Experimental Investigation of gold coated tungsten wires emissivity for applications in particle accelerators.

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2022 IBIC

ABSTRACT

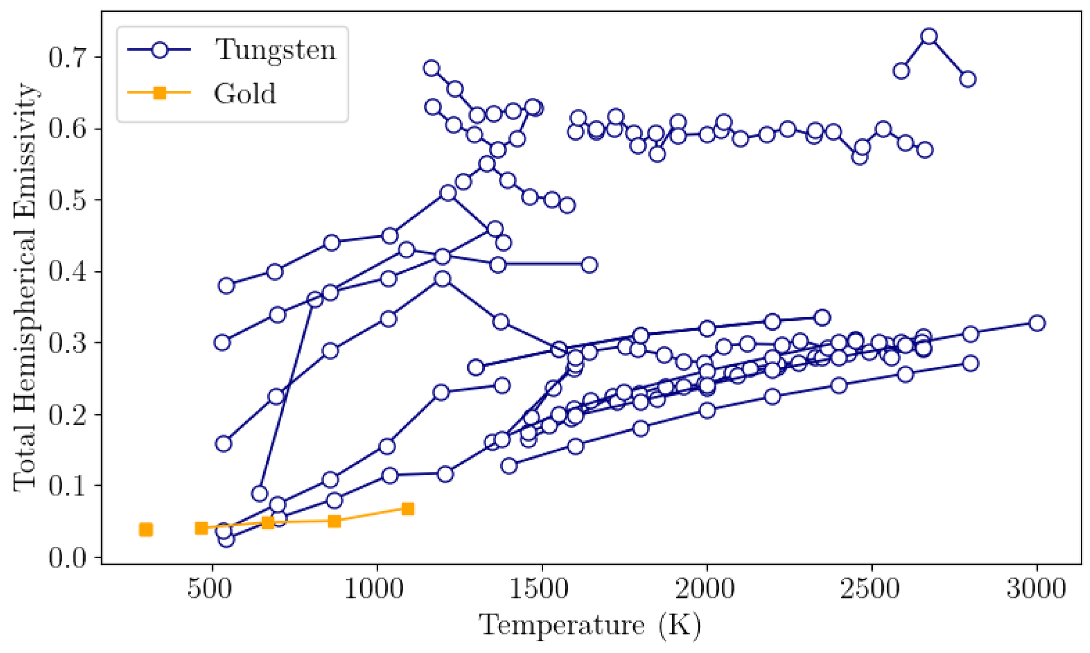
The operation of wire grids and wire scanners as beam profile monitors can be heavily affected, both in terms of measurement accuracy and wire integrity, by the thermal response of the wires to the energy deposited by the charged particles. Accurate measurements of material emissivity are crucial, as Radiative Cooling represent the most relevant cooling process. In this work, we present a method for emissivity measurements of gold-coated tungsten wires (diameters between 10-100 um) based on calorimetric techniques. The dedicated electrical setup allowed for precise current and voltage measurements up to 2 A and 6 V respectively, which allowed transient and steady state measurements for temperature measurements up to 2000K. Temperature determination as a function of current intensity probed to be a big part of uncertainty due to the non-uniformity of the thermal wire profile. A theoretical description of the measurement technique will be followed up by the electrical set up description and a detailed discussion about the measured results and uncertainties.

The Emissivity Problem

Wire grids are examples of thin target detectors extensively used in particle accelerators for transverse beam profile measurements. Depending on the detector characteristics and beam parameters the monitors operation can result in thermo-mechanical stresses.

For simulating the particle-detector interaction and predict detector material heating and damage, a finite difference program was been implemented (*).

Uncertainties in the material properties such as melting (or sublimation) temperatures, heat capacity, thermal conductivity and/or emissivity, induce large uncertainties in the simulation results.



*Scan Me!

Experimental Details

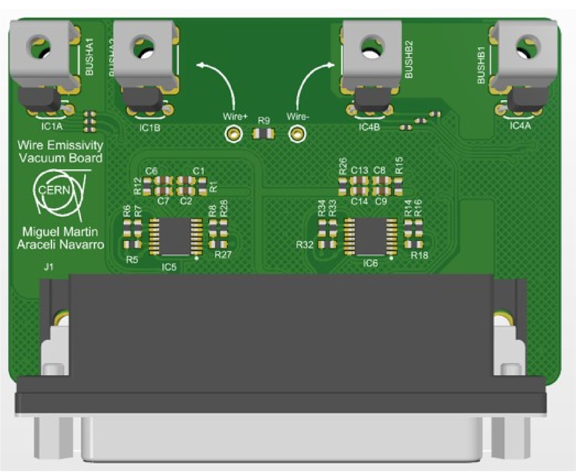
The acquisition system consists of an assembly of two circuit boards:

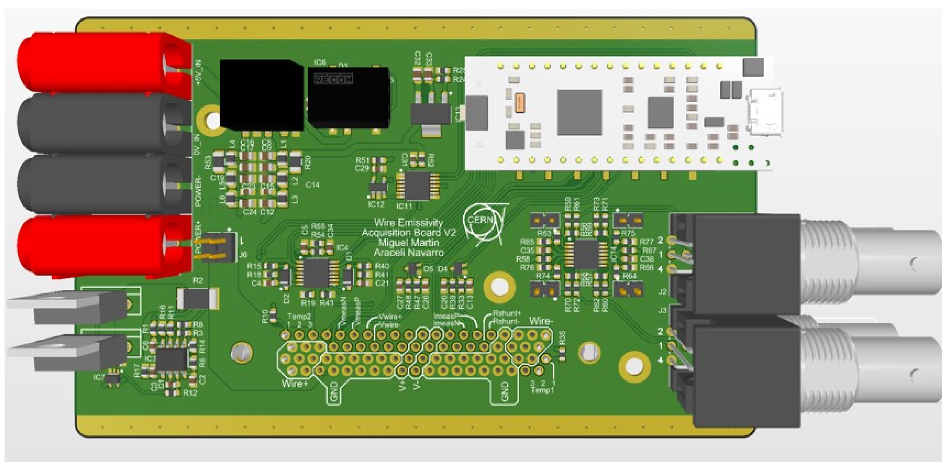
- The measuring board: holds the wire with both ends fixed on two turrets at a set distance, and measures the current and the voltage drop in the wire.

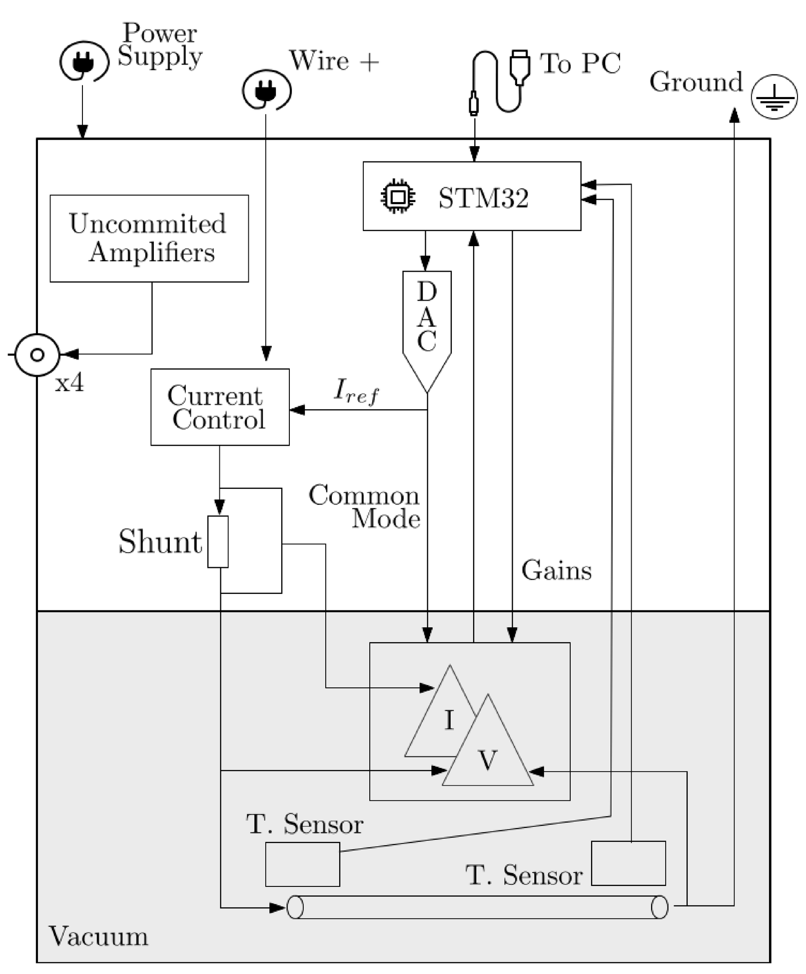
  The temperature at the extremities of the wire (T_{Left},T_{Right}) is measured by means of two temperature sensors mounted on the turrets.

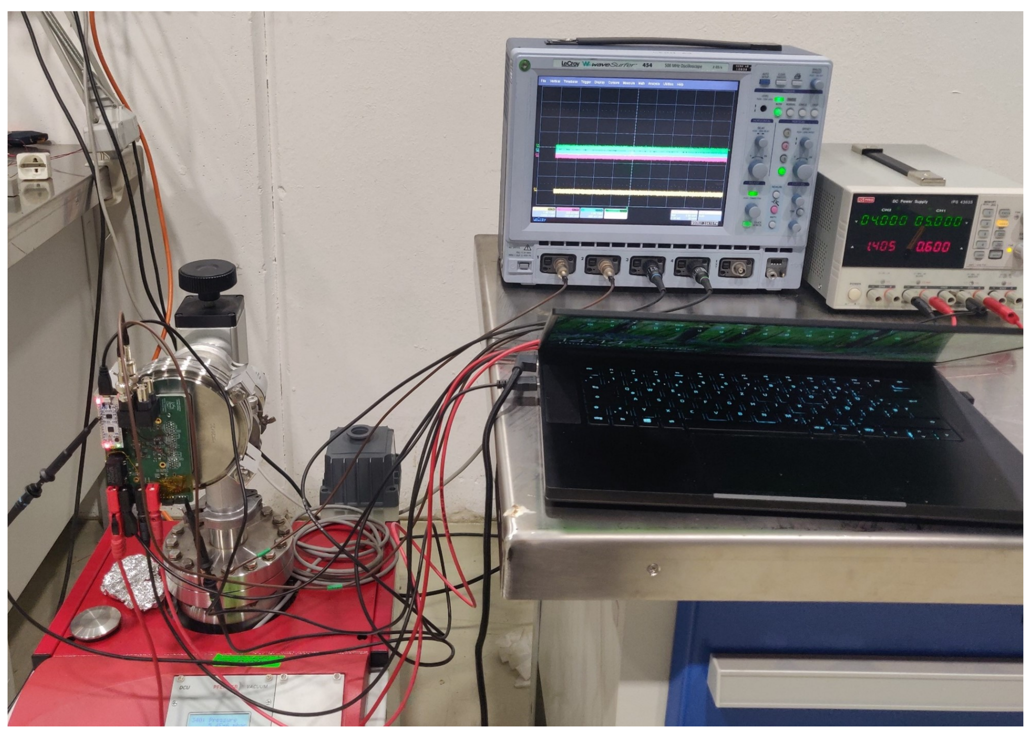
- The acquisition board: captures and digitizes the measured signals, regulates the current flowing into the wire, and configures the measurement board for gain and common-mode offset.

The system is powered by a lab power supply. Onboard DC-DC converters and linear regulators adapt the input voltage to the levels necessary to power the various analog parts of the circuit.









Calorimetric Method

The calorimetric method is based on studying the energy balance of the sample material at a certain temperature. Its temperature is maintained via joule effect using electrical power supply.

$$\frac{I^2 R(T)}{C_p(T)\rho_v V} = \frac{S\sigma_{SB}\cdot \varepsilon \cdot (T^4 - T_0^4)}{C_p(T)\,\rho_v V} + \alpha(T)\left(\frac{\partial^2 T}{\partial x^2}\right)$$

This methods gives information about the total hemispherical emissivity. It is a direct absolute method, so no standard emissivity reference is necessary.

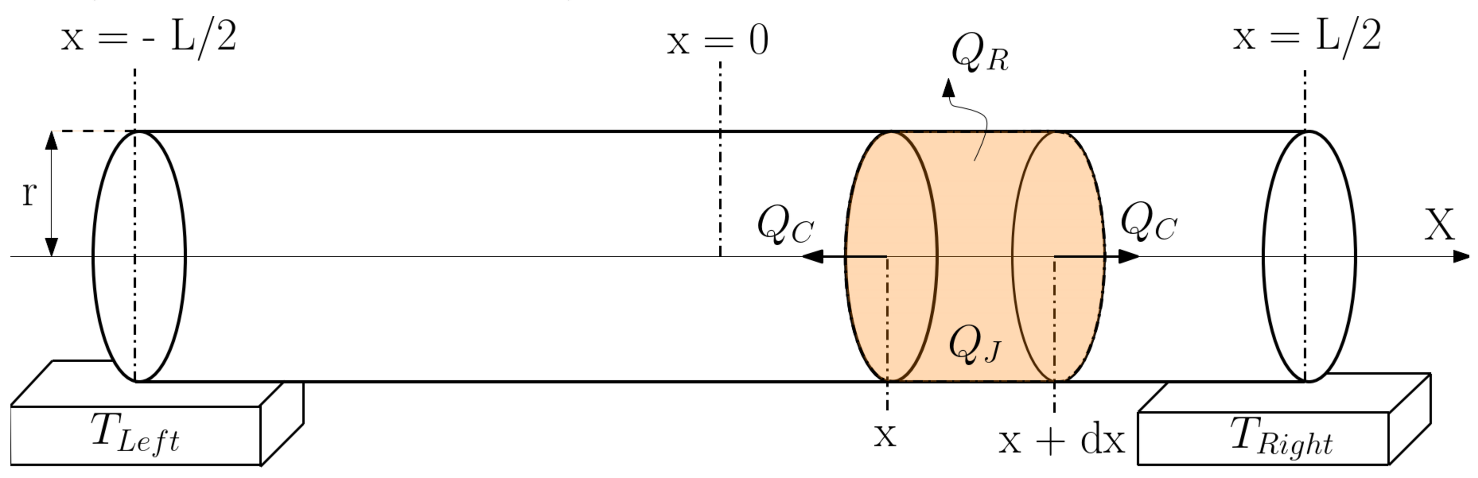
It is typically performed in steady state, which makes it time-consuming.

The average temperature of the sample can be determined by measuring the resistance and comparing it to the known values of R/R_0

The solution of this equation can be calculated numerically, it is a BVP problem. A central difference (CD2) method was considered.

The T^4 term makes it a nonlinear system of equations. For solving this system of equations Newton's method for non linear systems was used.

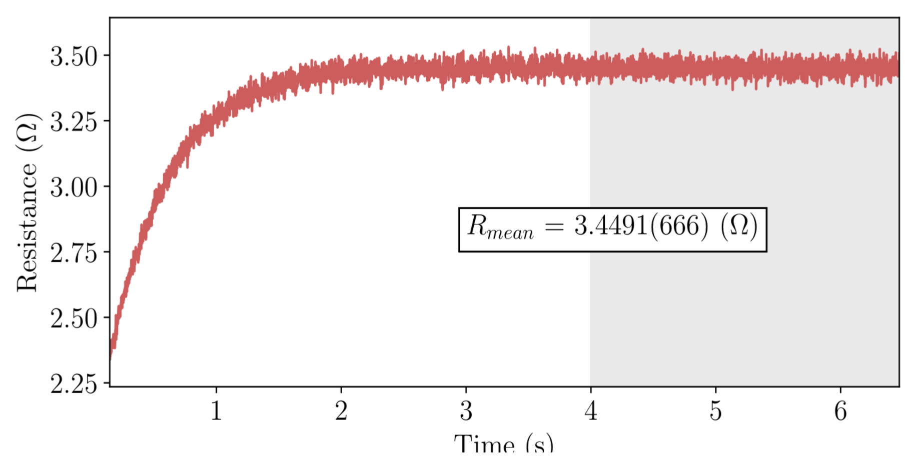
The emissivity is then calculated iteratively.

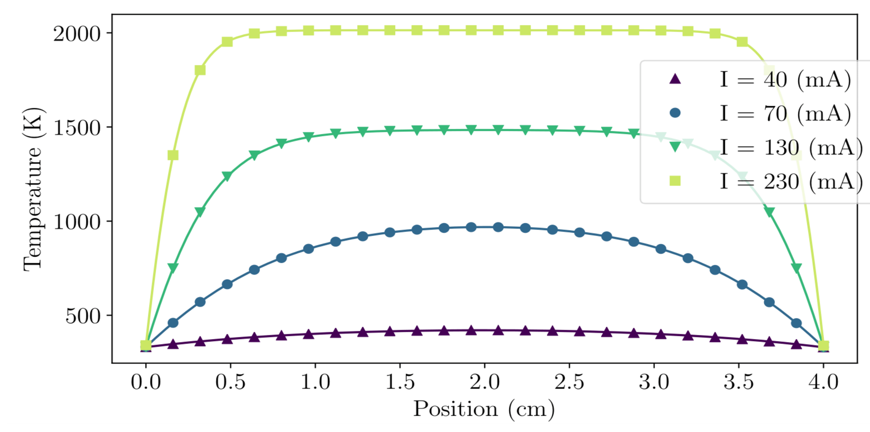


Results

For each sample, the steady state resistance was computed for a variety of applied currents.

A relationship between the average temperature and the applied intensity was calculated by comparing the measured resistance results with the tabulated values of R/R_0.



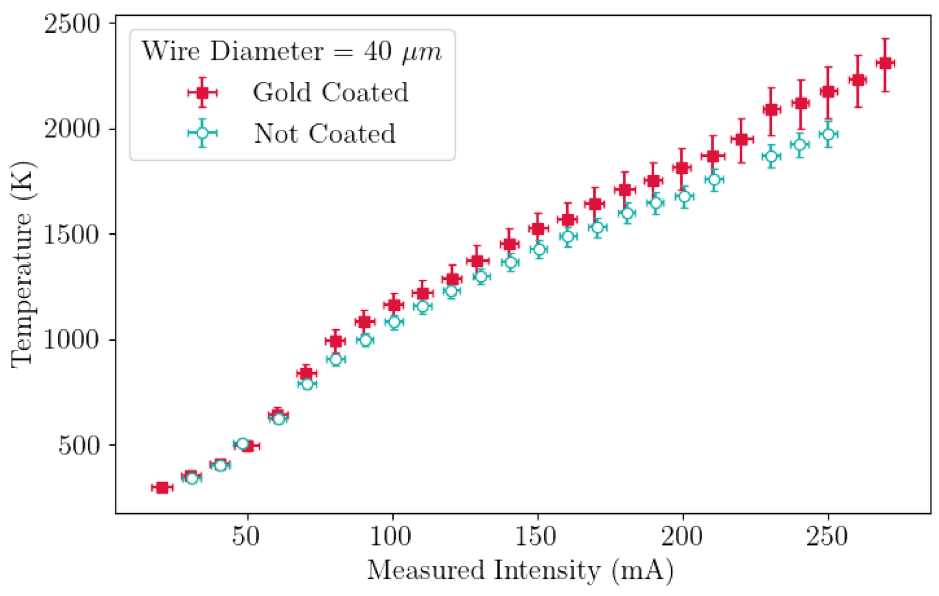


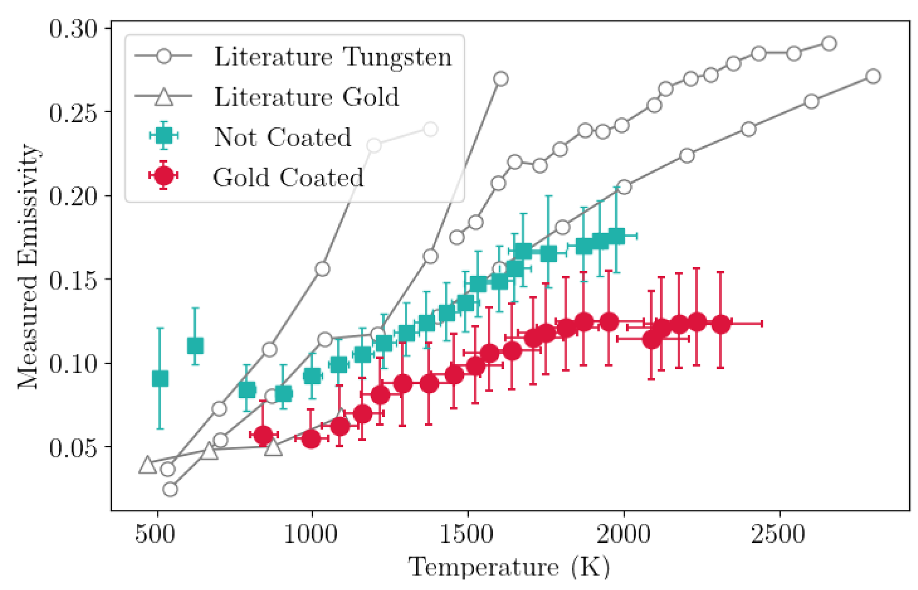
A range of temperatures from 300 (K) to 2500 (K) was measured. The average temperature in the wires seemed to increase almost linearly with the applied intensity.

With increasing temperature, the temperature profile along the wire length becomes more constant.

The boundary temperatures (T_{Left},T_{Right}) increased quadratically with the applied current, always remaining below 350 (K).

The emissivity of the material was calculated numerically for all the measured intensity range. For both gold-coated and pure tungsten wires.





Conclusions

In this article, a method to measure the emissivity of thin wires has been presented. Knowing accurately the value of the material is critical to properly simulate the thermal evolution of thin target detectors in particle accelerators. The big uncertainties in the reported values of tungsten's emissivities in literature brought us to design an experimental set up to measure the emissivity of the wires used in the SEM grid detectors at CERN. The measurement was done by means of the calorimetric methods. A dedicated set up, consisting was implemented and used. Numerical methods and experimental measurements were combined to obtain the desired values of the wire emissivity.