DEVELOPMENT AND TESTING OF RF DOUBLE WINDOW INPUT COUPLERS FOR TESLA*

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ABSTRACT

More and more accelerators are built with superconducting cavities operating at cryogenic temperatures. A possible window failure might result in contamination of the cavity surface and degrade the accelerating performance. As a result of the experiences obtained during the development of high RF power input couplers for the SNS and RIA projects, a cost effective design and fabrication method for a new coupler has been developed in the framework of a DOE STTR grant. This new design is an alternative to the present TESLA cylindrical ceramic windows layout. The new design includes two planar disc windows separated by a vacuum space. An alternative design option proposes filling dry nitrogen gas in between the two ceramic windows. Furthermore the new design is optimized for RF input power, taking into consideration the possible requirements of the TESLA superstructure layout. It is expected that this novel coupler will reduce the costs of fabrication and improve the RF performance. Two prototype couplers with this design have been fabricated. The couplers are being tested on the high power test stand at DESY, Germany. This paper describes the new coupler design and discusses the first measured results.

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 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.

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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. Other aspects of the design were also considered [1].

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 [2]. 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.

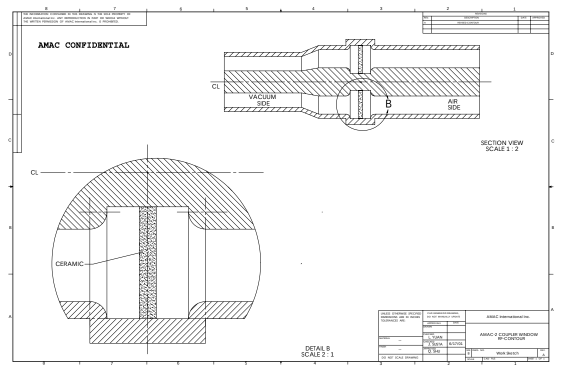

Figure 1 AMAC-2 coupler window geometry

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.

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.

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 CPI fabrication procedures for quality control, cleaning, plating, brazing, and leak checking were followed in all stages of the fabrication.

COUPLERS CONDITIONING

The coupler RF test was done in a way it is done for TTF couplers at DESY [11-13]. The couplers parts were assembled on the test stand (Fig. 5) in such a way that RF power transmission through the couplers pair is maximized.

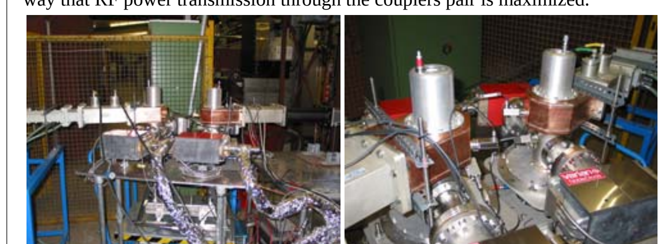

Figure 5: Couplers on the test stand.

Couplers diagnostics is based on the different types of sensors: vacuum gauges, charged particles (e-) and spark detectors and temperature sensors (Fig. 6). Each warm part was connected to two ion getter pumps (IGP) having pumping speed of 60 l/s through 150 mm tubes with diameter of 60 mm ensuring the high effective pumping speed. The cold parts mounted on the test waveguide box were pumped out using one IGP. RF power source was Thales 5MW pulsed power 1.3 GHz klystron.

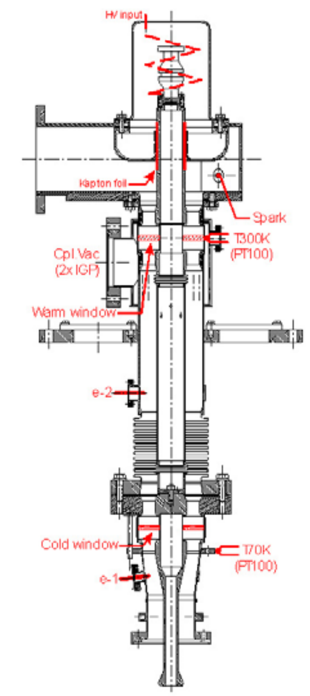

Figure 6 Coupler layout.

Table 1 Conditioning procedure

Pulse, µs	Max power, kW	Time, hr
20	1000	38
50		1
100		1
200		1
400		1
800	500	1
1000		1

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 vacuum exposed surfaces of the windows are coated with Titanium Nitride (TiN) using the evaporative method (in place of sputtering).

A high DC voltage bias of up to 4.5kV can be applied to the inner conductor of the coupler. 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. 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 Fig. 2.

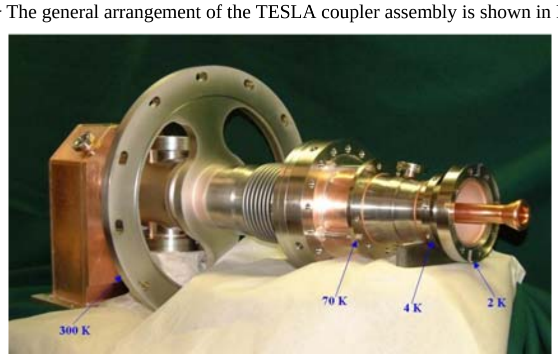

Figure 2 General assembly of TESLA coupler developed by AMAC and fabricated by CPI

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. Figure 3 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. 4. The design was optimized for RRR values obtainable after brazing, to avoid the necessity of performing electron beam welding operations.

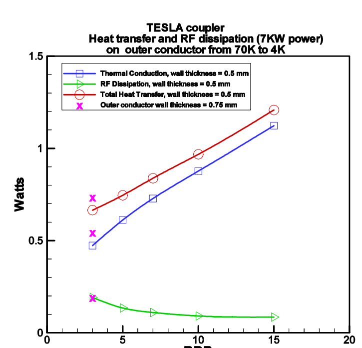

Figure 3 Cold Window Assembly: Conductive Thermal losses calculation results

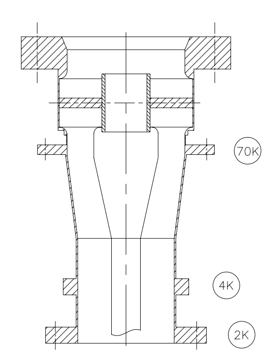

Figure 4 Cold window subassembly for AMAC TESLA coupler

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.

Conditioning Procedure

The milestones:

- Baking at 150°C. Temperature is reached within 24 hours and is kept at this level for 24 hours more. Vacuum pressure is constantly monitored, at the end 10^{-9} mbar pressure level is reached.
- RF power conditioning is done in travelling wave regime at 2 Hz rep.rate with different pulse lengths from 20 to 1300 µs. Maximum power level reached is 1MW (Table 1). The power rise is limited by the different thresholds, set for the coupler vacuum and e- in the coupler vacuum, as well as for the ceramics temperatures. A hardware interlock can switch off the power at high readings of vacuum, electrons or ceramic temperature and for the spark in the waveguide.
- RF power sweep 50..500kW for 1.3 ms pulse.

Conditioning Results

Total RF power rise time was 44 hours, total RF ON conditioning time was 56 hours, after conditioning standard power sweep done for 40 hours showing almost no activity. Average conditioning time for the TTF3 type couplers at DESY is 60..130 hours (Fig. 7).

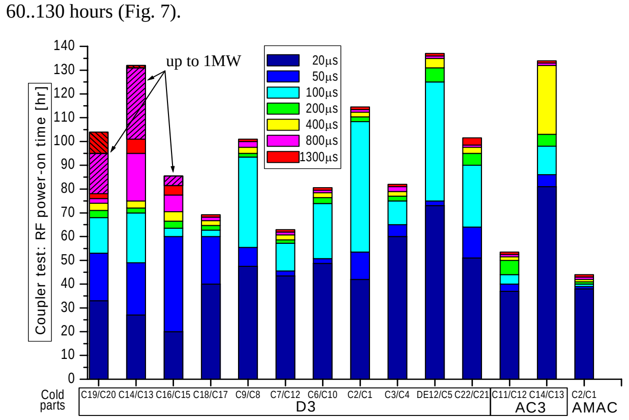

Figure 7 Couplers conditioning time: TTF3 and AMAC

At the long pulse lengths there was sparking in the coupler waveguide part caused by isolation kapton foil RF breakdown near the doorknob. Rounding of the sharp edges of the inner conductor holding eliminated this.

After the coupler conditioning was completed the bias program was started. No multipacting was observed after couplers were conditioned without bias high voltage. The test was done for voltages +500V, -500V, +1000V, -1000V. Some multipacting levels were found at +500V. For -500V some short couplers conditioning was needed before 500kW at 1.3ms pulse could be reached, no multipacting after that. +1000V went just smooth without anything to report. Testing the coupler with Bias HV value of -1000V caused some events and strong deterioration of the performance of the coupler number 2, the input coupler on the test stand. New conditioning without bias afterwards was unsuccessful. Now upon reaching of 400kW at 20 µs pulse length the RF power was reflected from the coupler, with signs of discharging plasma in the coupler. After disassembly of the test stand the coupler was inspected and showed some surface damages from sparking in the region between the window and the pumping slits. No damage was observed at the windows. The damaged coupler part was cleaned using citric acid and will be retested this month.

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