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THERMOMECHANICAL DESIGN OF NORMAL-CONDUCTING DEFLECTING CAVITIES AT THE ADVANCED PHOTON SOURCE FOR SHORT X-RAY PULSE GENERATION

A 15 Minutes Insight in a Typical Research Project

'If we knew what we were doing, it wouldn't be called research, would it?'

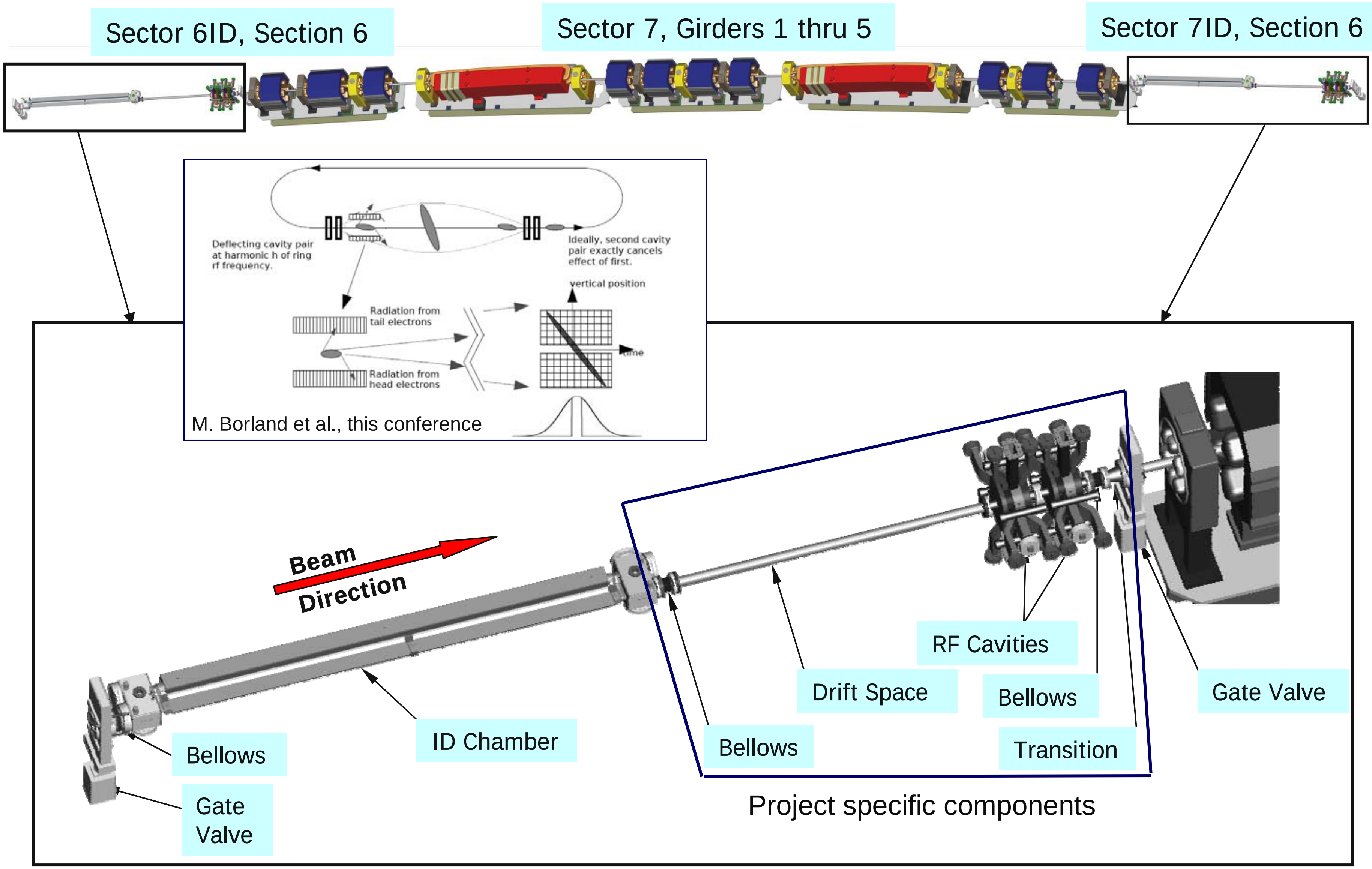
Attributed to Albert Einstein

Bran Brajuskovic
Jeffrey Collins
Pat Den Hartog
Leonard Morrison
Geoff Waldschmidt

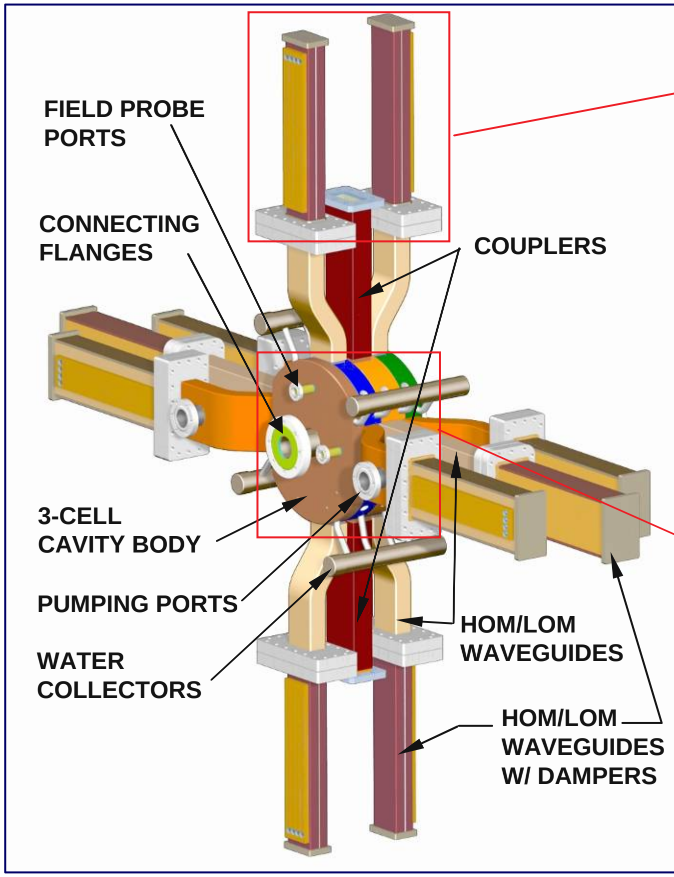
PAC 2007

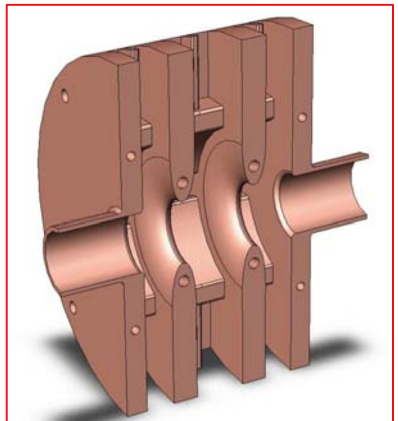
June 29th , 2007

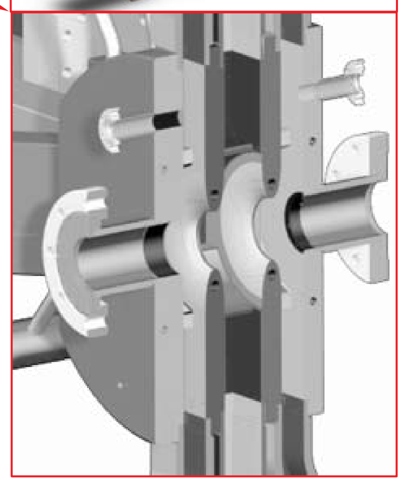
Short Pulse X-ray Project Layout



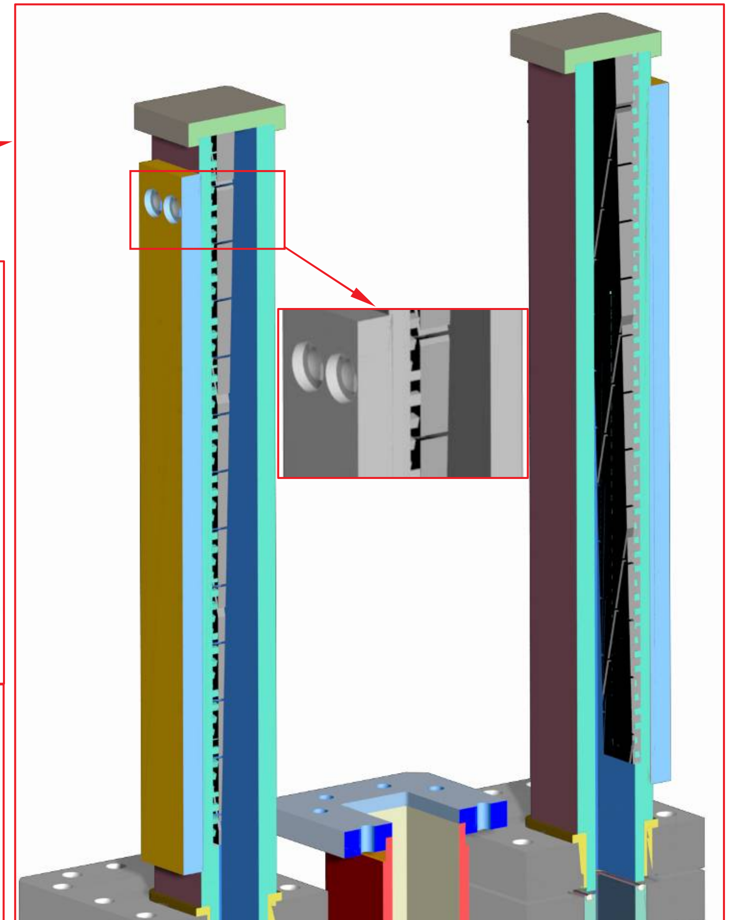
RF Cavity Design





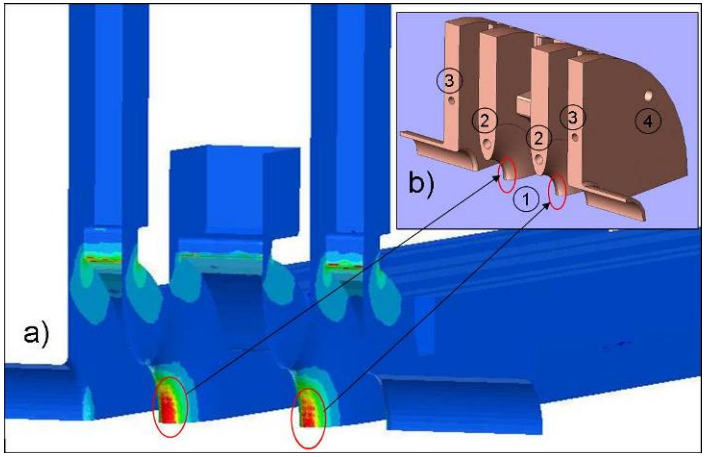


Heating of the Dampers



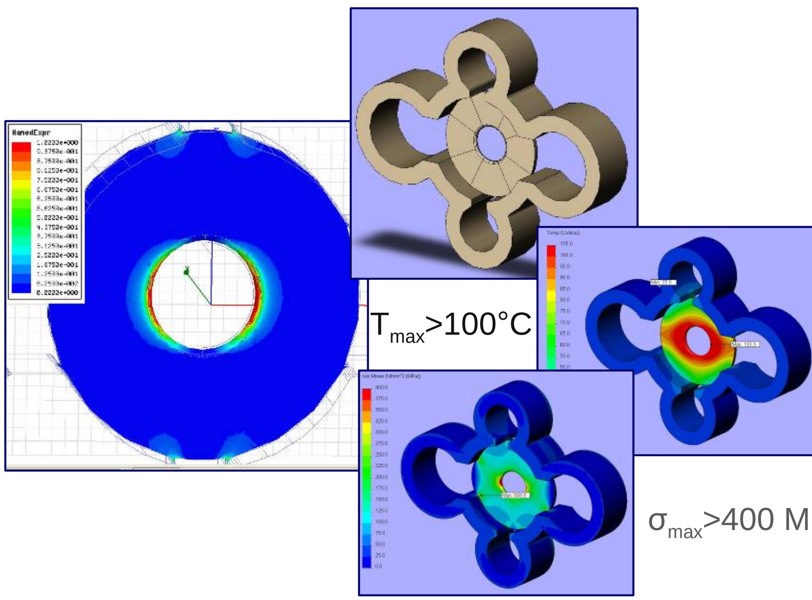
Heating of the Cavity Proper

Thermal Design of the Cavity Proper



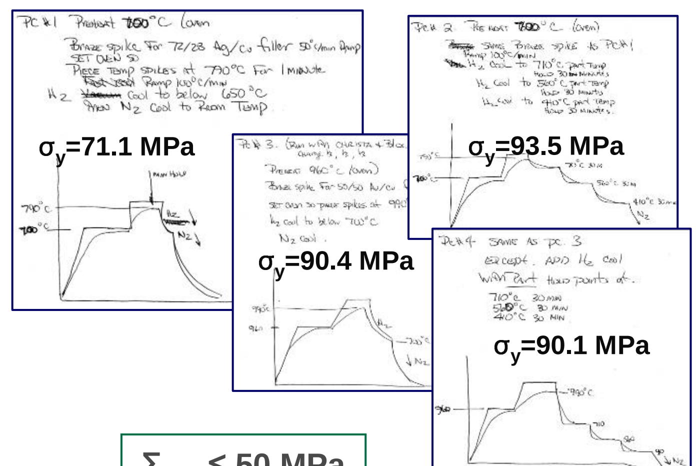
Due to the dipole operating mode of our cavity, most of the heat is generated in a limited region on the iris of the cavity.

Initial computations indicated trouble!



σ_{max}>400 MPa

First step: Establish the maximum allowable stress level

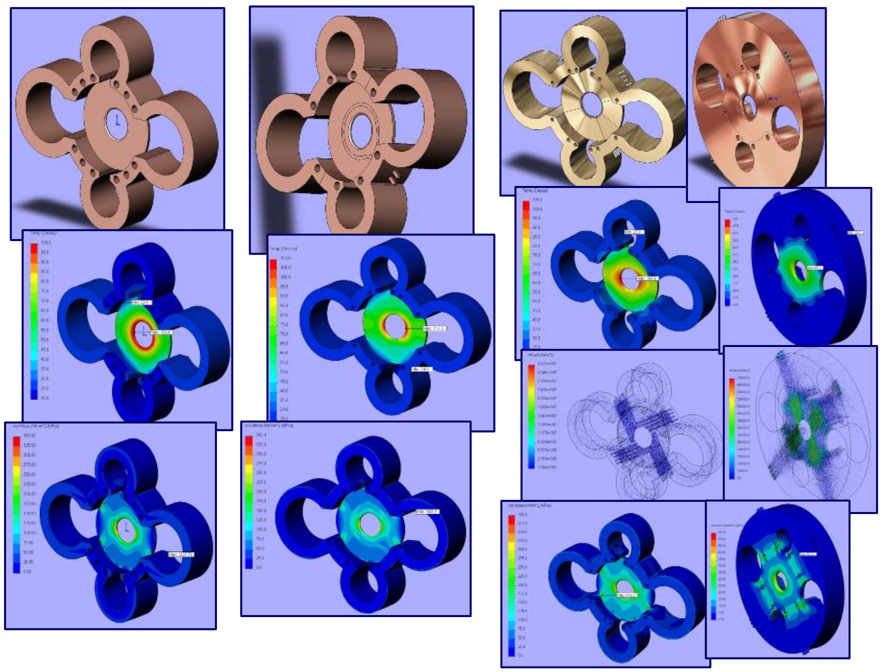


$\Sigma_{max} \leq$ 50 MPa

Thermal Design of the Cavity Proper

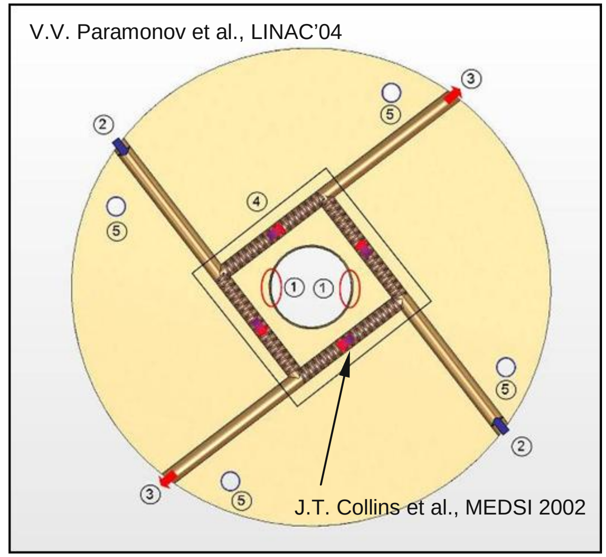
Second step: Design a cooling system capable of removing 4.1 kW of generated heat within a 4 to 6 mm-thick iris.

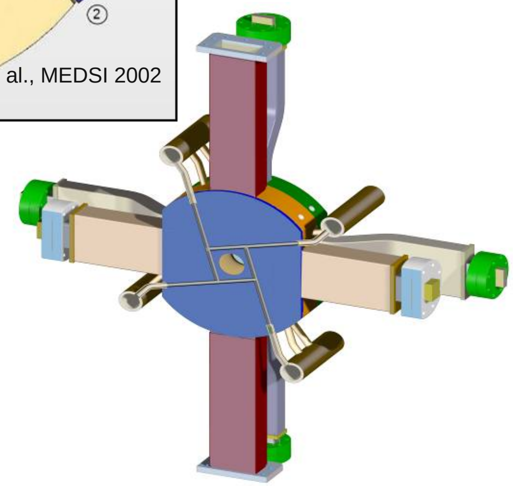
Peripheral cooling | **Peripheral + iris cooling** | **Peripheral +iris cooling w/heat pipes**



Failure – stresses ≥ 50 MPa

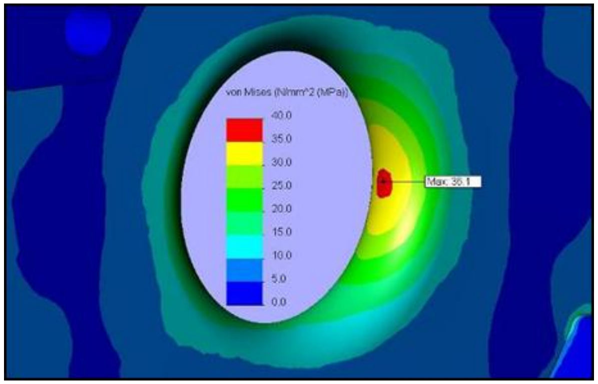
Third step: Design a cooling system capable of removing 4.1 kW and then determine how thick iris has to be.



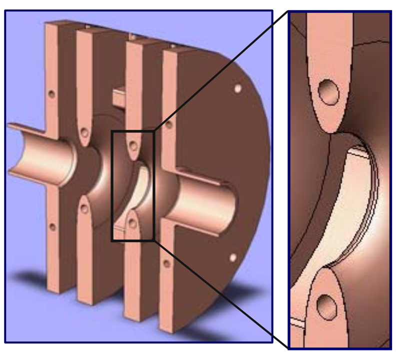


Thermal Design of the Cavity Proper

Fourth step: Optimize the thickness and the shape of the iris.



Iris thickness [mm]	15	12	10
T_{max} [ºC]	34.3	36.9	42.5
ΔT [ºC]	17.2	20.1	25.3
$\sigma_{vM\ max}$ [MPa]	36.1	44.1	54.3
Max. resultant displacement [µm]	9.9	10.7	10.4



For the elliptically shaped iris tip needed to ensure proper rf cell-to-cell coupling, the thickness was increased to 18 mm in order to keep the maximum stress below 50 MPa.

Fifth step: Coupled field analysis.

A comprehensive coupled field analysis of the rf- generated field, thermally induced deformation, and frequency shift using ANSYS Multiphysics is in its final stage, and the results will be published separately. Obtained results indicate that the proposed cavity design will perform within the requested limits.

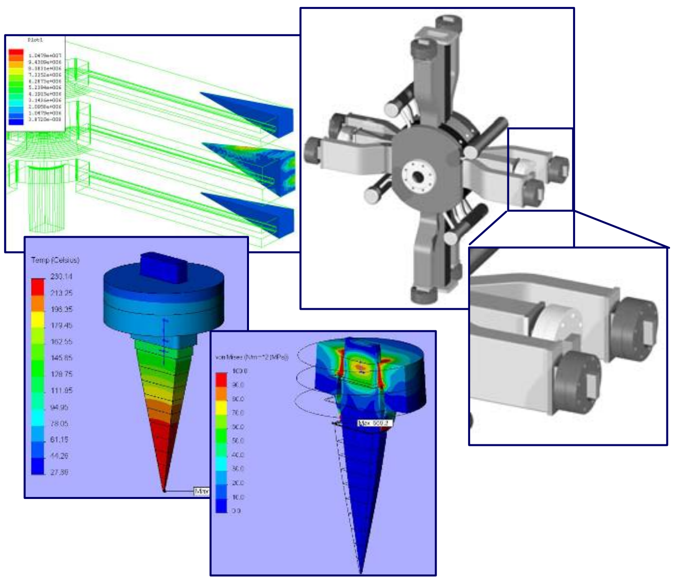
Thermal Design of the Dampers

- The thermal design of the damper system has to ensure that:

1. the damper structures survive brazing of the SiC dampers to OFE copper substrate (typically the critical phase),
2. the heat generated during the operation is efficiently removed by cooling of the substrate.

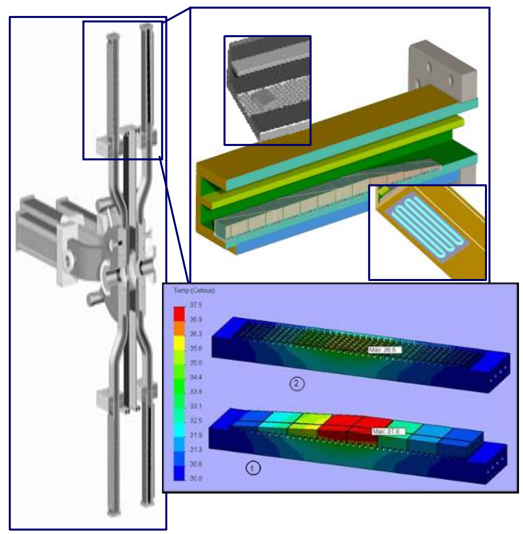
- The power loss in the damper system of our deflecting cavities, due to the inadvertent coupling with the operating mode and due to the extraction of the parasitic modes, is 2.6 kW.

Initially proposed 'pyramid' design was abandoned



when computations indicated that the dampers with highest power losses can not survive operating conditions.

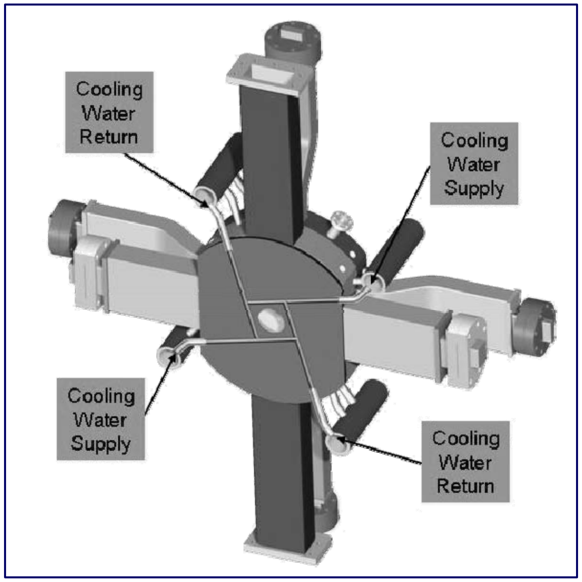
Instead the 'pin bead' design similar to one reported by Cheng et al. at this conference was adopted.



'Tiling' of the SiC dampers and brazing the tiles atop the pins of the pin matrix machined into the Cu substrate effectively decouples SiC dampers from the substrate and greatly reduces stresses developed after brazing.

The pin matrix reduces the efficiency of the cooling of tiles, yet computations indicate that the cooling is adequate and that the temperature gradient in the damper structure remains below 10 ºC

The Cooling System



- The cooling system will provide efficient cooling of the cavities.
- Cooling system will provide better than 0.1 ºC temperature stability needed to tune and maintain the cavity frequency over the required range of operation.
- Operating range of the system will be within 30-50ºC thus ensuring that cavities operate above the room temperature.
- The system will consist two separate stages. The first (remote) stage is expected to bring the cooling water temperature within 1.0ºC or better of the target temperature. The second (local) stage will be much smaller and will deliver cooling water with better than 0.1ºC stability.
- Four identical but independent cooling water systems are required for the four cavities so that each may be maintained at different operating temperatures if desired.

Conclusions

- A design for a novel normal-conducting deflecting rf cavity that is used to generate short-pulse x-rays on the picosecond timescale is being developed at the APS.
- Efficient cooling ensures that the thermal stresses in the structure remain below the yield stress values.
- The proposed design of the dampers is based on known brazing concepts and provides adequate cooling.
- A two-stage cooling system will provide the required 0.1 ºC temperature stability within the 30-50 ºC temperature operating range.