Karlsruhe Institute of Technology

Measurement of the Heat Transfer from a Spark Gap Electrode Through its Connecting Rod

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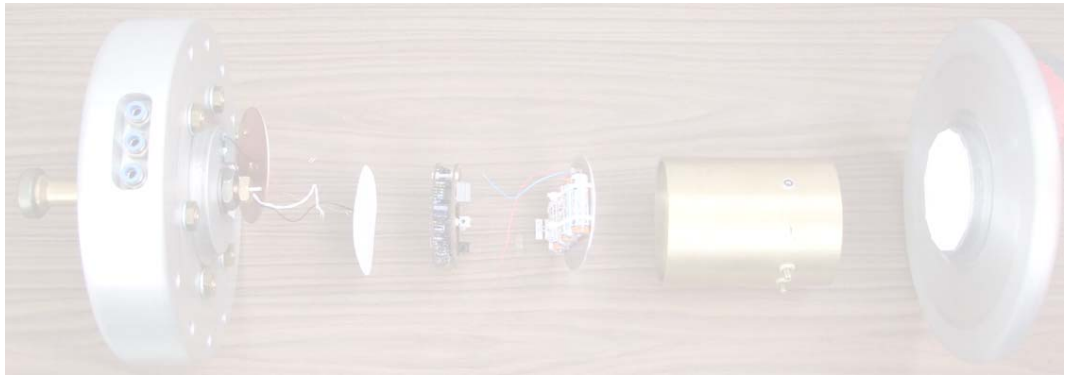
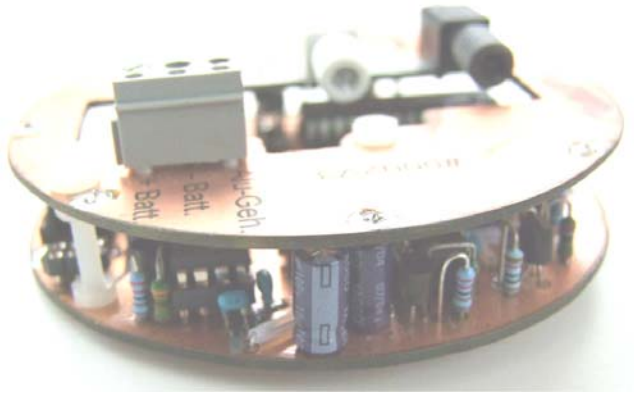




Motivation

- Repetitive operation of spark gaps in Marx generators for electroporation
- Switched pulse currents
  - Strongly damped or aperiodic shape
  - Peak current in the kA range
  - Pulse lengths in the microsecond range
  - Repetition rate in the order of 20 Hz

→ Continuous heating of spark gap electrodes by switching arcs

→ Spark gap electrodes are subject to erosion

Influence of heating power on erosion processes?

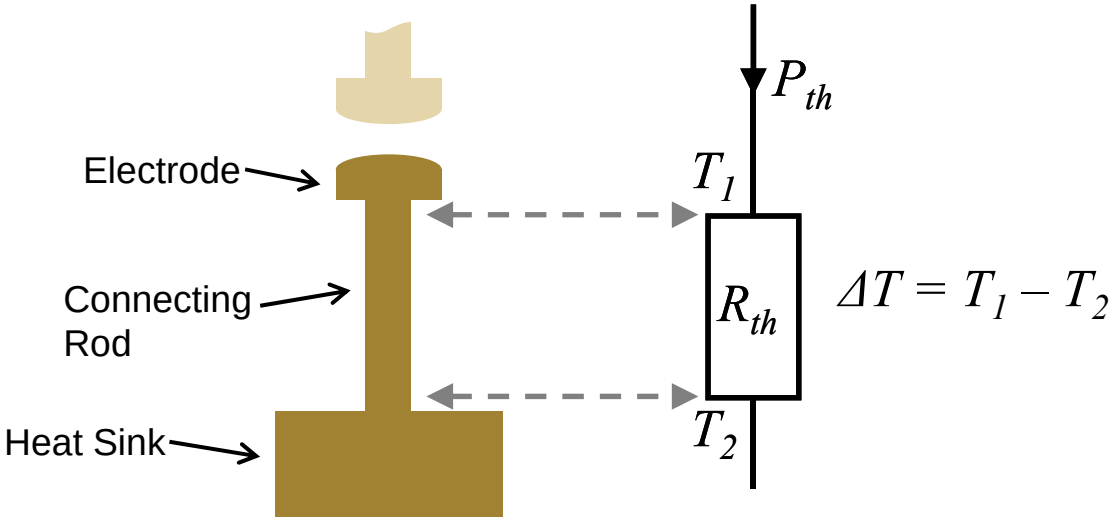
→ Measurement of heating power

Topics

- Design of Measurement System
  - Mechanical Design of a Sensor for Heating Power
  - Electronic Measuring Circuit
- Characterization and Calibration of the Measurement System
  - Linearity
  - Estimation of Accuracy
- Conclusion

Measurement Principle: Thermal Shunt

- Based on the flow of thermal energy → well suited for repetitive operation
- Connecting rod: heat conductor with thermal resistance R_{th}
  - Electrode: heat source (T_1)
  - Heat sink (T_2)
- Flowing heating power P_{th} causes a measurable difference in temperature



$$P_{th} = \frac{1}{R_{th}} \cdot (T_1 - T_2)$$

Design of the Connecting Rod

Requirements:

- Defined thermal resistance
- Contains two temperature sensors with distance between them
- Mechanical support of given electrode (possible influence on geometry)

Thermal resistance, chosen values:

- heating power of 8W
- difference in temperature of 10K @ 8W

→ R_{th} = 1.25 K/W

Temperature sensors integrated into the connecting rod

→ tube like geometry of the connecting rod, heat conducting cross section A (circular ring):

$$A = \frac{1}{\lambda} \cdot \frac{d}{R_{th}}$$

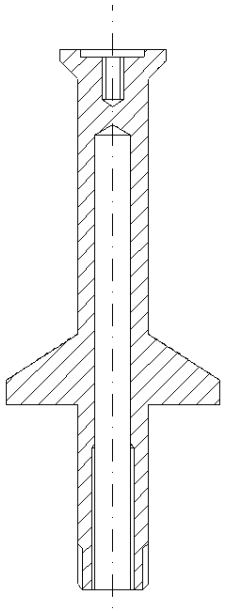
d: distance between temperature sensors

λ: heat conductivity of used material

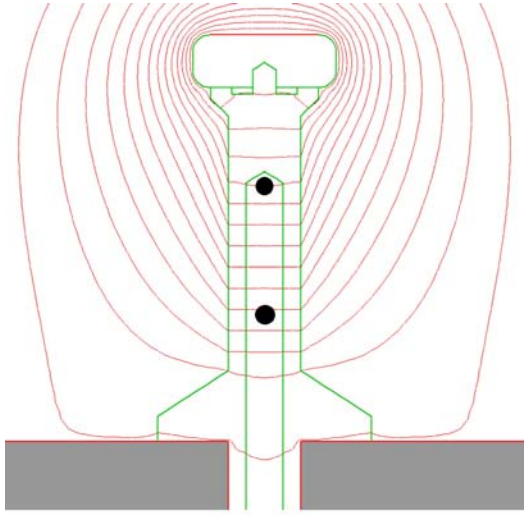
R_{th}: thermal resistance of th. shunt

Connecting Rod

- Electrode screwed on upper end
- Heat sink: through-hole mounting on lower end
- Mechanical connection: threads
- Thermal contact: cone-shaped expansions



Cross-sectional view of the connecting rod



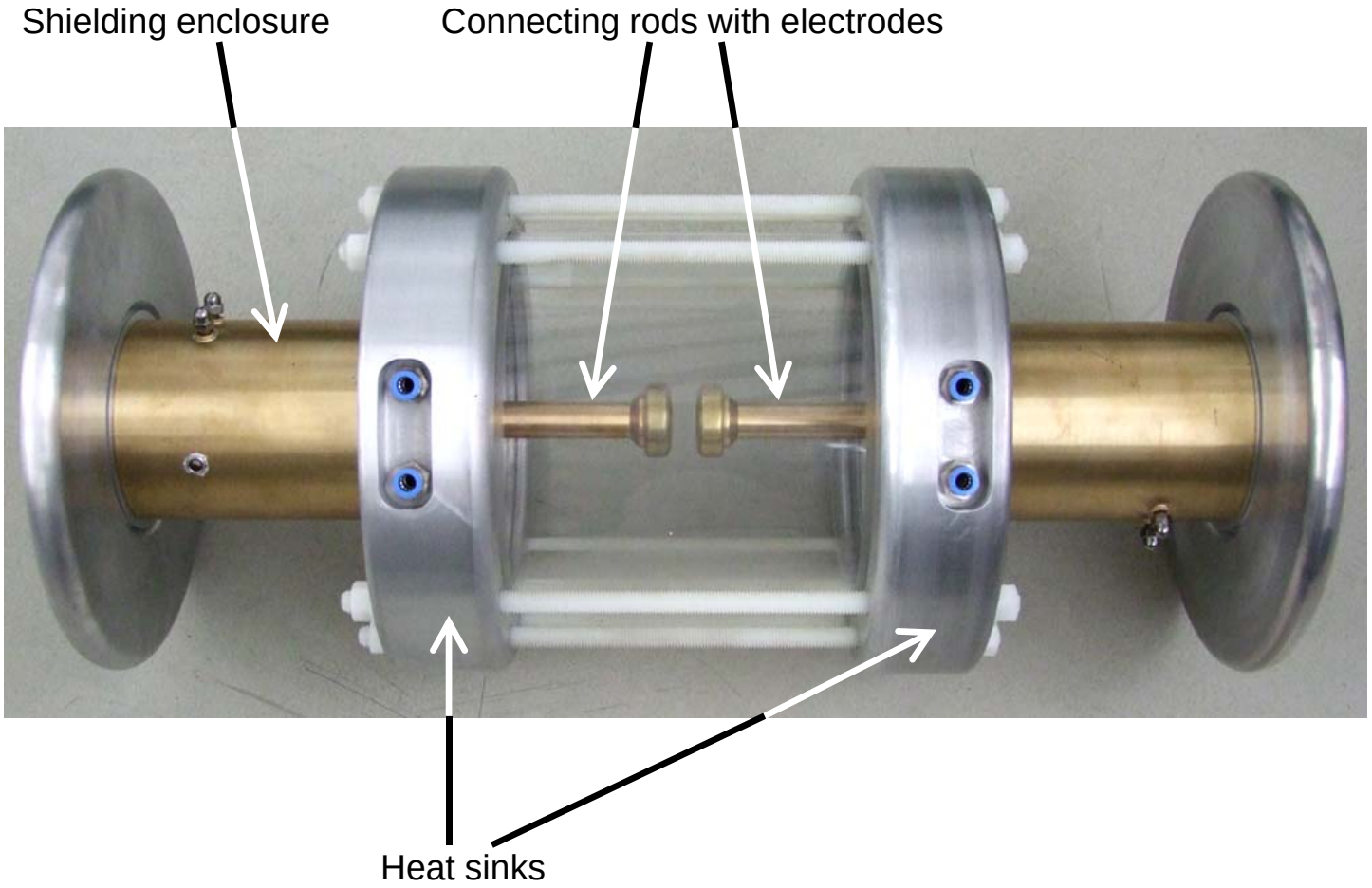
Simulation of temperature distribution,
black dots: positions of temperature sensors

Difference to tube geometry

→ Simulation of temperature distribution

Result: almost equidistant distribution of isotherms confirms simplified calculation as tube like geometry.

Mechanical Assembly

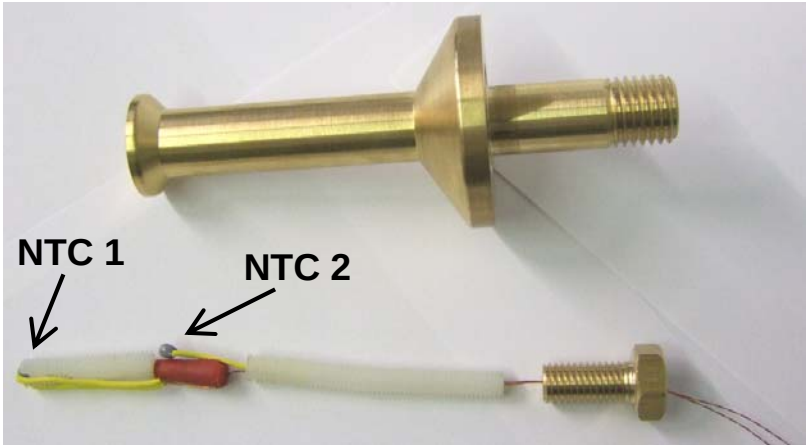


Temperature Measurement

Requirements:

- Accuracy of temperature measurement: 0.1K (range from 10°C to 30°C)
- Data transfer to a PC
- Ability to measure on high electrical potential

- Chosen temperature sensors: NTC thermistors
- NTCs mounted electrically insulated because of inductive voltage drop along connecting rod
- Self heating less than 0.1K



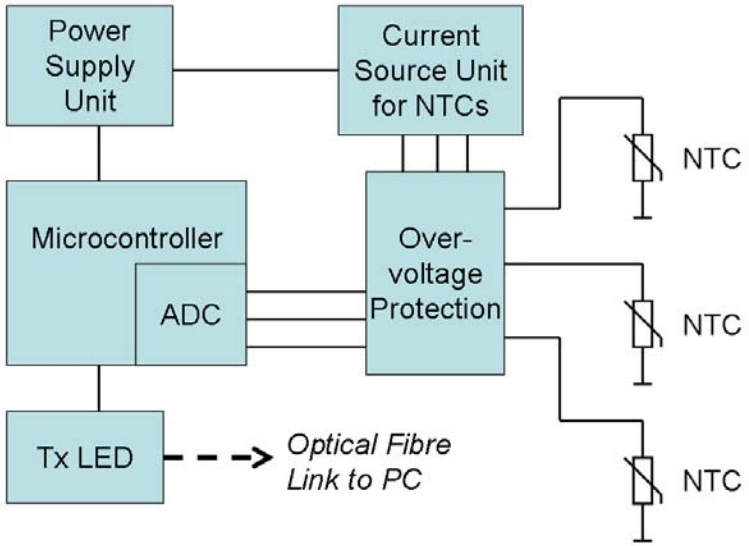
Arrangement of thermistors inside connecting rod

Data Acquisition and Transmission

- Data acquisition
  - Overvoltage protection
  - Integrated 10 bit ADC: up to 36°C resolution is 0.1K or better
- Linearization of thermistors
  - According to extended Steinhart-Hart equation:

$$T = \frac{1}{a_0 + a_1 \cdot \ln R + a_2 \cdot (\ln R)^2 + a_3 \cdot (\ln R)^3} \quad **$$

  - Implemented as look up table
- Data transmission
  - Optical fiber communication for potential isolation
- Power supply: battery powered



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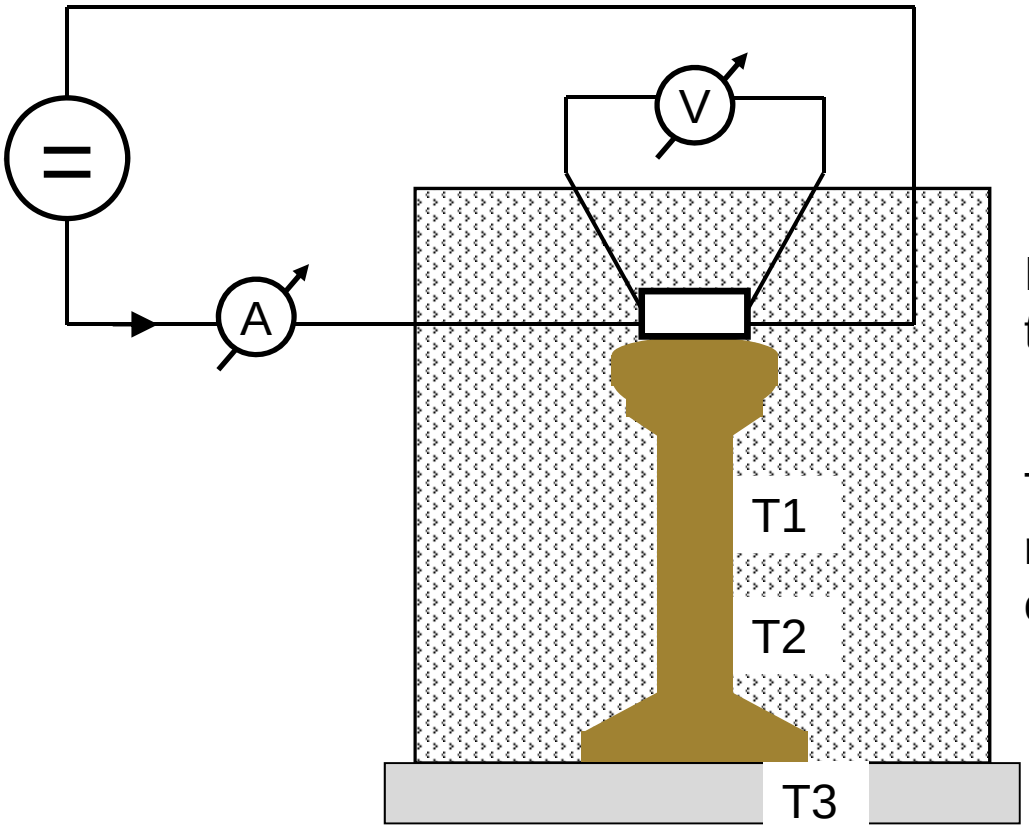
T: absolute temperature
$a_0 - a_3$: Steinhart-Hart coefficients
R: resistance value of thermistor

Characterization and Calibration: Set-Up

- Application of thermal power and variation in a pre-defined manner
  - → Linearity of measurement system
  - → Calibration

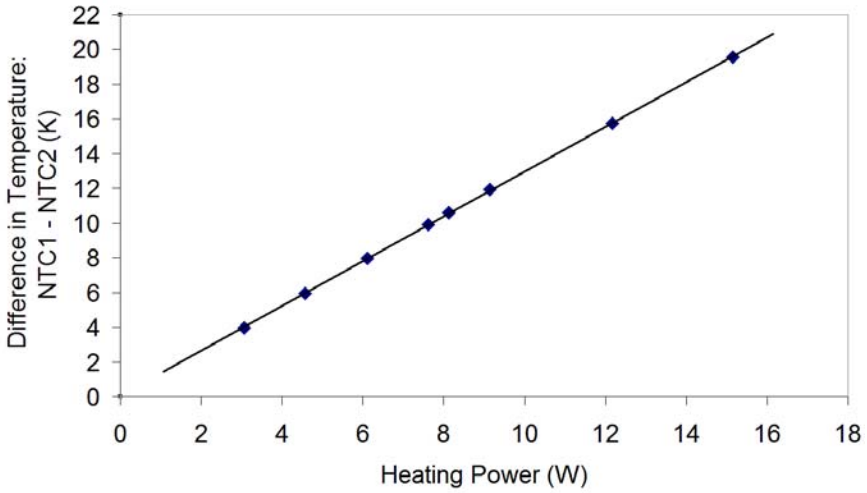


Heating resistor (four-wire technique because of thin wires)

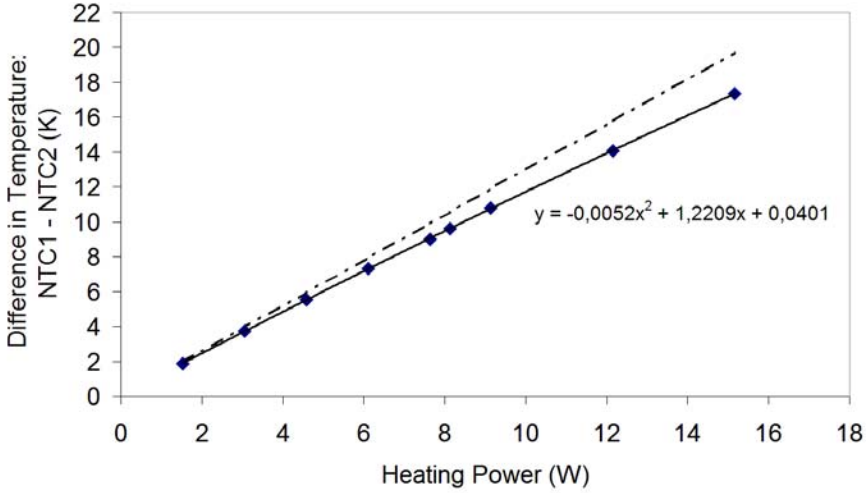
Thermal insulation of heating resistor, electrode and connecting rod (polystyrene)

Heat sink: 14.5°C ± 0.75K

Characterization and Calibration: Results



- Almost no deviation from the linear regression curve: very good linearity (blue rhombs), even on extended range
- Conversion factor: 1,30 K/W (4% deviation from 1.25 K/W)
- With complete thermal insulation (polystyrene) for calibration and testing

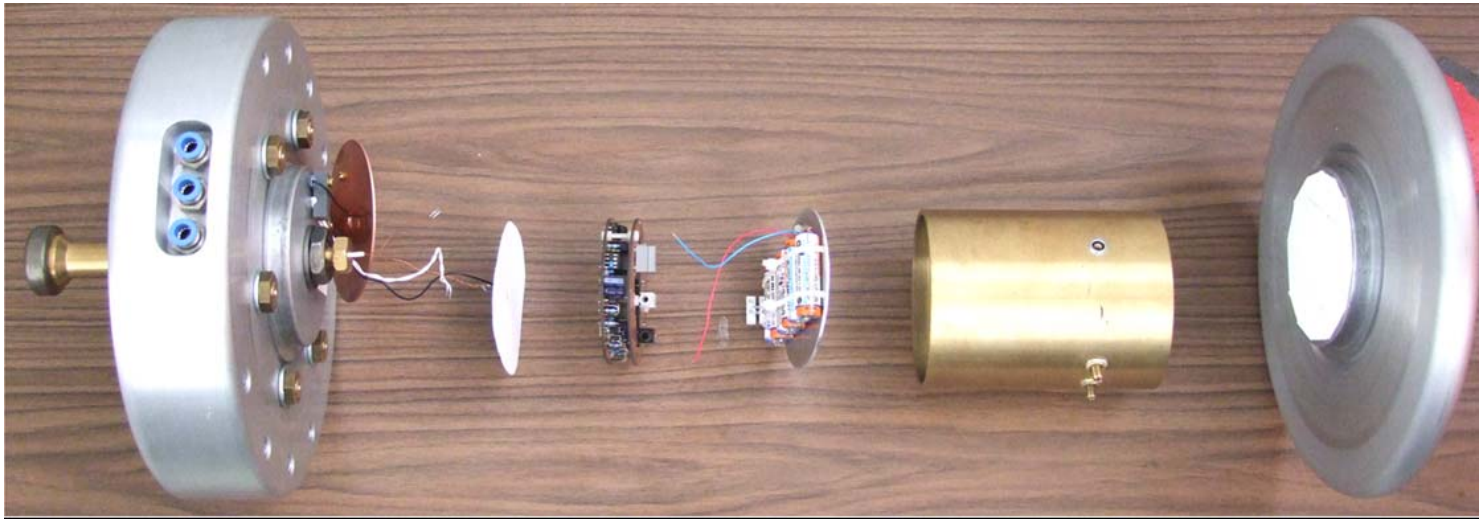


- Without thermal insulation as estimation of worst case of operation
- Deviation to linear curve: 9% @ 8W, 12% @ 15W

- Intended operation with thermal insulation of the connecting rods

Putting into Operation

- Modular construction → easily adaptable for experiments
- Operated for three days: 380000 current pulses, aperiodically damped shape, approx. 2.8 kA peak current, 2.0 to 2.2 µs pulse length
- Approx. 40 h operating time with a fully charged battery pack
  → about one work week of operation without recharging



Conclusion

- Design of a spark gap assembly with integrated measurement systems for measurement of heating power
  - Thermal shunts
  - Electronic measuring circuits
- Electronic measuring circuits work well in presence of the electromagnetic interference of pulse currents
  - 380000 withstood current pulses without damage
  - Very good linearity