Passive cooling of precision measuring equipment by means of latent heat

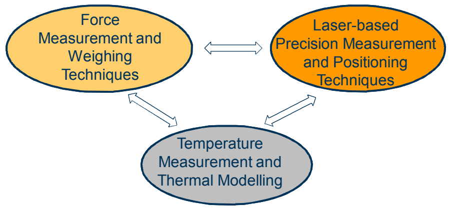
Schalles, M. Breitkreutz, P.
Technische Universität Ilmenau
Flügge, J. Köning, R.
Physikalisch Technische Bundesanstalt, PTB

EMRP IND13: Thermal design and time-dependent dimensional drift behaviour of sensors, materials and structures

Institute of Process Measurement and Sensor Technology

Process Measurement Technology
Chair: Univ.-Prof. Dr.-Ing. habil. Thomas Fröhlich

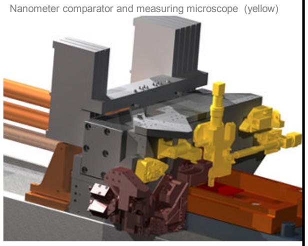
Precision Measurement Technology
Chair: Univ.-Prof. Dr.-Ing. habil. Eberhard Manske



Background

- EMRP IND13: Thermal issues in precision dimensional measurement and engineering
- Thermal optimisation of measuring microscope of nanometer comparator at PTB
- Measuring microscope used to observe the lines of linear encoders

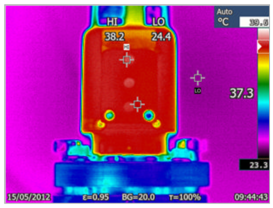
Nanometer comparator and measuring microscope (yellow)



Background

- Joule heating due to electrical power of camera $P \sim 4.5$W
- Obvious: problem with generated heat
- Difference of camera surface temperature to room temperature $\Delta T_{surf} \sim 15$ K
- Heat exchange with measuring microscope and comparator
- Non-homogeneous temperature field x different thermal expansion coefficients → unknown changes in temperature (and time) dependent dilatation
- Need for thermal improvement/ optimisation

Camera used in microscope



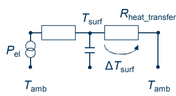
Thermal image of mounted camera

Starting conditions

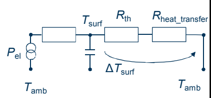
- Aim:
  - Camera should be cooled down
  - Enable stable thermal conditions during dimensional measurement
  - Thermal decoupling of camera from measuring set-up
  - Provide thermal shield between warm camera and comparator set-up
- Conditions:
  - Temperature stabilised room, T_{amb} = 20 °C, v_{air} = 0.2…0.4 m/s
- Methods:
  - Passive cooling (heat sinks without additional active cooling)
  - Active cooling (water cooling, air cooling, peltier cooling)

Cooling Strategies – Passive Cooling

- Camera is thermally decoupled from set-up
- Camera is cooled only by convective heat transfer from air flow in climate room and radiative heat transfer
- Convection coefficient $\alpha \sim 8..12$ W/m²/K, emissivity $\varepsilon \sim 0.9 \rightarrow R_{heat\_transfer} \sim 7.5..12$ K/W
- $\Delta T_{surf} > 30$ K to environment



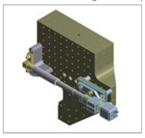
- Cooling elements can be mounted at camera
- With fin coolers increase of surface by factor 30
- Problem: Thermal resistance of cooling elements $R_{th}+R_{heat\_transfer} \sim 0.5..2$ K/W (v~0.2…0.4 m/s)
- $\Delta T_{surf} \sim 2…9$ K to environment

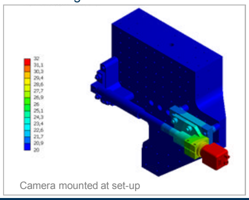


Comparison with FE-Simulation

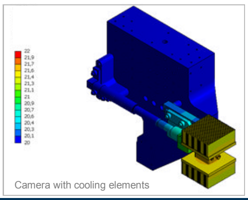
- Stationary thermal calculations
- Temperature fields are plausible and agree with preliminary calculations
- With cooling elements still significant temperature gradients in the microscope
- Further reduction of ΔT in this setup only possible with active cooling

Model of measuring microscope





Camera mounted at set-up



Camera with cooling elements

Active Cooling

Active cooling by air (fan)

- Advantage:
  - If v=∞, then $R_{heat\_transfer} \rightarrow 0$ K/W
- Disadvantages:
  - air flow can cause mechanical vibrations
  - air cannot be cooled in place

Active cooling by liquid (water)

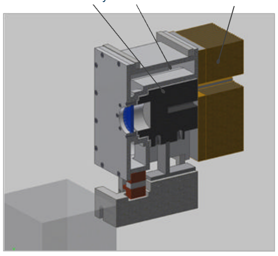
- Advantages:
  - Water can be transported to camera/ microscope
  - Water can be cooled below room temperature (controlling)
  - Highly effective cooling elements availible (CPU/ GPU cooling)
- Disadvantages:
  - Mechanical vibration can disturb measurements

Cooling by Phase Change and Latent Heat

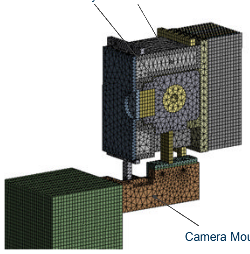
- Preliminary considerations showed:
  - No active water cooling system and no active air cooling system should be used (avoiding of mechanical vibrations)
  - Cooling power of passive air cooling by heat sinks is too low
- Passive cooling by means of a phase change material (PCM) is chosen
- PCM absorbs parasitic heat of camera
- Heat brings material to melt and is transformed into latent heat
- Which PCM to use?
- Most PCMs based on hydrocarbons or salt hydrates have broad temperature range of phase transition (unsuitable)
- Eutectic alloy GaSn changes phase at ~20.4 °C
- Advantages:
  - Phase transition temperature is close to working temperature range of Nanometer Comparator
  - Narrow melting temperature range

Design of Cooling Element – Demonstration Model

- Development of demonstration model with camera dummy

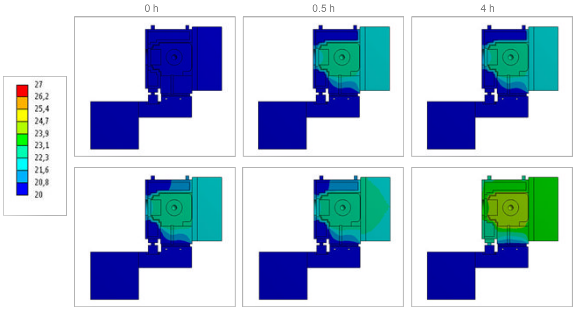


Construction drawing of Demonstration Model

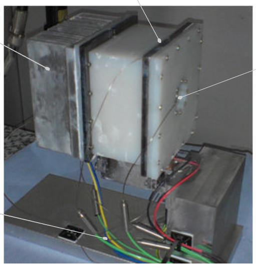


FEM – Model of Demonstration Model

Thermal Simulations

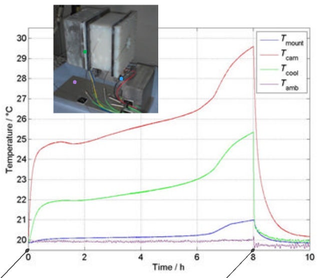


Measurement Setup in Climatic Chamber



Measurement in Climatic Chamber

- Temperature stabilises after ~ 0.5 hours
- Phase transition lasts 6 to 8 hours (melting)
- Temperature at mounting remains constant within 6 hours
- After switching off, material freezes again
- Improvement of plateau shape and duration of phase transition



t = 0 h
Electrical power of camera dummy switched on (*P* = 4.5W)

t = 8 h
Electrical power switched off

Summary and Outlook

<u>Summary</u>

- Proof of principle of passive cooling method by means of latent heat
- No moving parts and fluids, no vibrations
- Thermal shield for camera provided
- Stable conditions at camera mounting for 6h

<u>Outlook</u>

- Further improvement of design (homogenisation of phase transition)
- Development and construction of final design of cooling element which is appropriable in Nanometer Comparator

<u>Acknowledgement</u>

- The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union.