High power coupler for the TESLA superstructure cavities

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HIGH POWER COUPLER FOR THE TESLA SUPERSTRUCTURE CAVITIES*

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Abstract

More and more accelerators are built with superconducting cavities operating at cryogenic temperatures, and the probability of a ceramic window failure presents increasing problems because of the resulting contamination of the cavities' surfaces and the resulting accelerating electric field degradation. Double ceramic window couplers are required to reduce this risk. The TESLA superstructure cavity requires a new coupler for the higher power input and the coupling characteristics. A cost effective design and fabrication method for these couplers has been developed to meet these demands. This new design presents an alternative to the present TESLA cylindrical ceramic windows, uses two planar disc windows separated by a vacuum space, and is optimized for RF input power, vacuum characteristics, and thermal properties.

Two couplers with this design have been fabricated and are presently being tested at DESY, Germany on the RF high power testing stand and will also be tested on a test cryomodule. The design will be discussed in this paper.

INTRODUCTION

A window failure allowing the inrush of atmospheric air into the superconducting cavities could potentially degrade the performance of extensive sections of the accelerator. The consequent disassembly of the cryostats and other accelerator components for repairs is viewed as a disastrous event because of the time and resources required. The costs and the time loss for a repair and reconditioning of the accelerator structure are considered to be too high in comparison with the costs of a double window coupler design.

The main specification parameters for the TESLA superstructure coupler are:

Frequency: 1.3 GHz
Forward Power for TESLA upgrade: 1110 kW
Pulse length: 1.3 ms
Repetition rate: 5 Hz
Cryogenic losses: 12 W max at 70K, 1 W max at 4K, 0.12 W at 2K.
Movement of 1.5mm in cavity axis direction during cool-down
Double window coupler design
DC bias up to 4 kV
High pumping speed for the space between ceramic windows.

The window closer to the cavity must be assembled on the cavity in the clean room. The flange connection to the outer part of the coupler must be located at a maximum distance of 10.95″ from the cavity centerline, to allow insertion of the cavity assembly into the cryostat.

TECHNICAL GOALS

- VSWR lower than 1.10
- Low electric and magnetic fields near the ceramic windows to reduce the possibility of multipacting
- Good thermal and vacuum performance to meet TESLA specifications
- Less complexity in the fabrication and operation of the couplers
- Fabrication of two complete coupler assemblies
- High RF power testing of coupler

RF DESIGN

The RF calculations and optimization were performed using the HFSS finite analysis code. A tolerance analysis was performed to determine the critical dimensions. The design of the transition regions at the ceramic windows needed to compensate for the effect of the ceramic window insertion was based on the successful AMAC-2 prototype for the SNS project [1]. Figure 1 shows the window geometry for the AMAC-2 coupler. This geometry allows for easier fabrication and better cleaning of the surfaces as compared with the traditional choke design.

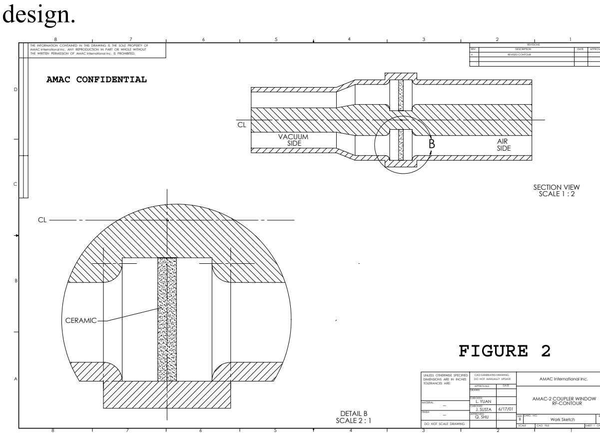

Figure 1: AMAC-2 coupler window geometry

The TESLA HFSS calculations give a maximum voltage gradient of 1440 V/m per Watt of input power,

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which corresponds to a voltage of 30.3 kV across a 2cm gap (for 1.11 MW peak power) in the coupler region with the highest electric field.

$$\text{Breakdown voltage:} \quad V_{DC}^{max} = \sqrt{Zo \times P_{peak}^{max}} \qquad (1)$$

The breakdown voltage calculated from literature breakdown power values [2] for a comparable standard coaxial line with the same impedance as the TESLA coaxial coupler is 108 kV. This breakdown voltage is 3.5 higher than the calculated maximum peak voltage at the TESLA coupler

The principal expected limitation during operation of the coupler could be the secondary electron emission at high power levels (multipacting). The multipacting properties for the coupler window sections were calculated at DESY with a program that tracks electron trajectories in the electromagnetic fields [3]. The calculations results show that this is not a problem for ideal surfaces with the proposed geometry, but to take account of surface irregularities near the brazing region of the ceramic window that could become potential electron emitters, it was decided to coat the vacuum exposed surfaces of the windows with Titanium Nitride (TiN) using the evaporative method (in place of sputtering). The plot in Fig. 2 shows the calculated multipacting bands for the TESLA coupler.

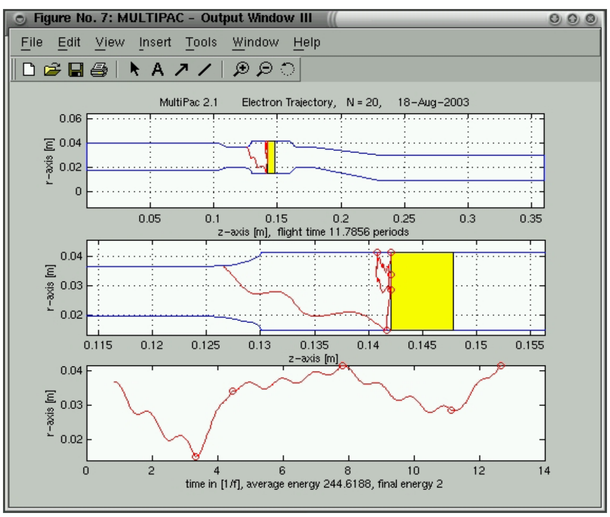

Figure 2: Multipacting trajectories near warm ceramic window at power level 900kW – 1300kW

A high DC voltage bias of up to 4.5kV can be applied to the inner conductor of the coupler as an additional way to suppress eventual multipacting activities. Secondary Electron Emission Tests were performed at DESY [4] on samples provided by AMAC/CPI to determine the secondary emission coefficients for surfaces with the same brazing materials used in the fabrication of the couplers. These tests were performed to determine real values for these coefficients and to compare them with the SEE values for the standard materials used in coupler fabrication. Au – Cu brazing material shows a reduced conditioning time.

- The AMAC coupler design is free of multipacting trajectories in the regime of the specified power.
- The window surface shows short living multipacting trajectories.
- The general arrangement of the TESLA coupler assembly is shown in the photo Fig. 3.

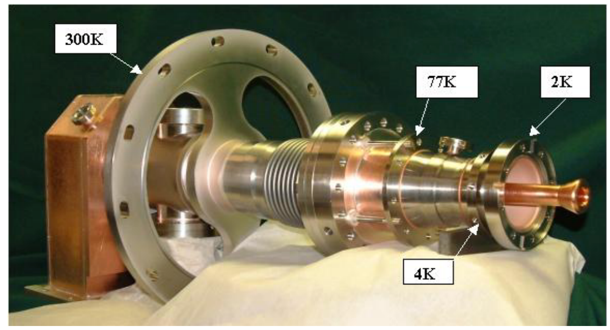

Figure 3: General assembly of TESLA coupler developed by AMAC

THERMAL DESIGN

The thermal calculations were performed with the help of the ANSYS program and used material properties data [5-6] in algorithms developed at DESY [5] and AMAC, to take into account the temperature and the respective thermal conductivity and electrical losses after the final brazing [7]. The thermal conductivity values at different temperatures for the aluminum oxide for the ceramic windows were taken from [8].

The expected RRR values after brazing were taken from tests results obtained at DESY [7, 9] which take into account a series of Ni strike and copper plating thickness, and several heat treatment temperatures. The materials, parts dimensions, and materials combinations used for this TESLA couplers design were varied until the required thermal performance was obtained. The most difficult specification heat loss value to meet was found to be in the section between the cold window and the flange attached to the 2K cavity because of the limited length available. Figure 4 shows the results of a typical optimization array of curves used to determine the optimum parameters for the stainless steel window components, copper coating thickness and heat treatment for the cold window assembly shown in Fig. 5. The design was optimized for RRR values obtainable after brazing, to avoid the necessity of performing electron beam welding operations.

COOLING

The 7.2 kW average power level specified results in moderate temperature gradients in the ceramic as shown in the thermal calculations. These results allow the use of conductive cooling to ambient temperature and to the cold intercepts at 4K and 70K. This was achieved by material choice and dimensional optimization to meet the heat loss requirements to the 2K, 4 K and 70K stations.

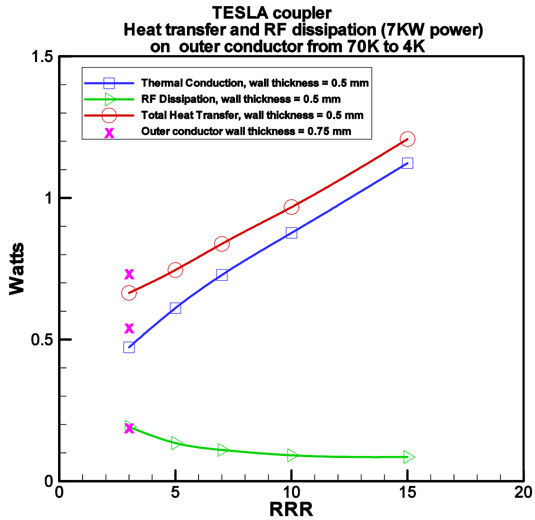

Figure 4: Cold Window Assembly: Conductive Thermal losses calculation results

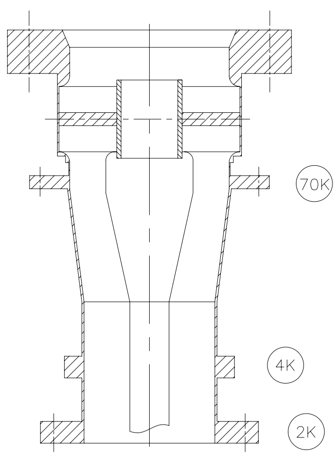

Figure 5: Cold window subassembly for AMAC TESLA coupler

VACUUM

High vacuum in the low 10^{-9} torr range has to be maintained in the space between the two ceramic windows to avoid multipacting during RF operation. This requires adequate pumping capacity and good conditioning of all the surfaces exposed to the vacuum. The limit maximum pressure is easily achieved in the volume that is common with the RF cavity, but more difficult to reach and maintain during operation in the space between the two windows because of the pumping conductance limitation. The present TESLA design combines 8 couplers with one pump and a pumping manifold.

All improvements in the pumping capacity yield only improvements of less than one order of magnitude due to the geometric conductance limitation. To reduce the gas load of the coupler, all stainless steel parts will be degassed prior to brazing at 600°C. This reduces the hydrogen degassing of the bulk material by an order of magnitude [10] or more. The STTR TESLA couplers will incorporate a controlled heater at the cold window to insure that the temperature of the window is always kept at a temperature of 110 to 115K.

FABRICATION

The couplers will require only brazing operations, and this will reduce the cost for larger coupler quantities because it allows the brazing of a large number of complete couplers in single oven charges. The materials and the geometry have been optimized to meet the electric and thermal specification requirements, and take into account the changes in electrical and thermal conductivity of copper during the brazing process. The CPI fabrication procedures for quality control, cleaning, plating, brazing, and leak checking were followed in all stages of the fabrication.

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