Cryogenic cooling of the sample manipulator of the BEAR beamline at Elettra: finite element analysis and experiment.

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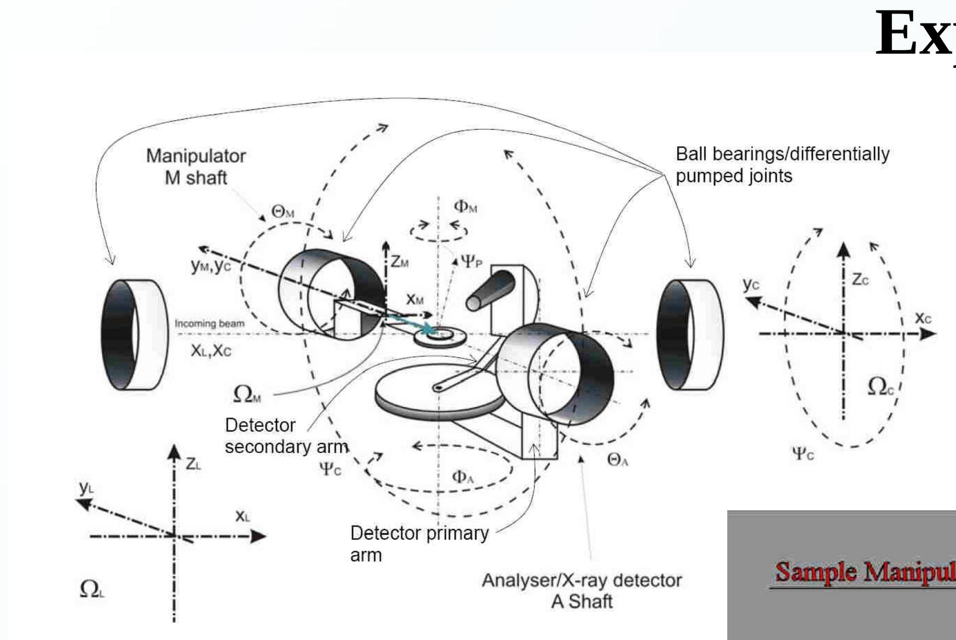
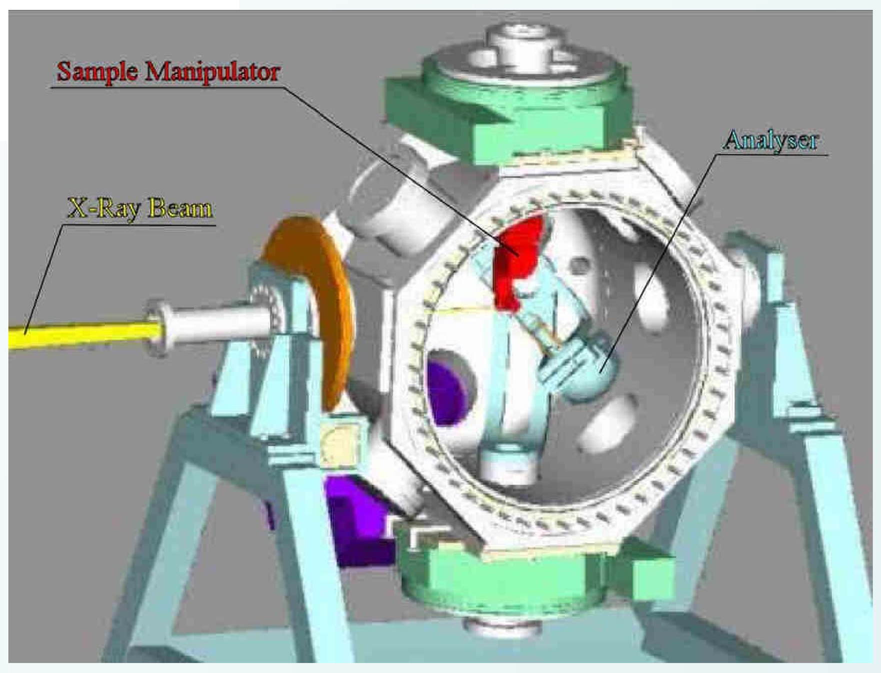
Experimental Chamber and Manipulator Description

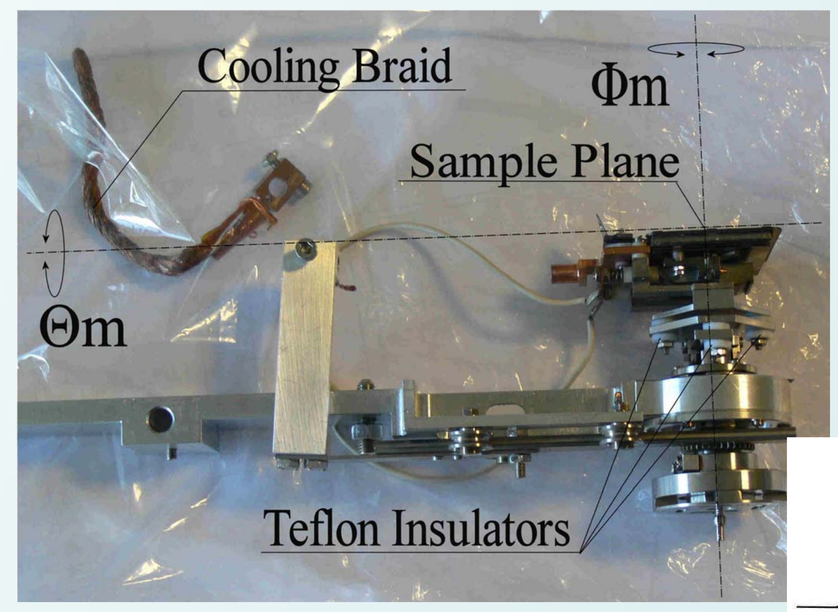


The first degree of freedom is the rotation of the overall chamber along the XL≡XC axis, which is also the x-ray direction.

The analyzer/ x-ray detector has two rotational degrees of freedom (ΘA, ΦA). The first is the rotation around yC itself and realized by means of an external goniometer, while ΦA is the rotation around zC axis

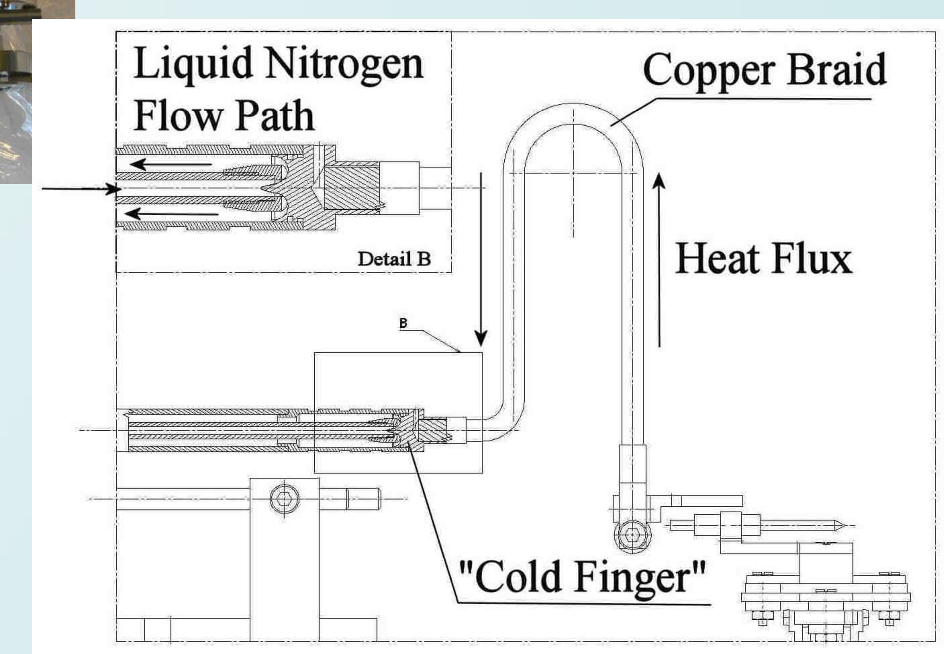
BEAR beamline at Elettra (Trieste) is intended for optical studies (reflectivity, absorption, luminescence and fluorescence) in ultra high vacuum (UHV) and sample manipulation presents a number of demanding issues including six degrees of freedom, mechanical stability, geometrical reproducibility, micro-manipulation in UHV, wide range of sample (variable) temperature, ranging from liquid nitrogen (LN) to 1500 K and sample transfer from the atmosphere.



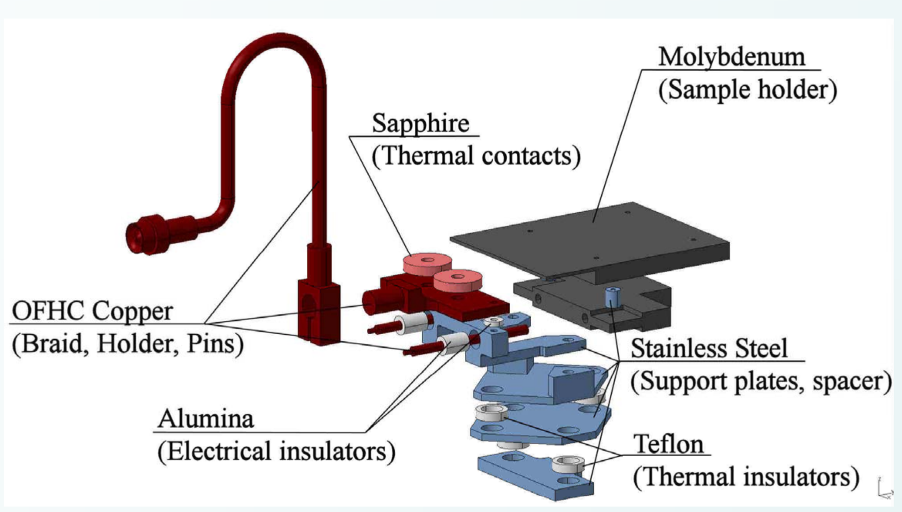


All the six degrees of freedom of the sample manipulator are controlled. The roll ΘM is obtained by means of an external goniometer, while the yaw ΦM is obtained by means of a rack-pinion coupling. The pitch angle is controlled with an internal joystick and the three translations are driven with proper external slits

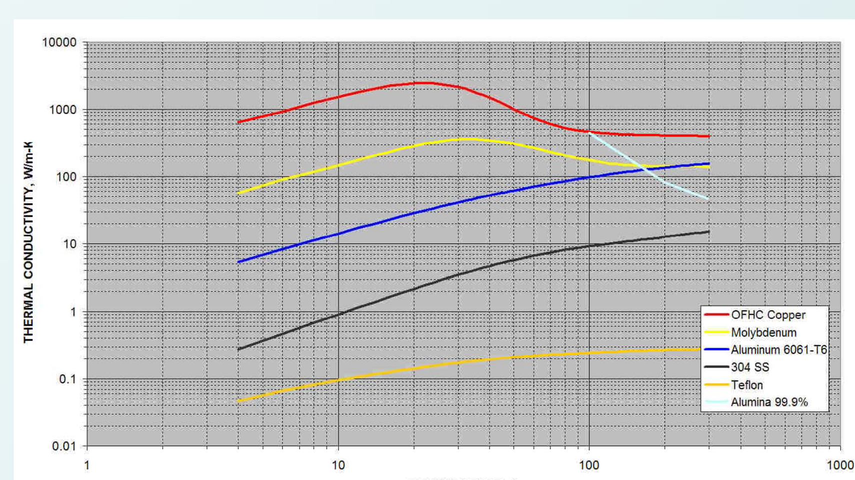
The heat flux is driven by the braid screwed on the copper support of the sample ("warm side") to the cold side constituted by cold finger. The latter is realized by means of a coaxial stainless steel pipe in witch the liquid nitrogen (LN2) flows from the inside pipe to the external casing. The stainless steel body, where the LN2 flux inverts its velocity, represents the "cold finger" of the cooling system, i.e. the connection point of the braid extremity.



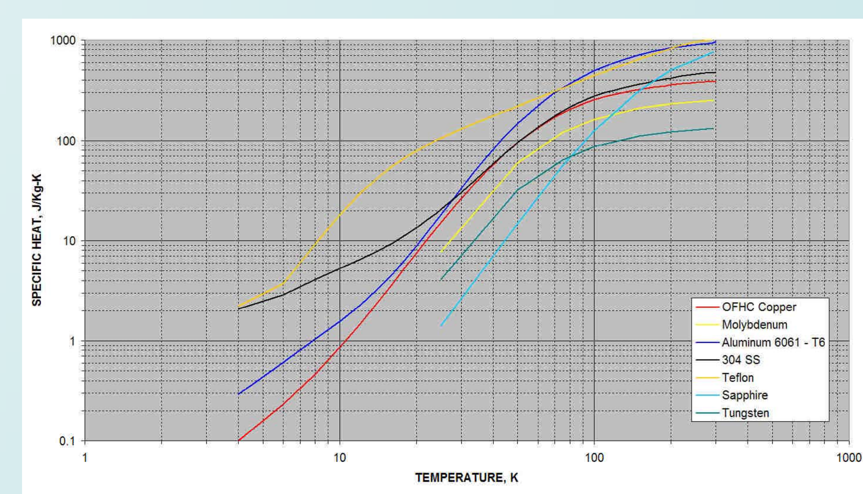
Cryogenic Materials Behavior



The 3D CAD explosion view shows the different elements and materials of the sample manipulator.

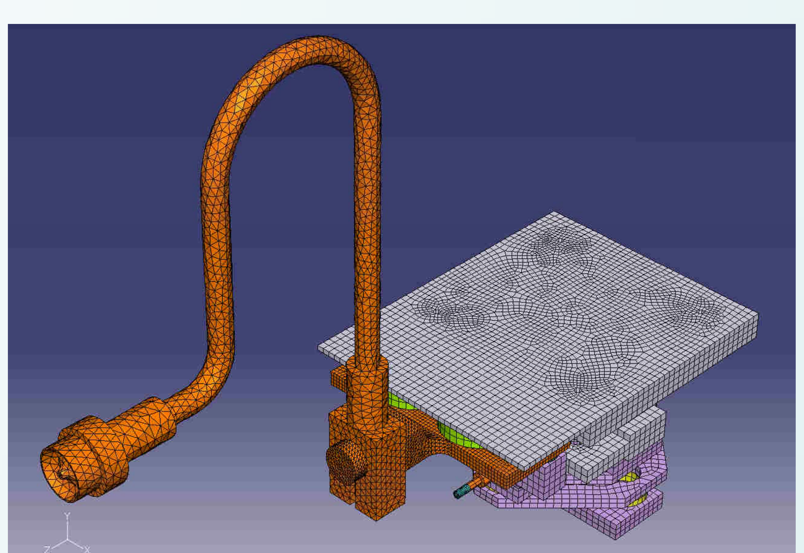


Thermal Conductivity vs. Temperature

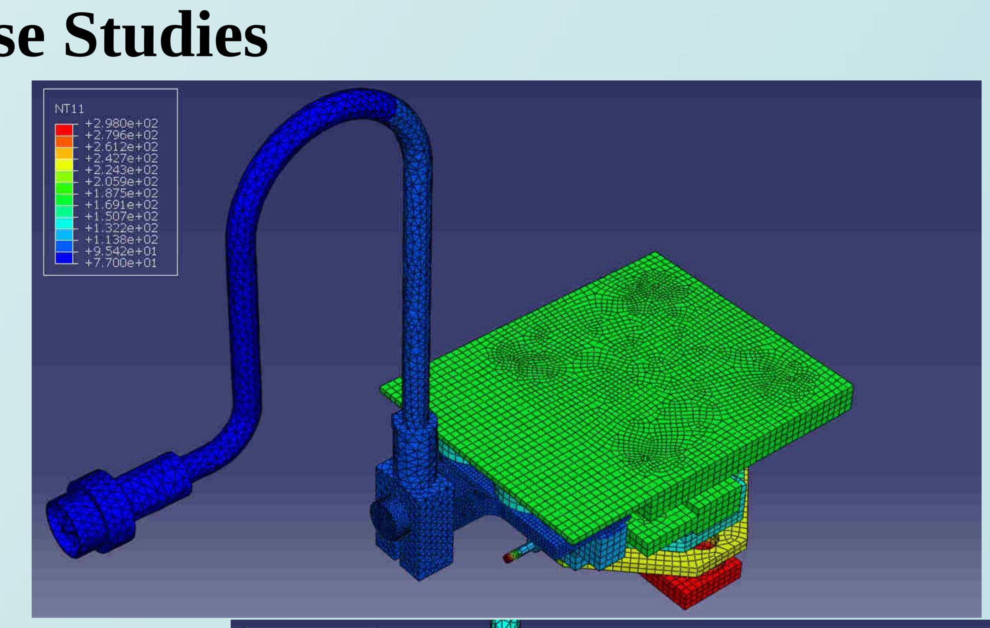


Specific Heat vs. Temperature

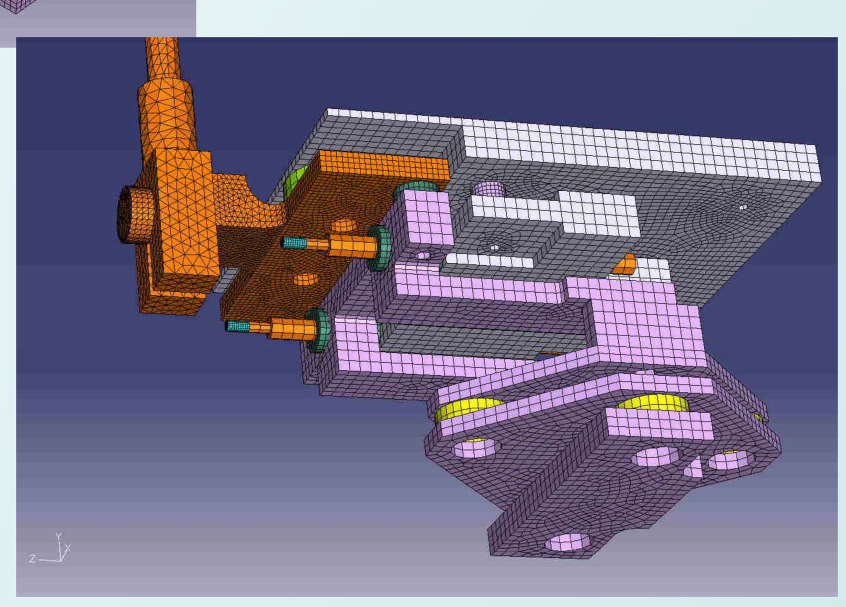
FEM Heat Transfer Steady State Analysis - 5 Case Studies



	Case 1	Case 2	Case 3	Case 4	Case 5	Experiment
	T [K]	T [K]	T [K]	T [K]	T [K]	T [K]
Constant material parameters						
End braid temperature	91.0	111.2	115.9	115.1	114.5	106
Sample temperature	91.8	113.0	118.1	130.7	185.9	184
Variable material parameters						
End braid temperature	89.7	108.0	112.2	111.8	111.4	106
Sample temperature	90.2	109.2	113.7	124.7	180.3	184

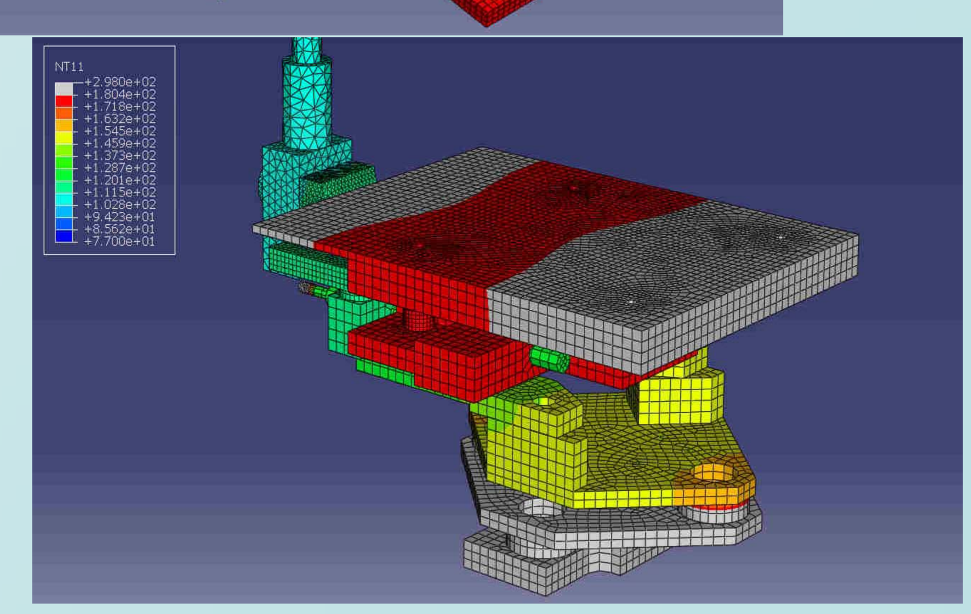


The software used in the FEM analysis is ABAQUS. The finite element mesh has 63923 elements and 51933 nodes. We have taken advantage of the ability of the software to mesh separately each part, find out the contact pairs and define the contact status with a parameter that can be easily changed. The FEM model has been conceived as a flexible investigation tool, able to discover any possible source of problems in the cooling scheme.



Five case studies are considered:

1. 77 K on braid extremity, 298 K end plate, perfect contact.
2. Electric wires influence, perfect contact.
3. Radiation influence, perfect contact.
4. Sapphire contact removed.
5. In this last case we have iteratively modified the value of the contact conductivity between pins and sample housing to get the same result as in the experiment. The corresponding value of contact conductivity is k=13 W/mK. Of course, this is done to show that the experimental results can be reproduced only admitting a limited contact conductance and not finding out a precise value of this parameter.



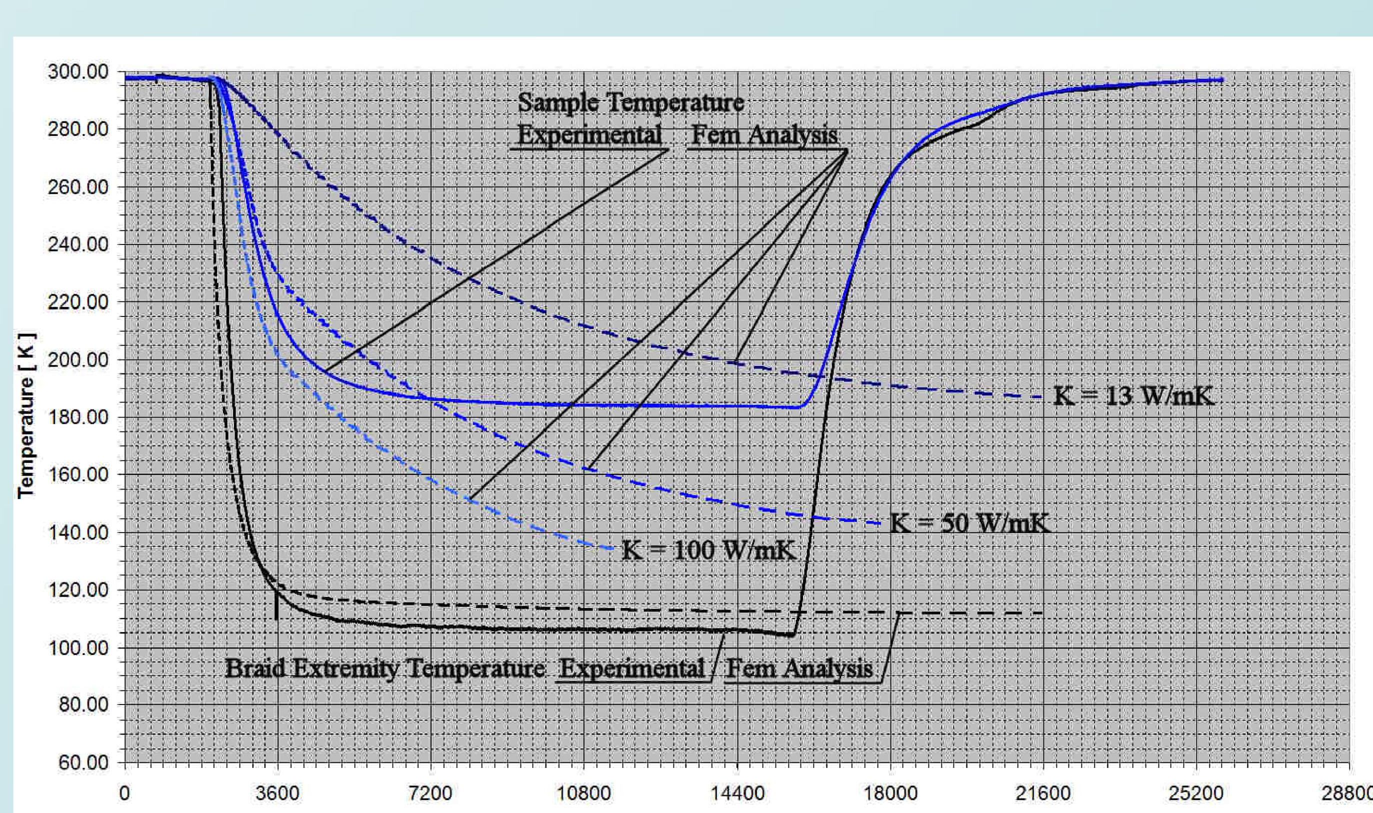
Experimental Results and Comparison with FEM Transient Analysis

Experimental measurements

The performance of the cooling system has been tested measuring the temperature of the sample holder and of the copper braid. Two thermocouples have been used. One of type N (TC1) was fixed on the copper plate at the end of the braid, the other of type K (TC2) was clamped in the center of the sample holder .

Transient heat transfer analysis

The comparison of the temperature behavior of the sample shows a meaningful difference between calculation and experiment. Although the transient analysis confirm the same steady state temperature on sample as in the experiment (about 185 K), the time required in FEM analysis is considerably longer than in the experiment. In order to check the influence of contact conductivity k on the temperature profile of the sample, the transient analysis has been repeated with increasing values of k. In fig.8 are shown the FEM results for k=13 W/mK (case 5 of steady state analysis), k=50 W/mK and k=100 W/mK. A reasonable explanation of this behavior is that, during the cooling down process, the electrical pins contracts cool down faster than the housing; the contraction in diameter will probably reduce the contact area, which results in an overall reduction of the contact conductivity.



Conclusions

The result of the analyses leads to the conclusion that the contact interfaces are of paramount importance in the specific problem. Although the contact problem is well known in cooling schemes of synchrotron devices, it is difficult to predict the behavior of each contact in complex systems, where a lot of parts are assembled together. Moreover a variability of contact conductivity with temperature is shown. Among the other sources that affect the cooling scheme, the heat transfer through the electrical wires appears to be the more important one. Radiation and material properties variability have a secondary order effect on the resulting temperature field, at least in this range of temperatures.