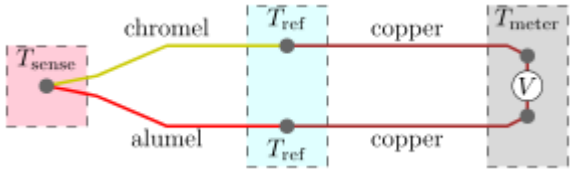





Temperature measurement

- Base metal thermocouples
  - Type K (Chromel-Alumel)
  - Type N (Nicrosil-Nisil), better stability than Type K
- Noble metal thermocouples
  - Type R (PtRh (13% Rh)/Pt)
  - Type S (PtRh (10% Rh)/Pt)
  - Type B (PtRh (30% Rh)/PtRh (6% Rh)) (t > 250 °C)
  - Au/Pt
  - Pt/Pd

$$\nabla V = -S(T)\nabla T,$$

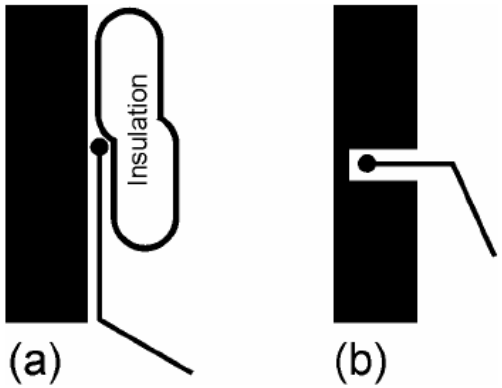
$$V = \int_{T_{\text{ref}}}^{T_{\text{sense}}} \left(S_+(T) - S_-(T)\right)\, dT,$$

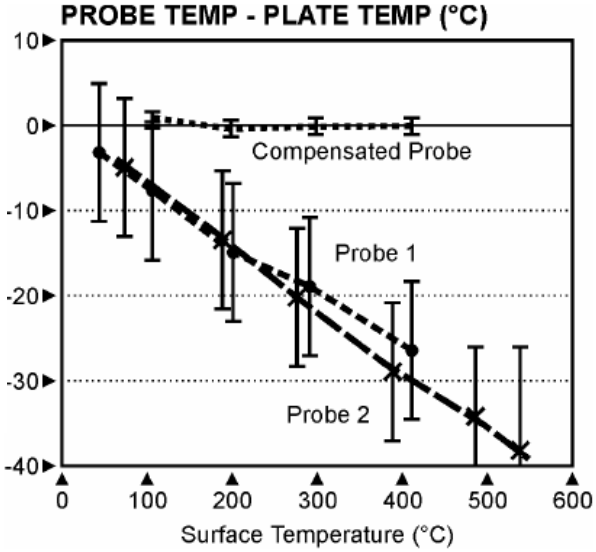


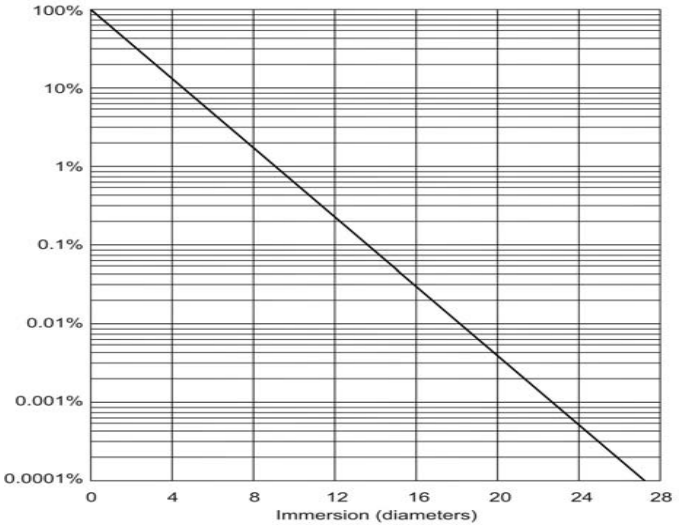
Thermoelectric voltage values, sensitivity values and class 1 tolerances at 850 °C for selected thermocouple types (EN 60584)

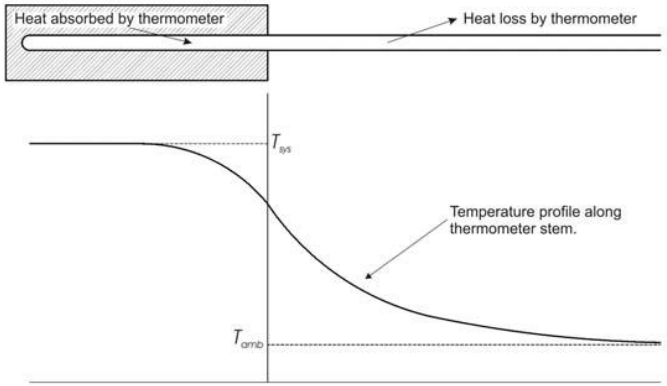
Thermocouple	Thermoelectric voltage (μV)	Sensitivity (μV/°C)	Class 1 tolerance (°C)
Type K	35313.1	40.5	±3.4
Type N	30415.6	39.2	±3.4
Type R	8571.4	12.6	±1
Type S	7892.7	11.0	±1

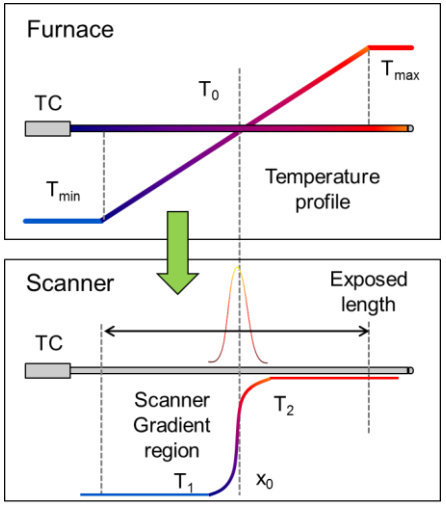
Temperature measurement









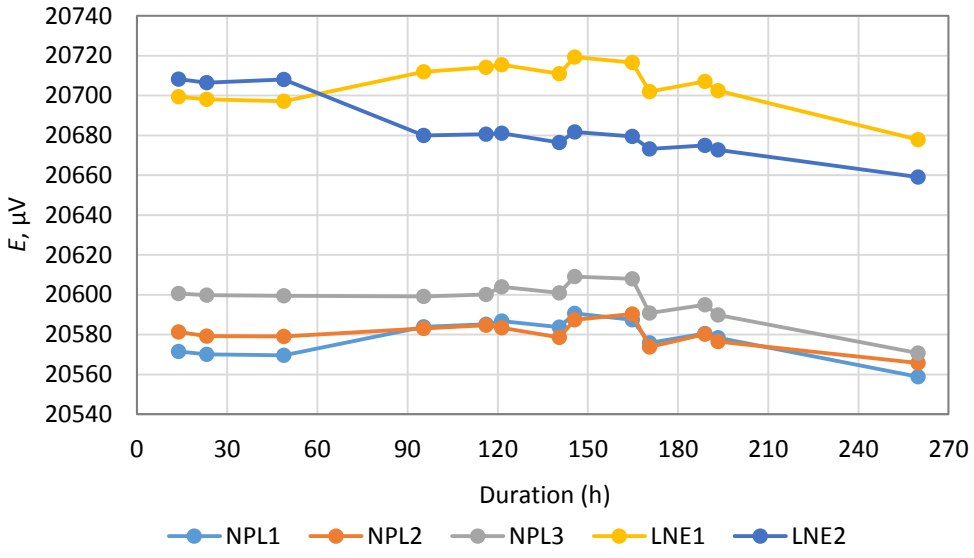


Description of measurements

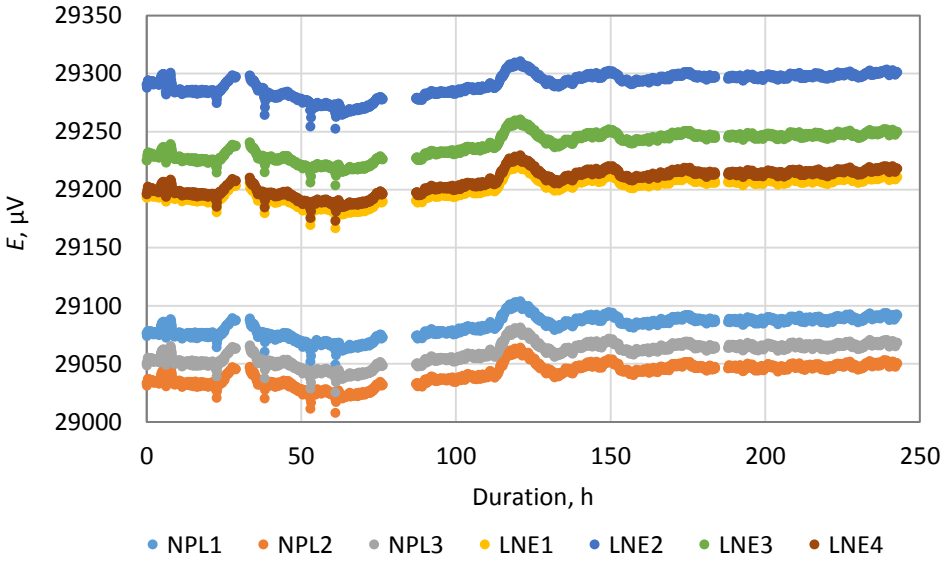
- Two batches of thermocouples
- Annealing of thermocouples at 850 °C
- Measurement of thermocouples homogeneity at 200 ° in oil bath
- Stability measurements at 600 °C (only 1st batch)
- Stability measurements at 815 °C (1st batch), at 825 °C (2nd batch)
- Reference junction: isothermal box (1st batch) or ice-point (2nd batch)
- Investigated thermocouples
  - MIMS type N thermocouples (1 mm diameter, different suppliers)
  - MIMS type S thermocouples (1.5 mm diameter)
  - (Reference S type thermocouple)

Results of stability measurements – 1st batch

Stability measurements at nominal temperature 600 °C

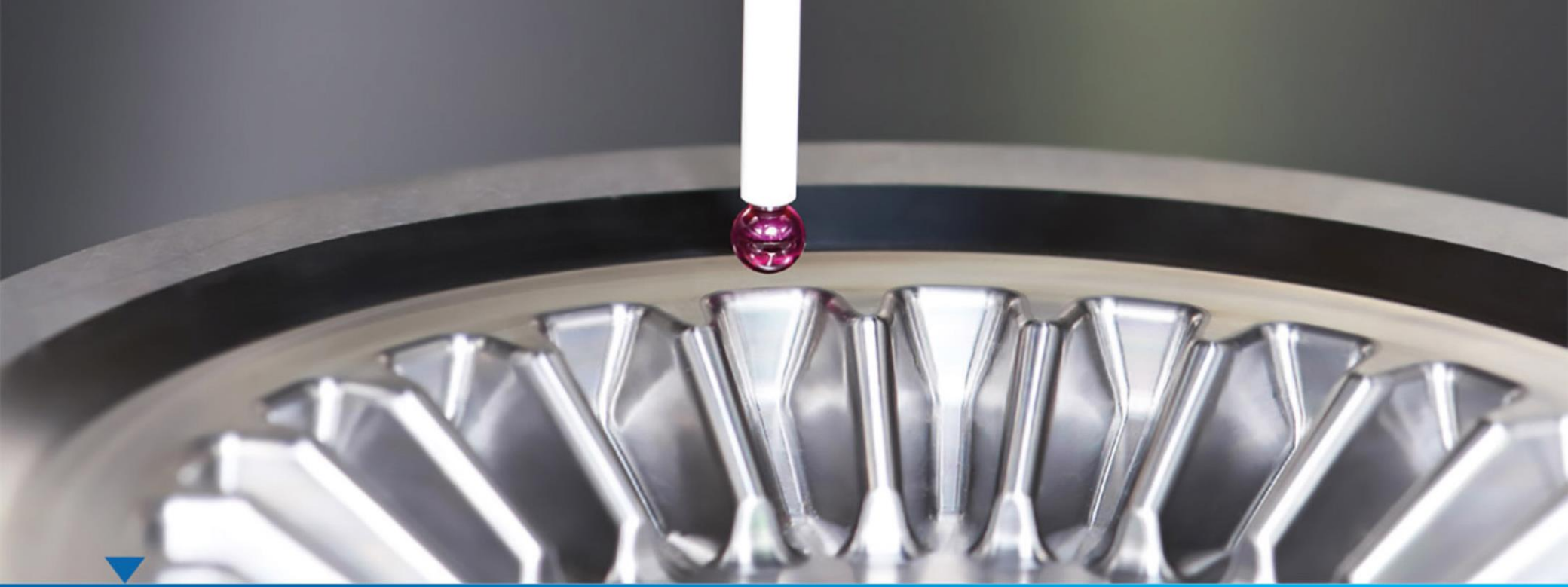


Stability measurements at nominal temperature 815 °C



- 6 type N thermocouples (NPL1, NPL2, NPL3, LNE1, LNE2, LNE3, LNE4)
- measurements reveal temperature drift of air furnace
- to filter out the influence of furnace thermocouples were compared to thermocouple LNE1

- temperature drift < 10 µV (~ 0.26 °C) within 250 hours



ČESKÝ
METROLOGICKÝ
INSTITUT

Results of measurements in oil bath at nominal temperature 200 °C

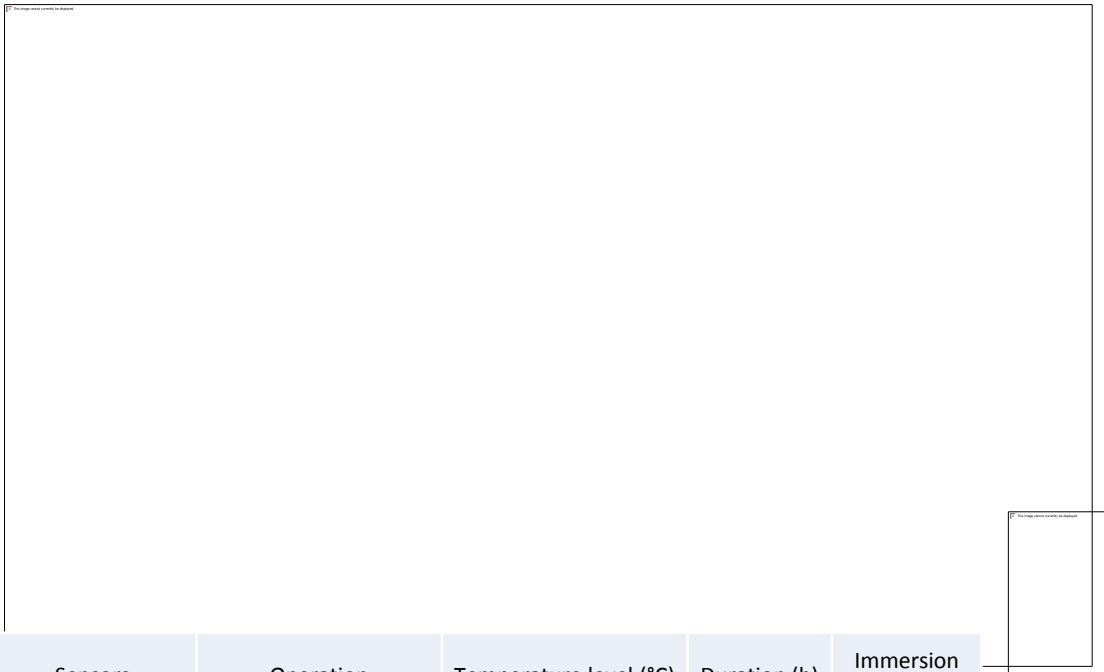
Label	*t* (°C)					
	1st Batch			2nd Batch		
	Before (200.05 °C)	After (200.06 °C)	Difference	Before (200.00 °C)	After (200.03 °C)	Difference
NPL1	199.1	199.9	0.8	-	200.3	0.4*
NPL2	199.2	199.8	0.6	-	200.2	0.4*
NPL3	199.2	200.2	1.0	-	-	-
LNE1	199.7	200.2	0.4	-	-	-
LNE2	199.8	200.3	0.5	-	-	-
LNE3	199.7	200.2	0.5	-	-	-
LNE4	199.7	200.0	0.3	-	-	-
LNE5	-	-	-	200.9	200.9	0.0
LNE6	-	-	-	200.8	200.8	0.0
CMI2	-	-	-	199.9	200.0	0.1
CMI3	-	-	-	199.9	199.9	0.0
S1	-	-	-	200.6	200.8	0.2
S2	-	-	-	200.7	200.7	0.0
S3	-	-	-	200.7	200.6	-0.1

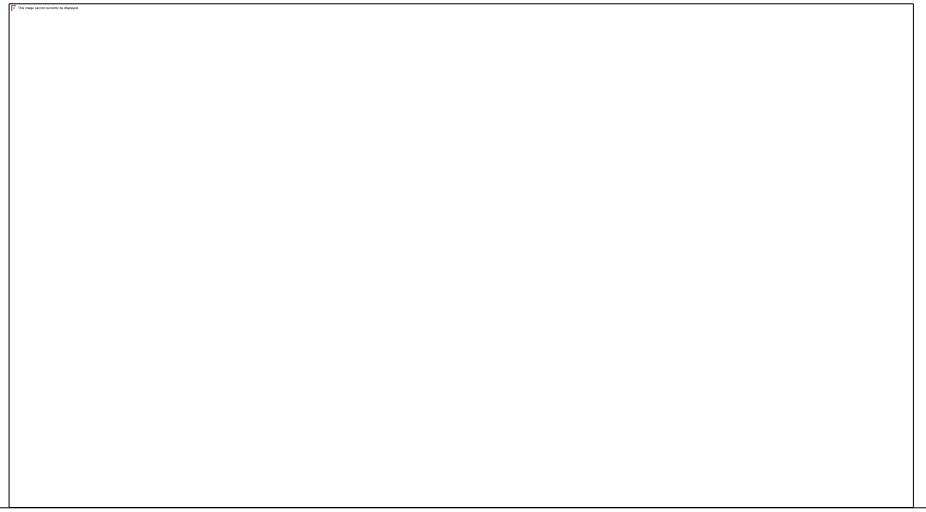
*Difference from "After" measurement within 1st batch

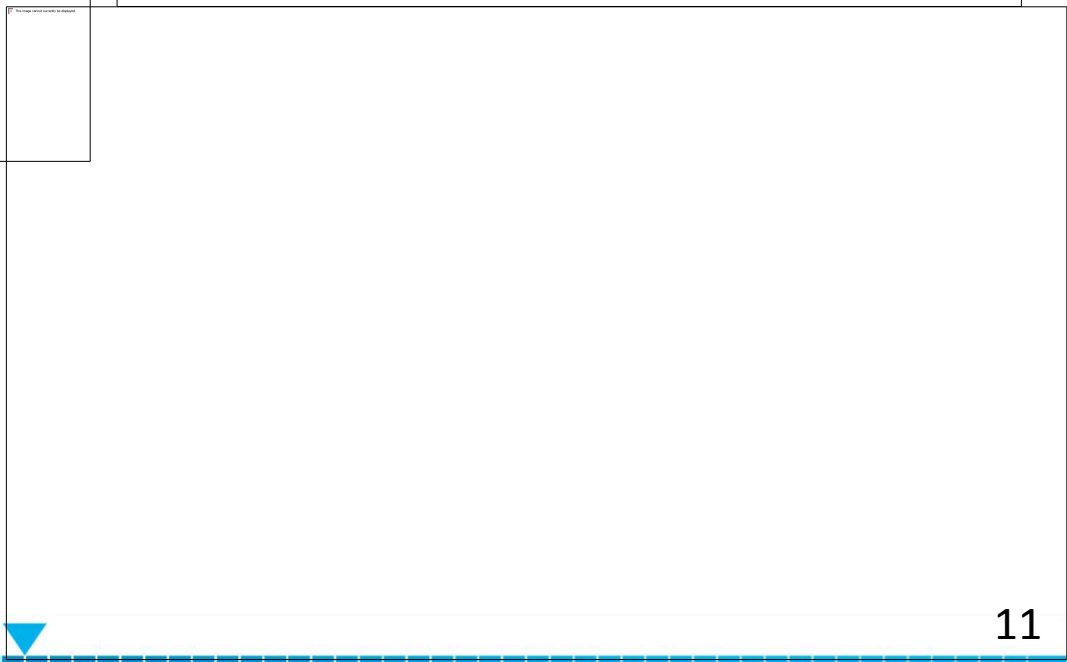
Temperature measurement - calibration

- Period of calibration?
- Period of replacing temperature sensors?
- Detection of temperature sensor drift?
- Batch agreement for thermocouples
- In-situ x External

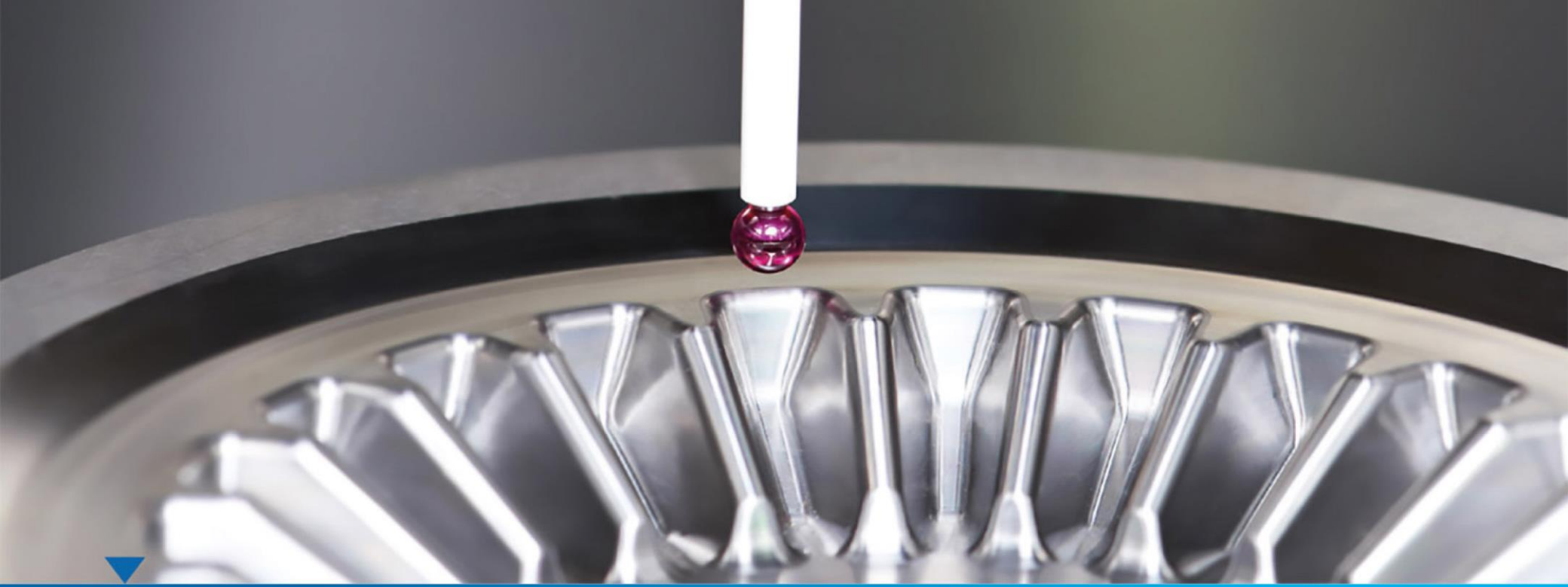
Detection of drift and deviation





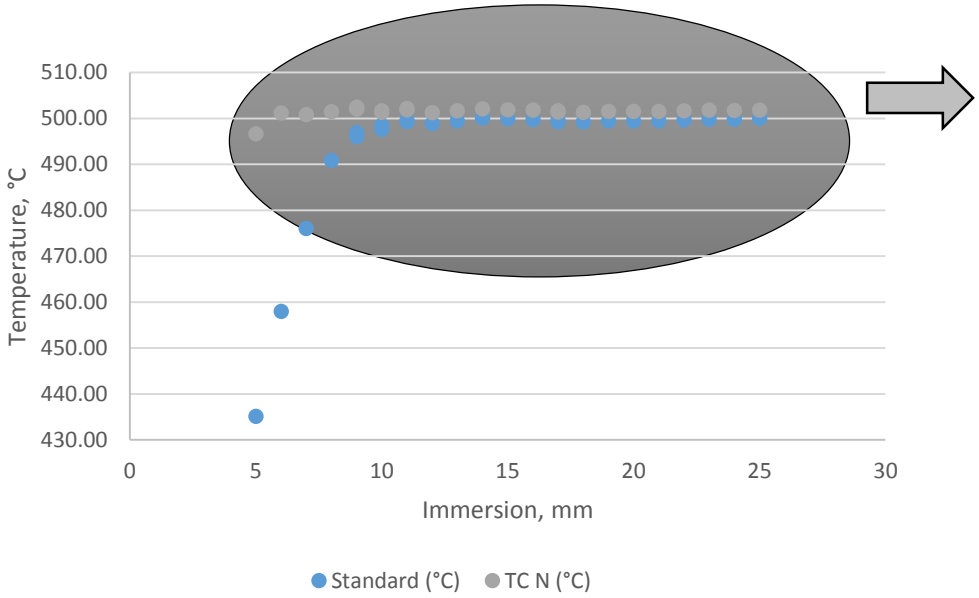


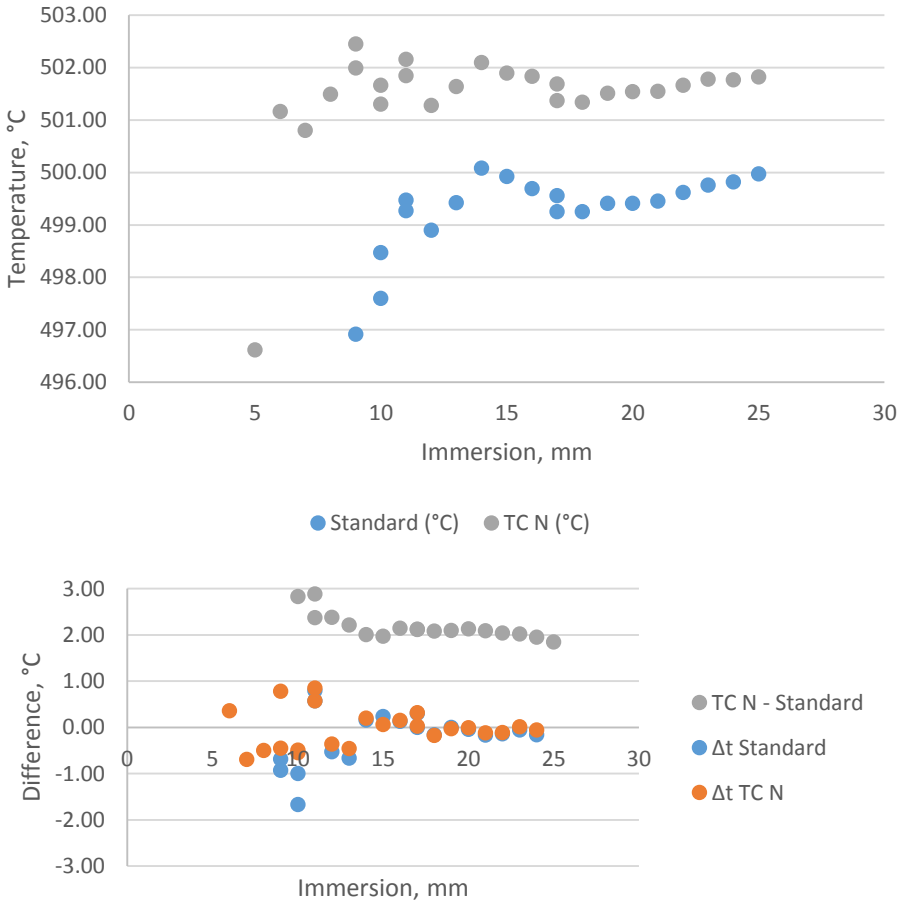
Sensors	Operation	Temperature level (°C)	Duration (h)	Immersion depth (mm)
K1 to K5 & N1 to N5	Annealing	800	24	600
K1 toK10 N1 to N10	Calibration 1	0 / 200 / 400 / 600 / 800	20	600
	Heat cycling	Up to 800	33	
	Calibration 2	0 / 200 / 400 / 600 / 800	20	
	Heat cycling	Up to 800	96	
	Calibration 3	0 / 200 / 400 / 600 / 800	20	
	Heat cycling	Up to 800	48	
	Calibration 4	400 / 600 / 800*	20	
	Heat cycling	Up to 800	72	
	Calibration 5	200. 400 / 600 / 800	20	



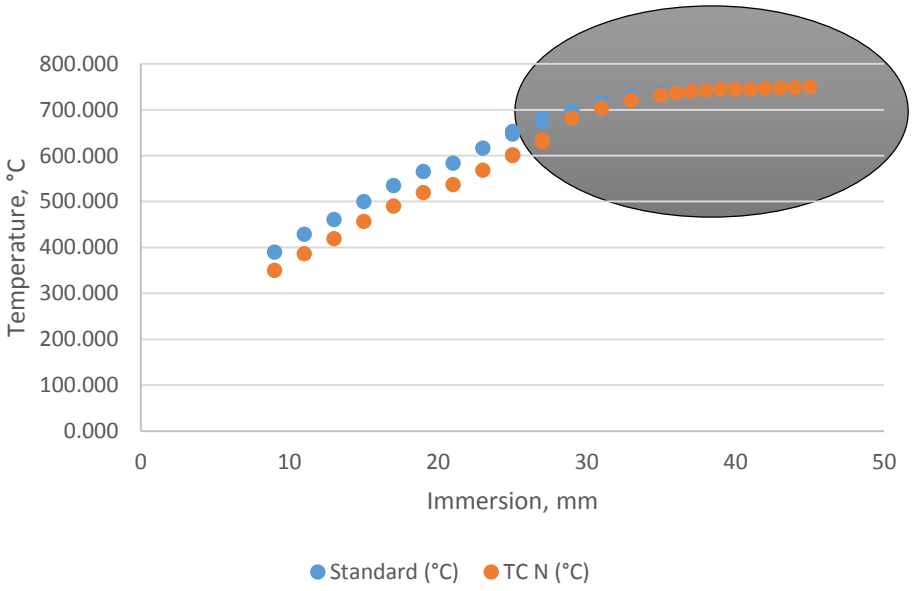
ČESKÝ
METROLOGICKÝ
INSTITUT

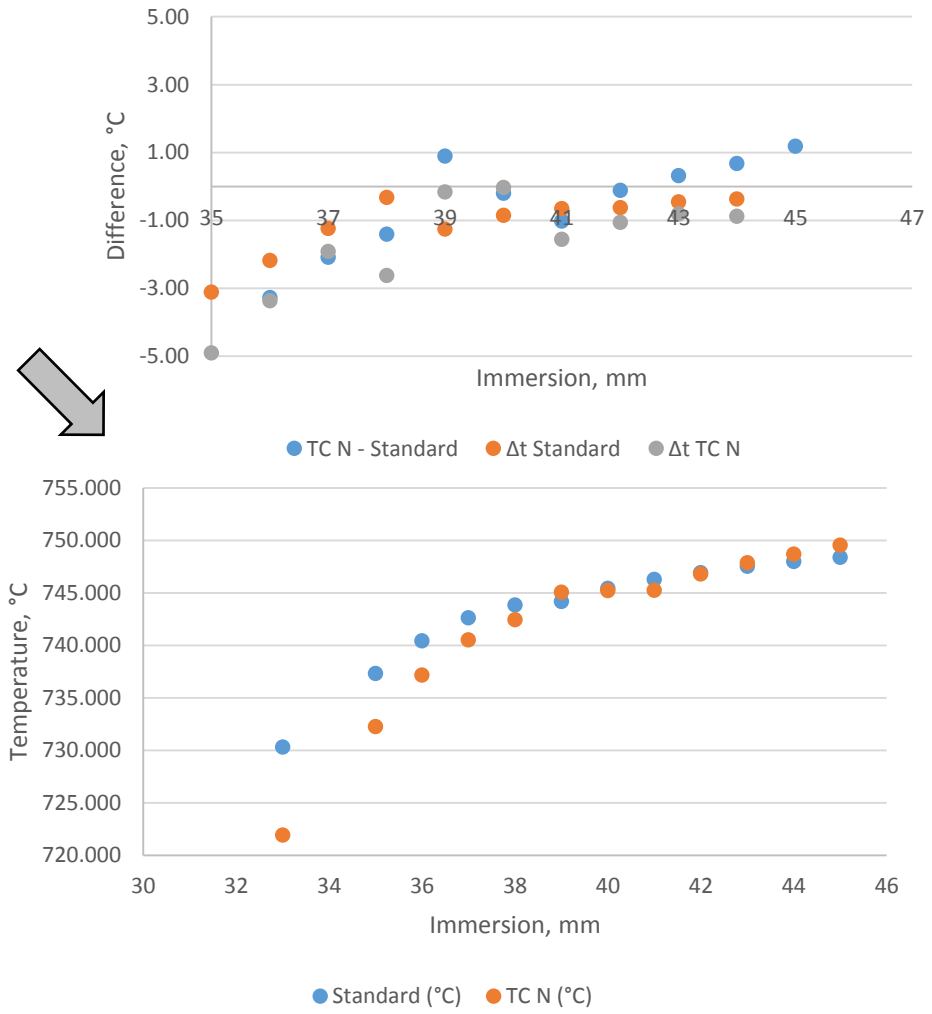
Temperature measurement





Temperature measurement



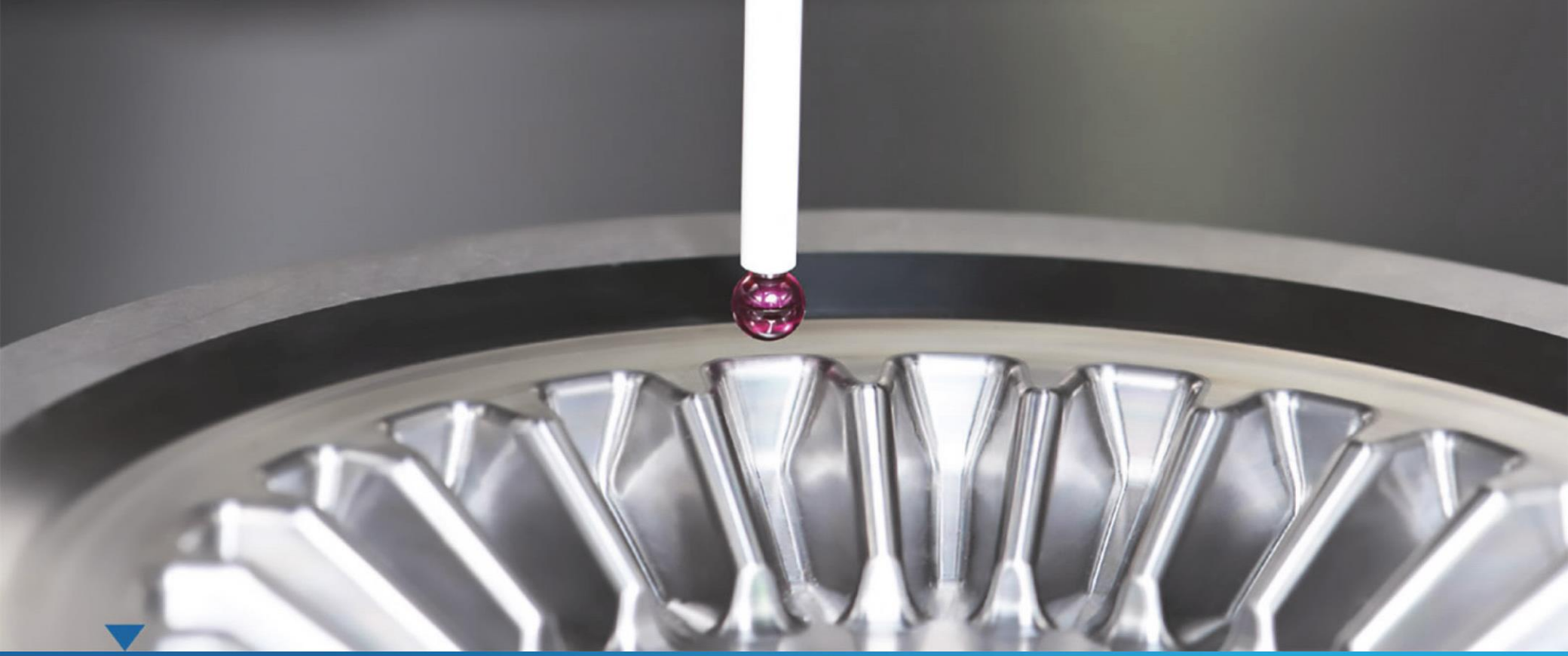


Temperature measurement - uncertainty

- Calibration (tc and multimeter – reading device)
  - Best 0.2 °C
  - Normal 0.4 to 1.5 °C
- Drift (tc and multimeter)
  - 0.2 to 1 °C
- Homogeneity of TC and material
  - Around 0.5 °C
- Heat conduction
  - 0.3 to 2 °C
- Non ideality of wires (switch)
  - Neglitible if good
- Cold junction
  - Stability and homogeneity – 0.1 to 0.6 °C
- Resolution

Conclusion

- Type N, S thermocouple
  - 1-1.5 mm diameter
  - Calibrated in different immersion
    - Minimum 34 mm
    - ON-SITE calibration
- Uncertainty
  - Absolut – around 1-3 °C
  - Difference – several tens of degree



THANK YOU!

ČESKÝ METROLOGICKÝ INSTITUT

Okružní 31, 638 00 Brno, Czech Republic, www.cmi.cz
ČMI OI Praha, Radiová 3, 102 00 Praha 10, rstrnad@cmi.cz

EURAMET