AMAC Int'l, Inc.
Excellence in Cryogenics and Superconductivity

R&D of High RF Power Couplers for Ultimate Cavity Performance

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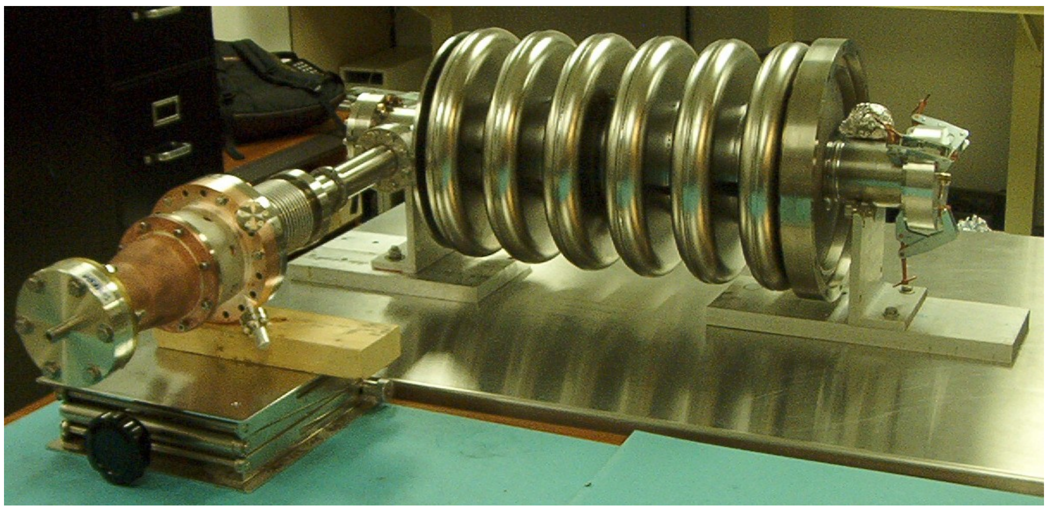
AMAC International, Inc., Newport News, VA
September 23, 2004

- Impact of RF Coupler on Cavity Performance
- Brief Introduction of Coupler Development by AMAC
- R&D
  - Better Vacuum, Easier Cleaning,
  - Less Multipacting
  - Pre-stress to Reduce Thermal Tension
  - New Materials
  - Higher RF Power

Crucial Function & Critical Impacts



- RF High Power Input Coupler Transfers the ultimate RF Power needed to cavities – a challenge
- Vacuum connected & insulated with/from cavities
- Electron emissions impact each other with cavities
- Mechanically connected with cavities – Thermal contraction compensation
- Thermally connected with cavities – reduce the heat leak to cavity and avoid local temperature raising

New TESLA High RF Power Couplers

- TESLA has three types of existing couplers, which work very well
- Motivations for new design:
  - New TESLA higher Eacc cavities need much higher RF power than originals
  - Each new coupler would like to provide RF power to two cavities instead of one
  - Lower the mutipacting level
  - Easier to be evacuated
  - Lower the total price

Original Coupler Design
- 1.3 ms
- 5Hz
- Eacc 25 MV/m
- Two cylindrical windows
- 60 mm OD
- Smaller pumping port
- Average RF Power 50kW
- Pulse 1.1 MW

New AMAC Coupler Design
- 1.3 ms
- 5Hz
- Eacc 35-40 MV/m
- Two desk windows
- 80 mm OD
- Smaller pumping port
- Average RF Power 250kW
- Pulse 4 MW

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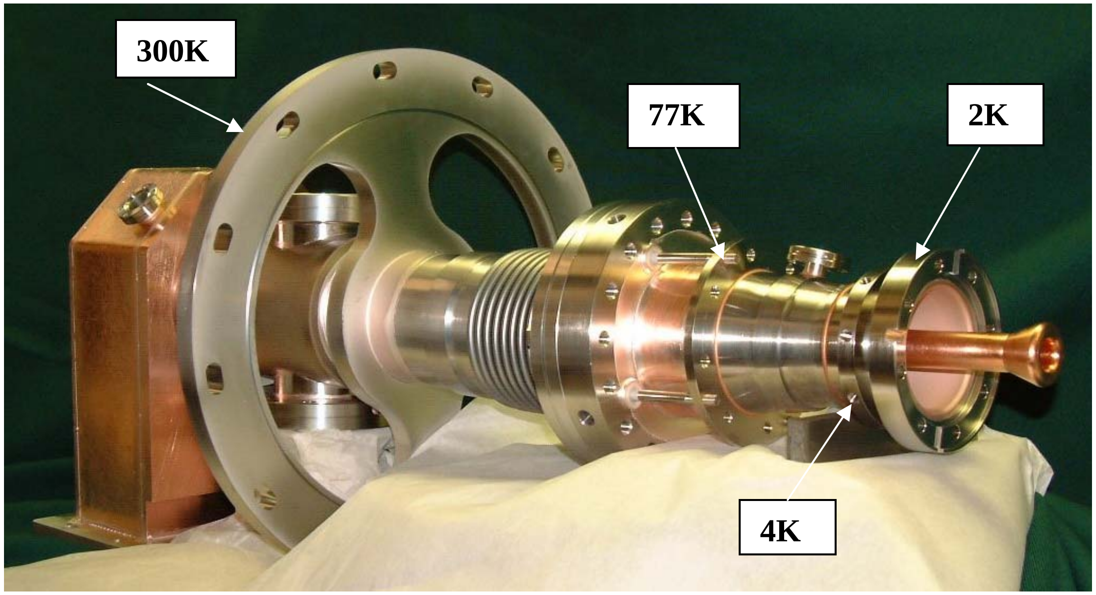
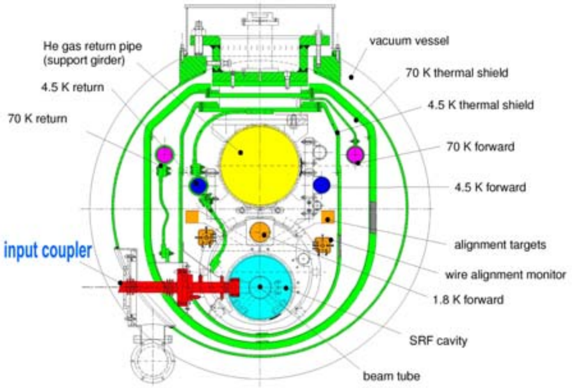
New TESLA High RF Power Couplers

- AMAC has signed a joint agreement in 2003 with DESY to develop a novel, reliable, low cost high power input coupler for the international TESLA project.
- Two New TESLA High RF Power Couplers (80 kW CW E-H wave fields) is under an award to AMAC by the US Department of Energy





New TESLA High RF Power Couplers

Warm Window Assembly

Cold Window Assembly

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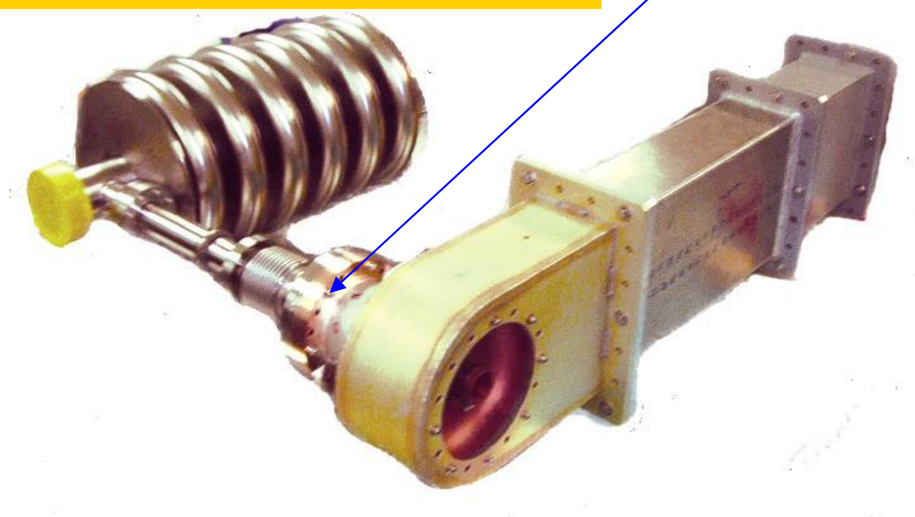
AMAC's RIA High RF Power Coupler

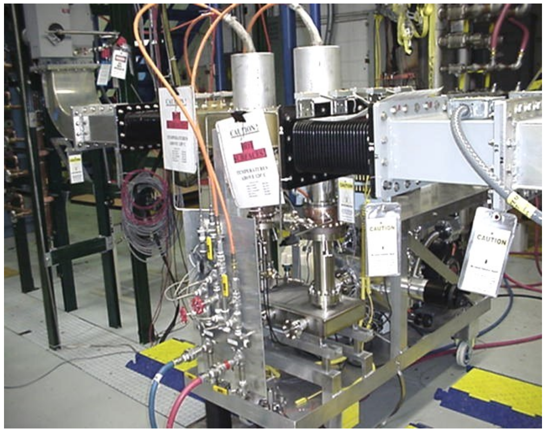
The Rare Isotope Accelerator (RIA) will be the world's most powerful research facility dedicated to producing and exploring new rare isotopes that are not found naturally on Earth

VSWR: 1.05 or lower at 805 MHz
Maximum CW power: 10 kW
External Q of coupler: 2 x 10^7
Maximum thermal load to 2 K circuit: 2 W

AMAC's Contribution (Coupler)
For Michigan State University - RIA

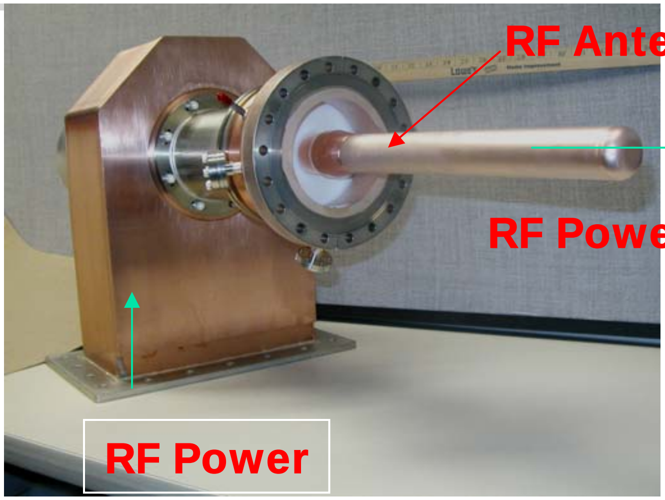


Tested at Jefferson Lab



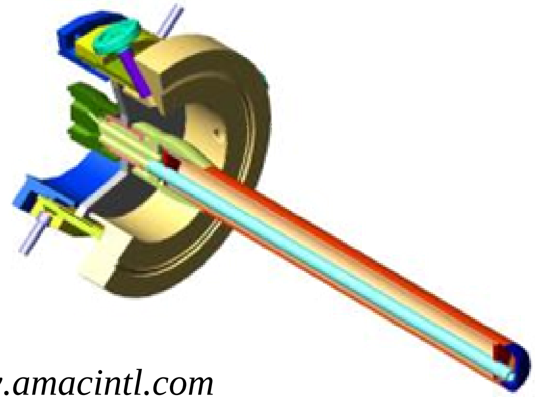
AMAC's SNS High RF Power Coupler

- The Spallation Neutron Source (SNS) is an accelerator-based neutron source being built in Oak Ridge. AMAC has produced three high RF power (2MW pulse) coupler prototypes for the US SNS project. (2002). Jlab has tested & qualified – meet requirements



S11: 0.00864
S12: 0.99939
VSWR: 1.0174
Power Loss in the Ceramic: 6.5 W (LT=0.0002)
Power Loss at the Copper Surface: 54 W
Peak Electric Field: 27.5 kV/m (at the choke corner)
Peak Magnetic Field: 91.4×10-6 Tesla (at the ceramic inner boundary)
Insertion Loss: -0.0053 dB

AMAC Design SNS High RF Power Coupler. The MAX CW RF Power – designed as 200 kW



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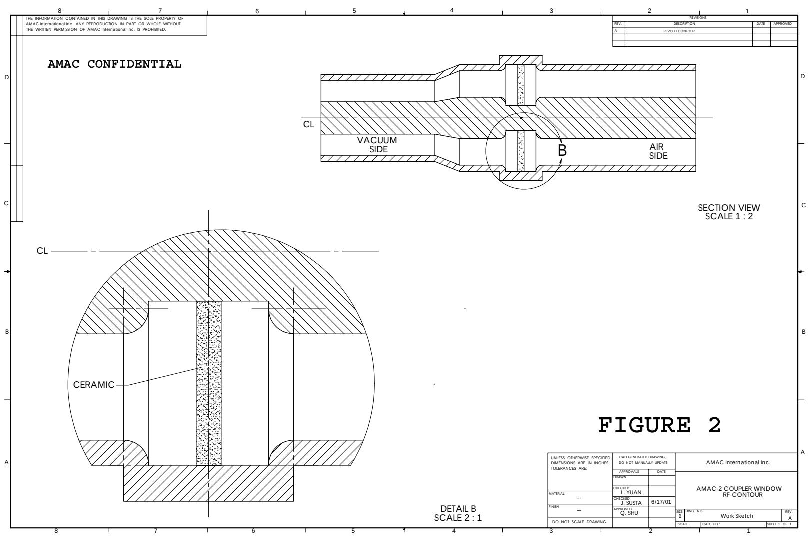
RF Surface Shape Consideration

AMAC-I Design

- Choke around ceramic window has been widely accepted in high RF power coupler design since KEK
- It has been successful in several applications. AMAC used it for SNS, RIA, etc.
- It reduces the E/H fields in specific areas
- It also raises several challenges

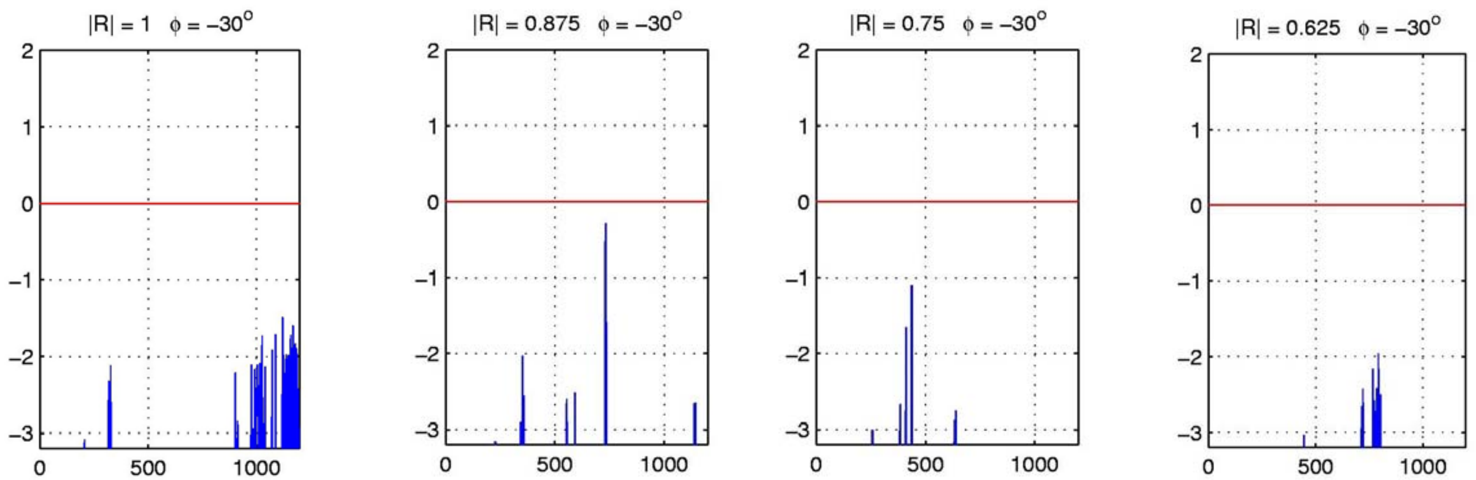
RF Surface Shape Consideration

AMAC-II Design



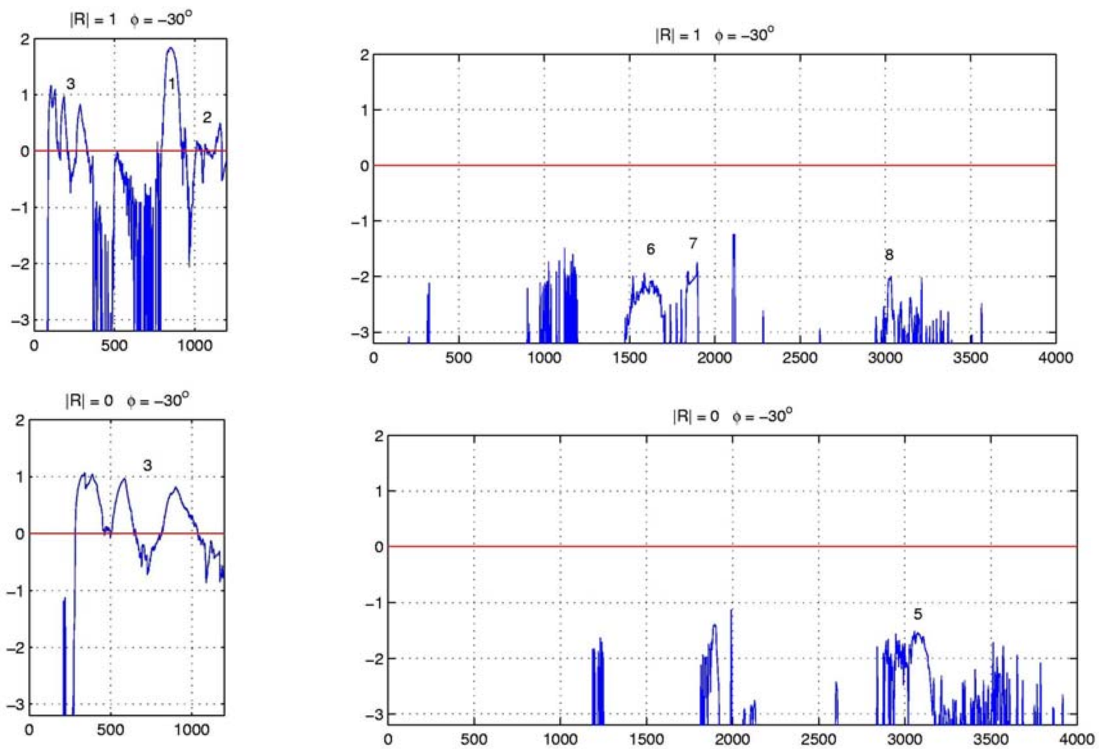
- How it can be designed – easier machining & cleaning
- Easier evacuated
- With less electronic multipacting
- And also not increase the local H/E field significantly
- An innovative RF surface design without choke has been successfully developed by AMAC, and constructed (CPA) and tested (Jlab)

RF Surface Shape Consideration



Multipacting calculations were performed at the University of Helsinki using a program that tracks electron trajectories in various wave reflection conditions and determines their enhancement possibility for different power levels. As illustrated in the Figs, the results show low multipacting activity at several phase angle positions. It is evident from the comparative results for up to 4 MW peak power levels (104 kW average power), that the AMAC-2 version shows a much lower multipacting activity than the AMAC-1 version in all reflection and power level conditions.

RF Surface Shape Consideration



Relative Enhanced Counter Function for (a) & (c) AMAC RIA Coupler (1.2 MW peak power), and (b) & (d) AMAC-2 coupler (348 kW average, 4 MW peak power). Note that the Ordinate represents Enhancement Possibility and the abscissa is Power Level.

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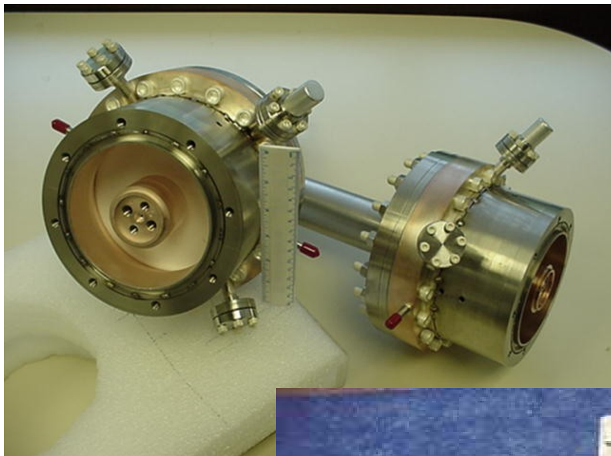
Compression Ring - Pre-stress the Ceramic Window for Ultimate Power

High RF Power windows with Compression Ring by AMAC



- Failures of windows generally occur in three categories:
- Excessive heating
- Arcing, and
- Weak mechanical designs
- AMAC's Resolutions:
  - Compression Ring
  - Strong cooling

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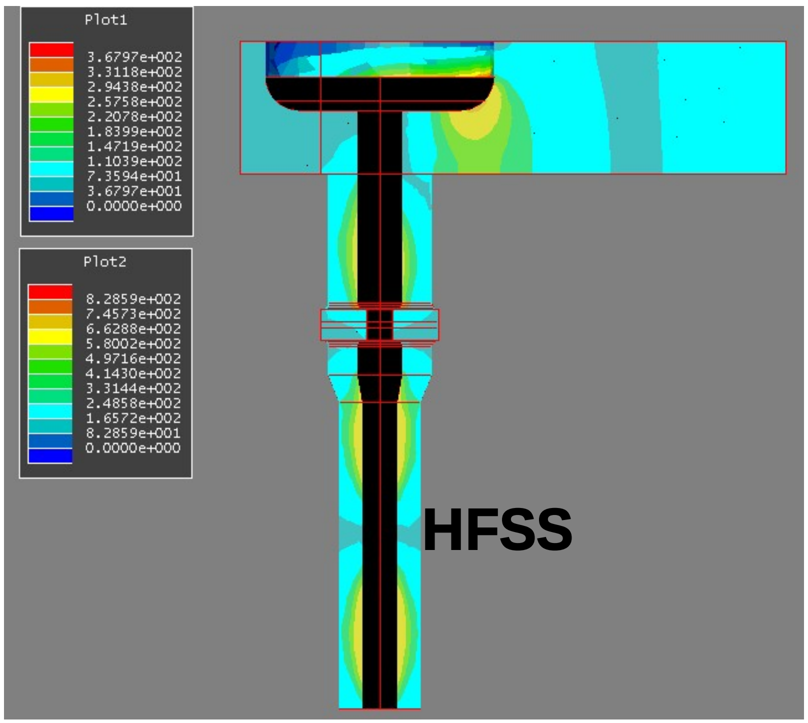
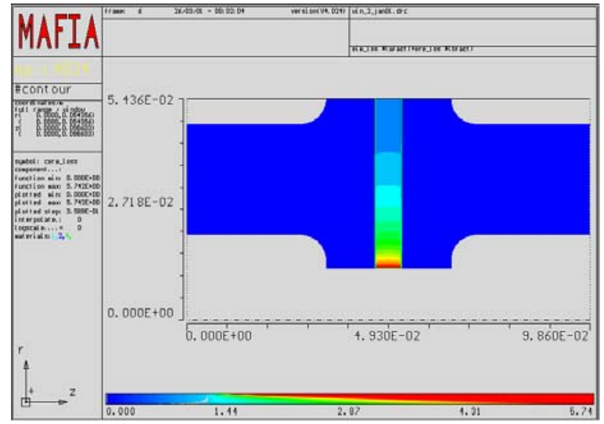
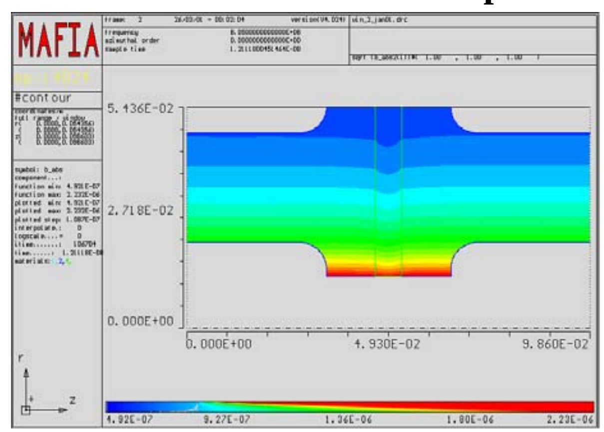
Compression Ring - Pre-stress the Ceramic Window for Ultimate Power





Contour plot of dielectric loss of ceramic in AMAC-2 at 1/2W of incident power



Contour plot of magnetic field in AMAC-2 at 1/2W incident power

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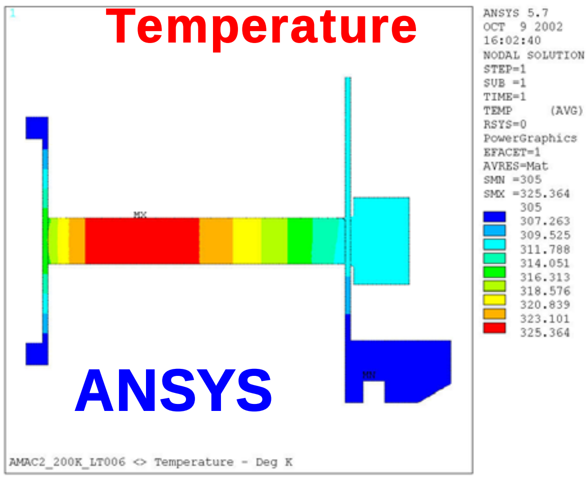
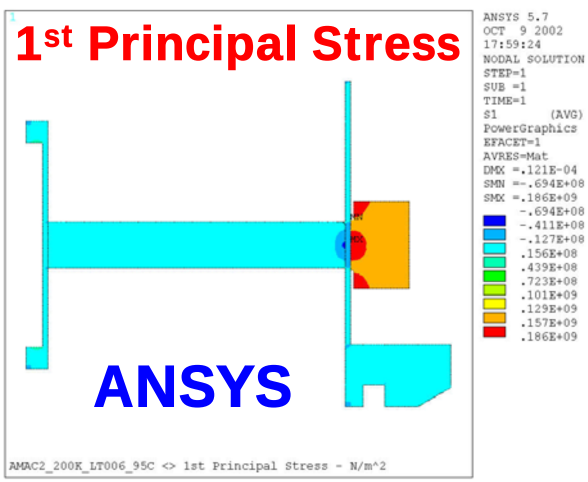
Compression Ring - Pre-stress the Ceramic Window for Ultimate Power



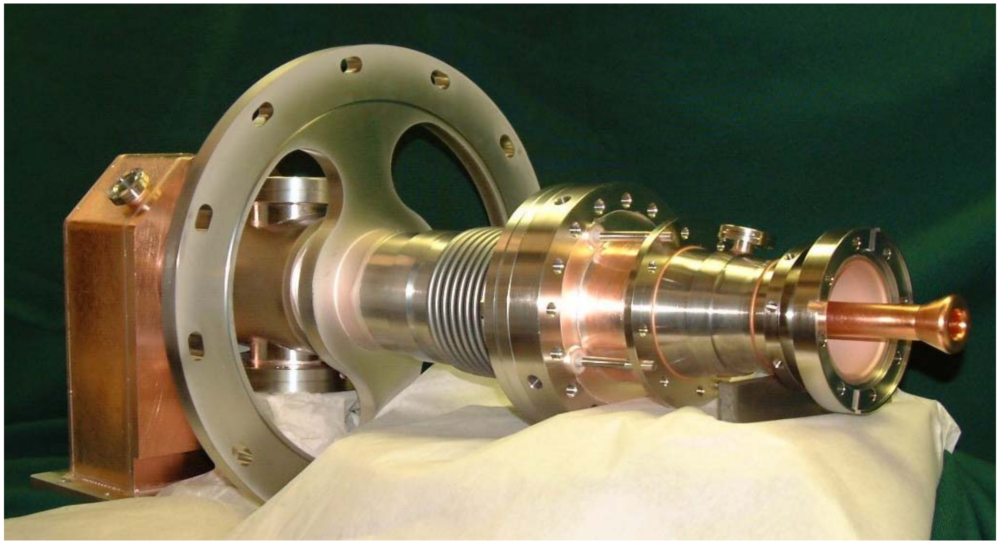


- **A stainless steel compression ring was added to AMAC-2 to reduce the thermal tensile stresses in the ceramic during high power operation.**
- **For a case of 500 kW input power with symmetric cooling, the compression ring reduces the maximum tensile stress in the ceramic to 2.7 kpsi (the maximum stress occurs at the outer brazing edges).**
- **This is only 47% of the corresponding stress without the compression ring.**

Table 1 Tensile Stress Comparison

Average Power (kW)	Max. Tensile Stress (kpsi)		Bulk Tensile Stress (kpsi)	
	without CR	with CR	without CR	with CR
Symmetric cooling				
500	5.7	2.7	0.7-4.9	0.4
200	2.7	2.3	0.9-1.7	0.2
53	1.5	2.1	0.5-0.8	0.2
Asymmetric cooling (32º C inner edge, 62º C outer edge)				
500	7.2	3.7	7.2	3.7
200	5.2	3.1	5.2	3.1
53	4.3	3.0	4.4	3.0
Asymmetric cooling (62º C inner edge, 32º C outer edge)				
500	7.0	2.9	7.0	3.7
200	5.1	2.3	5.1	3.1
53	3.8	2.2	3.8	2.2

Optimization of Thermal Performance - II



Consideration:

- ➢Allowed heat leak to 2K
- ➢Limited local heat & highest T
- ➢Cooling

Heating:

- ➢RF fields on all surfaces
  & ceramic windows
- ➢Conducting: to Low T, Room T
  And any thermal sinks
- ➢Thermal radiation: to tower T
- ➢Gas conduction if filling gas used
  between two windows

Parameters to be optimized: RF surface, SS thickness, thickness and RRR of copper coatings, diameters, turns, location and thickness of bellow, Ceramic materials, window locations, One/two, etc.

Optimization of Thermal Performance - II

FIGURE 7 shows the model geometry. Please note that only the outer-conductor portion from the 4-K flange to 70-K flange was under analysis. It is assumed that there is minimal heat flux that flow into/out of the top of 70-K flange and bottom of 4-K flange. Therefore, constant temperature boundary conditions are applied on the top surface of 70-K flange and also on bottom surface of 4-K flange.

As illustrated in FIGURE 7, the temperatures on top of 70-K flange are fixed to be 70 K and the temperatures on bottom of the 4-K flange are set to be 4 K. RF heating of the outer conductor is applied as heat fluxes that are normal to the inner surface of the outer conductor.

The major objective of present study is to investigate the influence of the coating copper RRR value on the thermal performance of the coupler. Up to five RRR values, RRR = 3, 5, 7, 10, 15, are quoted. The thermal conductivity of copper is temperature dependent. FIGURE 8 gives the measured thermal conductivities used in the finite element analysis.

Because the resistivity of copper is also temperature dependent, an iterative solution procedure is implemented to achieve a converged steady-state temperature field. The RF dissipation is updated at each step according to the temperatures solved in last step. The heat that is intercepted by the bottom surface of 4-K flange is calculated. The influence of RRR values on the heat transfer to 4-K flange is investigated as a function of the stainless-steel wall thickness and the copper resistivity. The results are shown in FIGURE 9.

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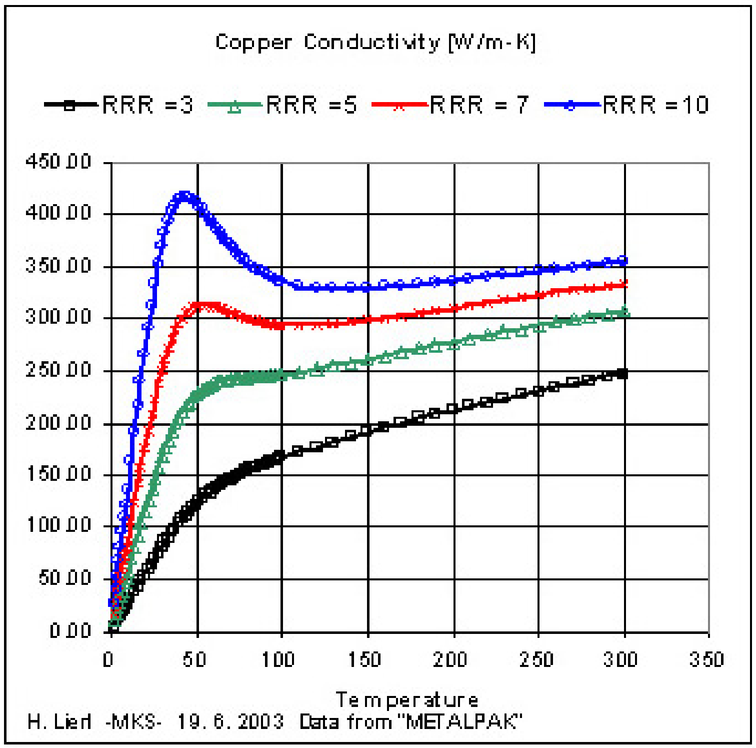
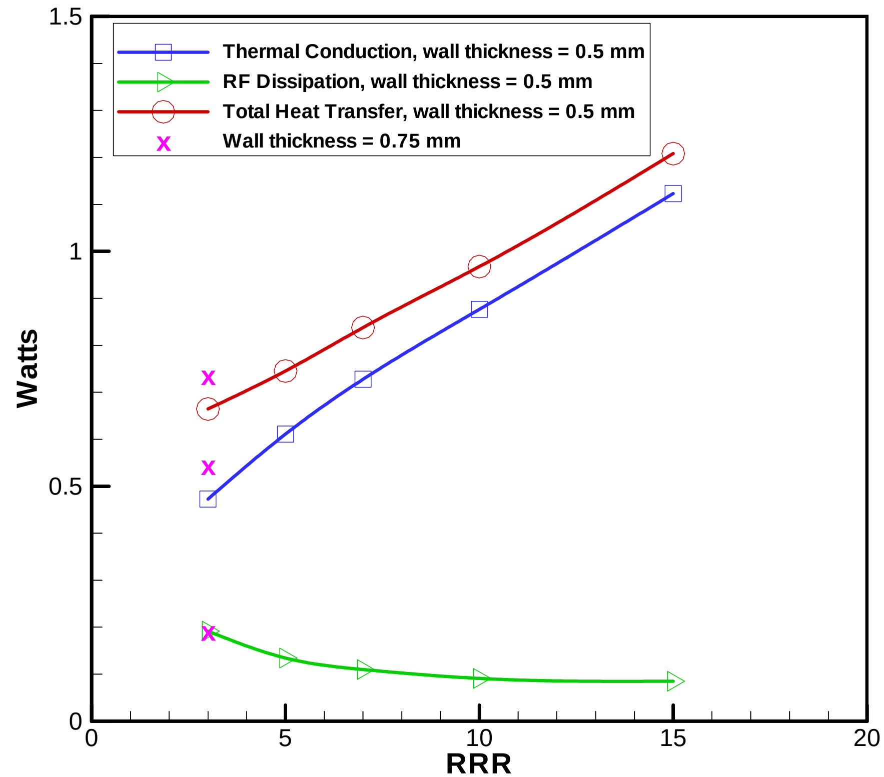
Optimization of Thermal Performance - II





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- **AMAC Team**