

Passive cooling of precision measuring equipment by means of latent heat

Schalles, M. Breitzkreutz, 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



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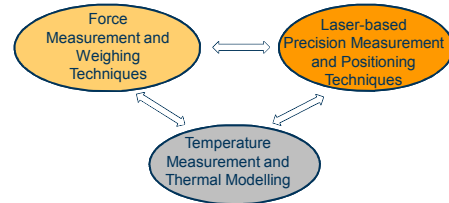
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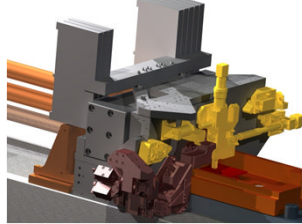
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Background

- 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)



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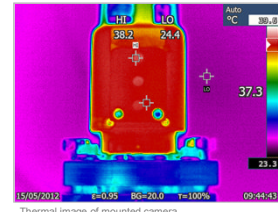


Background

- Joule heating due to electrical power of camera $P \sim 4.5W$
- 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 \rightarrow unknown changes in temperature (and time) dependent dilatation
- Need for thermal improvement/ optimisation



Camera used in microscope



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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, $T_{amb} = 20 \text{ }^\circ\text{C}$, $v_{air} = 0.2 \dots 0.4 \text{ m/s}$
- Methods:
 - Passive cooling (heat sinks without additional active cooling)
 - Active cooling (water cooling, air cooling, peltier cooling)

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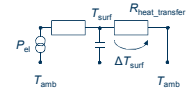
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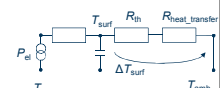


Cooling Strategies – Passive Cooling

- 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 $\alpha \sim 8 \dots 12 \text{ W/m}^2\text{K}$, emissivity $\epsilon \sim 0.9 \rightarrow R_{heat_transfer} \sim 7.5 \dots 12 \text{ K/W}$
- $\Delta T_{surf} > 30 \text{ K}$ to environment



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



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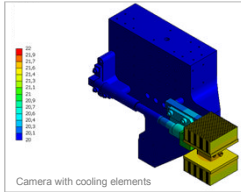
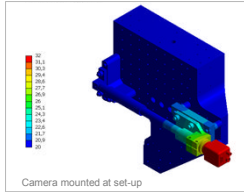
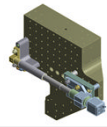
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Comparison with FE-Simulation

- 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



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Active Cooling

Active cooling by air (fan)

- Advantage:
 - If $v \rightarrow \infty$, then $R_{\text{heat_transfer}} \rightarrow 0$ KW
- 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 available (CPU/ GPU cooling)
- Disadvantages:
 - Mechanical vibration can disturb measurements

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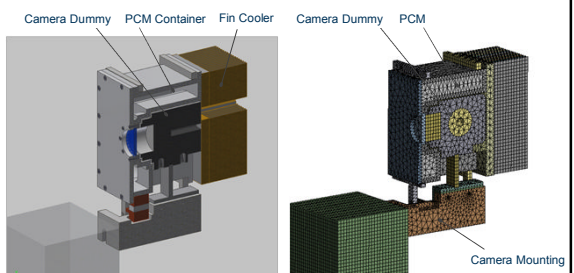


Cooling by Phase Change and Latent Heat

- 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



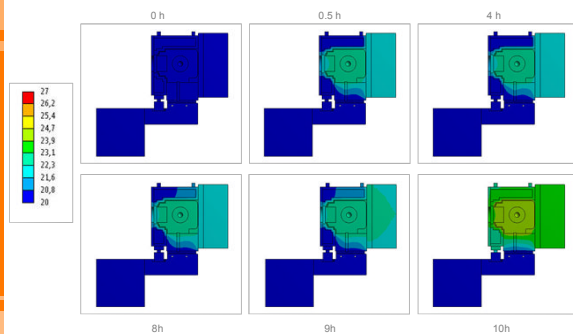
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Thermal Simulations



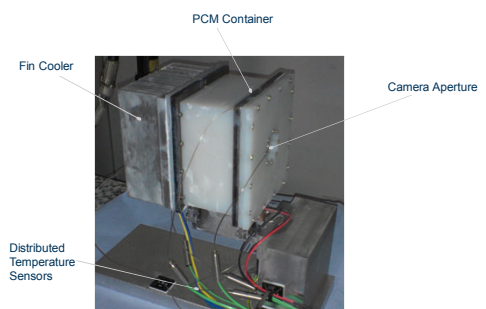
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Measurement Setup in Climatic Chamber



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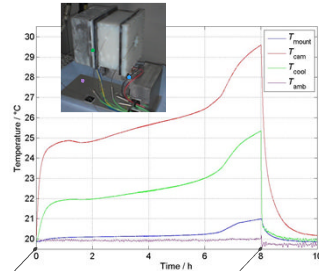
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Measurement in Climatic Chamber

- 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

Summary

- 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

Outlook

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

Acknowledgement

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