MKEH HTTCMA for thermal conductivity measurements

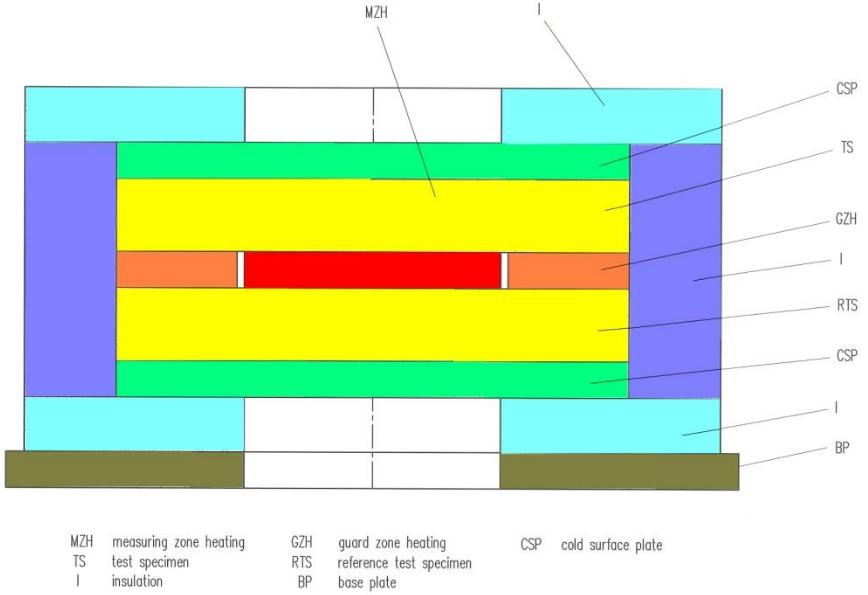
In case of the MKEH in-house built high-temperature thermal conductivity measurement apparatus (HTTCMA) a new conception was applied.

The aim is not to minimise the errors, but to quantify them and to take them all in correction, in this way minimising the measurement uncertainty.

The principle of operation of the HTTCMA is a GHP principle, having heated lateral guard.

MKEH in-house designed HTTCMA

- Double specimen apparatus
- Temperature range : 70 °C to 850 °C
- Thermal conductivity range λ: 0.02 $WK^{-1}m^{-1}$ to 5 $WK^{-1}m^{-1}$
- Pressure load : 5 kPa
- Specimen thickness : 20 mm to 60 mm
- High precision power meters for adjusting the electrical power supplied to MZH and GZH



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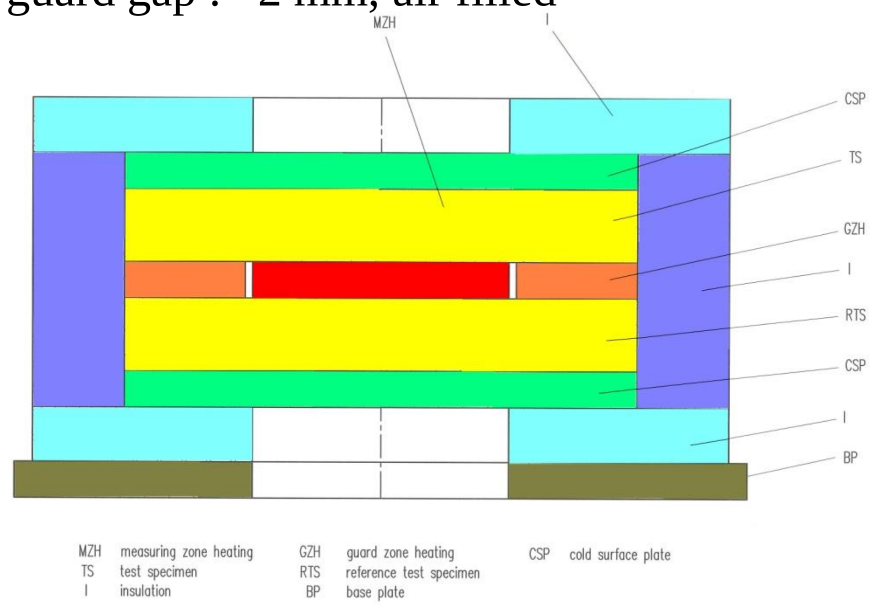
MKEH in-house designed HTTCMA

- Heater plates :
  - Thickness : 30 mm + 2 x 15 mm
  - Material : thermal resistant stainless steel
  - Emissivity : 0.8
- Dimensions:

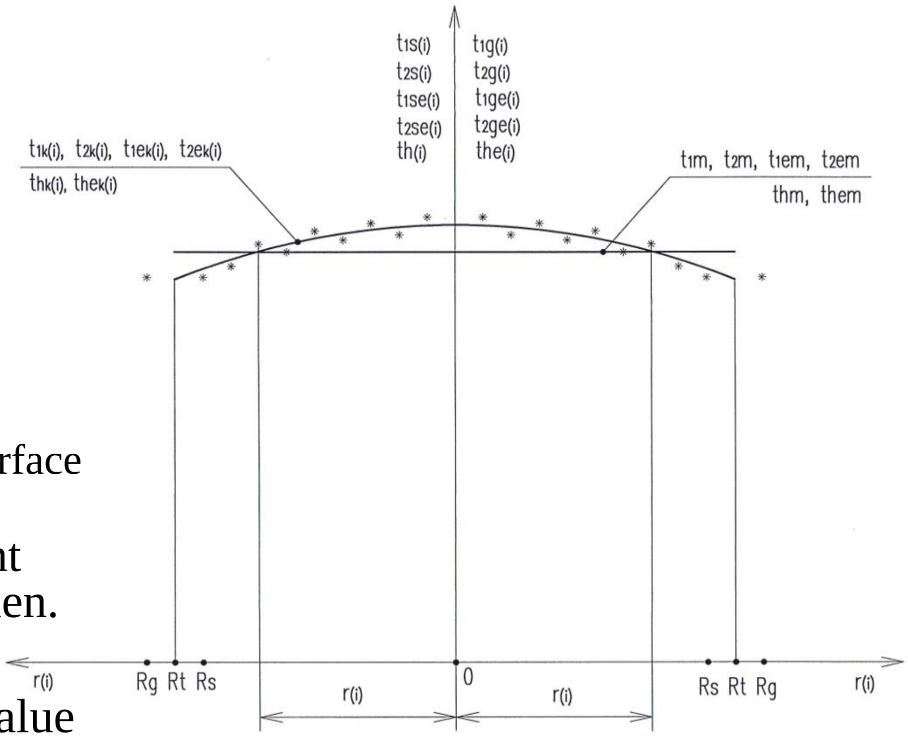
Overall lateral : Φ320 mm
Metering area : Φ200 mm
Centre-guard gap : 2 mm, air filled



MKEH in-house designed HTTCMA

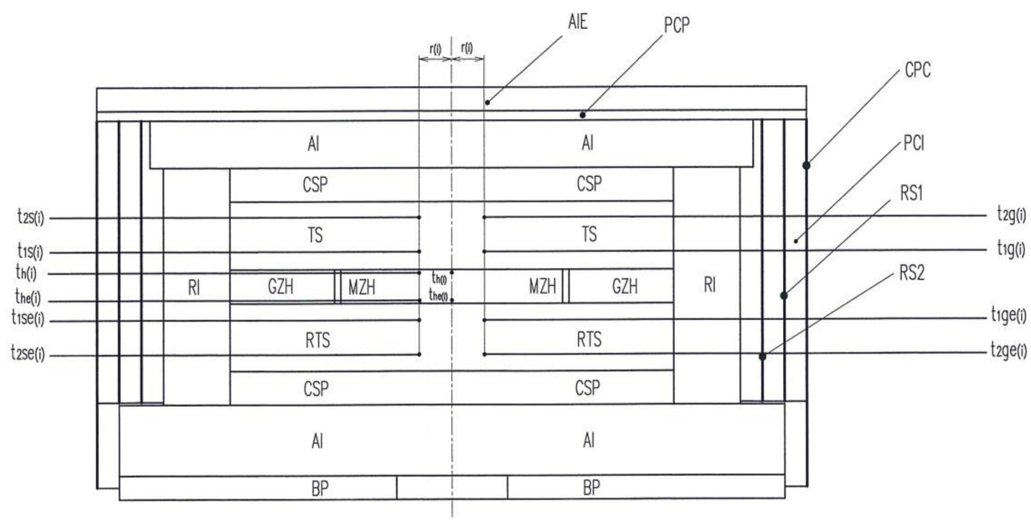
- Temperature sensors :
  - Type : „S" sheathed thermocouples
  - Number : 10
  - Thickness : Φ2 mm
  - Length : 350 mm
  - Thickness of the metal wire : 0.25 mm
- Position of the temperature sensors :
  - 4 + 4 in holes inside the specimens
  - 2 in grooves on the upper and lower surface of the heater plate
- The points in the graph are measurement results of temperature inside the specimen.

  Based on the measurement results, the function of temperature and the mean value can be determined.
- All temperature sensors are movable in radial direction.



MKEH in-house designed HTTCMA

MZH - measuring zone heater
GZH - guard zone heater
TS - test specimen
RTS - reference test specimen
CSP - cold surface plate
AI - axial insulation
RI - radial insulation
PCP - protective cover plate
CPC - cylindrical protective cover
PCI - Protective cover insulation
RS1 - radiative screen
RS2 - radiative screen
BP - base plate
AIE - external axial insulation



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Design differences between HTGHPs and the HTTCMA

- Modified design conform the standards CEN/TS 15548-1:2011 and ISO 8302:1991

Heated plates

- Cold plates not heated - optional in the standard
- Thicker heated plates

  Standard : „At high operating temperatures the heater plate has to be thicker to ensure uniform temperature distribution across the plate"

- High emissivity without using coating material

  The constantly high emissivity of the heater plate is obtained by forming an initial thin oxidation film on a thermal resistant metal.

  Standard : " The working surfaces of the heating unit and cooling unit plates shall not chemically react with the specimen „

Edge guard

- No active edge guard - optional in the standard
- Passive edge guard : Insulation + Radiative Screens

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- Passive edge guard : Insulation + Radiative Screens

The intention of applying passive edge guard was to eliminate some uncertainty components caused by active edge guards.
Some of the disadvantages of an active edge guard are :
different temperature gradients along the specimen and the edge guard caused by the existence of thermal contact resistance between the specimen and the heating plate,
possibility of additional heat given by the edge guard to the specimen.

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Centre-guard gap filled or unfilled

- In the HTTCMA the gap is unfilled
- An unfilled gap gives lower measurement uncertainty, because the physical and thermophysical properties of the air and its behaviour inside the gap is better known.
- A filled gap has unknown quality, unknown characteristics, unknown behaviour.

  Presence of 3 types of material together within the gap : some kind of powder, air and metal (thermophiles)

  If the gap temperature is measured with thermophiles, these are too close to the surface at the gap, resulting disturbation of the real temperature of the gap surfaces.

Design differences between HTGHPs and the HTTCMA

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Temperature sensors placed in holes in the specimen

- Standard : “The temperature difference across the specimen, ΔT, is measured by temperature sensors fixed on / or in the surfaces of the plates in contact with the specimen and / or those fixed on / or in the surfaces of the specimens themselves.”
- Standard : Use of sheathed temperature sensors to limit the degradation of these sensors due to oxidation
- The „S” type thermocouples are more thick in order to avoid their drift at high temperatures.

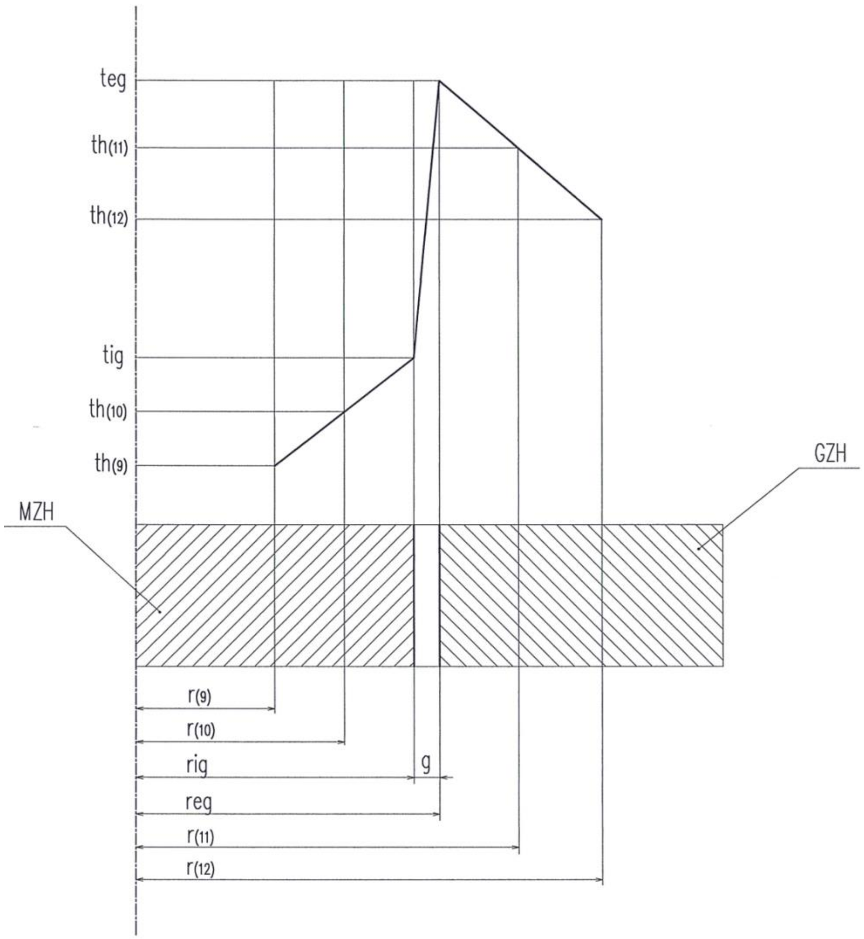
  And in this way there is no need to change them so often.
- Movable sensors for determination of temperature distribution in the specimen
- Direct measurement of TCR at surfaces.
- Applying extrapolation method

  In this way there is no distortion of the real temperature of the surfaces.
- Using this method, the temperature drop across the specimen can be larger. For larger temperature drop, the accuracy in determination of the λ is higher.

Determination of centre-guard imbalance

Imbalance error measured directly, using 2 movable “S” type sheathed thermocouples placed in grooves at the upper and lower surface of the heater plate, and applying extrapolation method.

In this way the real temperature of the surfaces surrounding the gap is not perturbed.



- Based on measurements effectuated by temperature sensors placed inside the specimen, the correction function can be determined.
- The change of the heat flow in axial direction (dQ(z)) is equal with the heat loss in radial direction (dQp).

$$Q(z) = -\lambda \cdot A \cdot \frac{dt(z)}{dz} \qquad Q(z+dz) = -\lambda \cdot A \cdot \frac{dt(z+dz)}{dz} \qquad dQ(z) = Q(z) - Q(z+dz)$$

$$dQ(z) = \lambda \cdot A \cdot \frac{d^2 t(z)}{dz^2} dz \qquad dQp = \frac{2\pi \cdot \lambda}{\ln \frac{R_G}{Rs}} \cdot [t_{RS}(z) - t_{RG}(z)] dz$$

$$t(z) = a_0 + a_1 \cdot z + a_2 \cdot z^2 + a_3 \cdot z^3$$

- The temperature difference can be determined from the following differential equation :

$$\frac{d^2 t(z)}{dz^2} = \frac{2\pi}{A \cdot \ln \frac{R_G}{Rs}} \cdot (a + b \cdot z)$$