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# DESIGN OF FUNDAMENTAL POWER COUPLER FOR HIGH INTENSITY HEAVY-ION ACCELERATOR

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*Abstract*

A single-window coaxial coupler at warm has been designed for high intensity heavy-ion accelerator. The coupler is designed to handle 100kW CW power of 325 MHz and is currently being fabricated. T-bend transition and doorknob have been taken into account. The length of the T-bend short circuit is sensitive to S parameters and contributes to the online adjustment of VSWR in RF conditioning. The doorknob type is adopted to realize the transition from a half-height WR2300 waveguide to a coaxial line ended with a coupling antenna. This paper describes the RF design, thermal stress and heat load analysis of the coupler as well as multipacting simulations.

## INTRODUCTION

Increasingly higher beam current and improved cavity gradient placed demanding requirements on fundamental power couplers. High reliability, bridging ambient and liquid helium temperatures, low cryogenic heat leak, reasonable cost, and preserving extreme cavity cleanliness are the main challenges for fundamental power couplers in continuous wave mode [1].

The ceramic window is a fragile component, and the cause of coupler failures is summarized as follows：

1）Cracked windows due to mechanical stresses

2）Cracked windows due to thermal stresses

3）Punctured windows due to electron activities

In addition, brazes and welds caused leakage is also one of the factors leading to damage.

The ADS proton linac adopted β=0.12 and β=0.21 superconducting Spoke cavities. Seven couplers for 325 MHz Spoke-012 SCC for Injector-I have been high power tested up to the nominal power levels in both TW (Spke-012: 10 kW) and SW modes (Spke-012: 5 kW) [2].

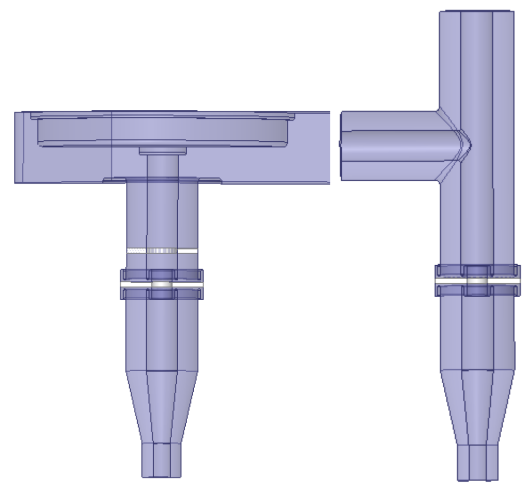
This coupler is designed for experimental purpose to deliver high RF power (100 kW). Its main parameters are summarized in Table 1.

Table 1: Main Parameters of the Coupler

| Parameter | Value |
|---|---|
| Frequency | 325 MHz |
| Input power | 100 kW CW |
| Type | Coaxial, Antenna E-coupling, Fixed |
| Window | Single, coaxial disk |

## CALCULATIONS

The basic design of doorknob type is based on BEPCII 500MHz coupler, including a 50 Ω coaxial line, a planar window and a doorknob transition [3]. The T-bend type shares mutual window and outer conductor with doorknob type. Figure 1 shows the electromagnetic model.



（a） (b)

Figure 1: The electromagnetic model (a) doorknob type (b) T-bend type.

RF window works as a vacuum barrier for the cavity and delivers power. The ceramic window(97.6% Al2O3 Morgan Φ=170mm) adopts a choke structure to avoid the high electrical field at ceramic braze joints and adds vacuum, electron flow, ARC probes in the vacuum side. The S11 of original design of the ceramic window is -27dB at 325MHz.

Figure 2 shows the calculated S11 curve of the whole coupler. The S11 reads -49dB at 325MHz, and the bandwidth is approximately 13MHz at -25dB for doorknob coupler. The geometry of the T-bend transition is a crucial part to satisfy the matching condition as it is very sensitive to S parameters and nominal frequency.

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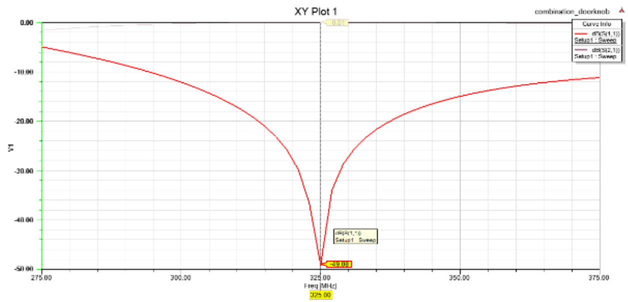
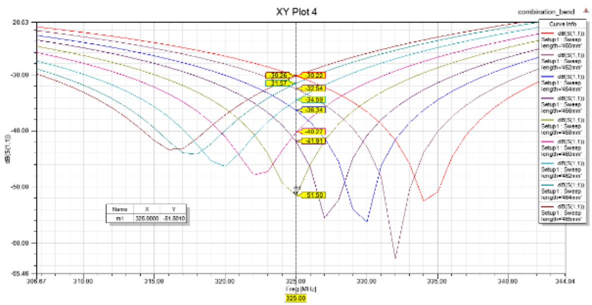



(a)

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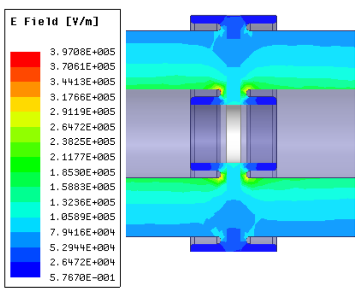


(c)

Figure 2: (a) Calculated S11 parameter of the doorknob coupler. (b) Calculated S11 parameter varied with the length of short circuit for T-bend coupler. (c) The complex electric field contour of the window at 200 kW RF power.

## MULTIPACTING SIMULATIONS

Multipacting can lead to vacuum deterioration, limit the operation power of the coupler, and even cause arc and sputter of copper. The simulations of multipacting in the vacuum side of coupler were performed with CST Particle Studio. It is carried out for the coaxial line and window structure respectively.

The growth of secondary electrons could be simply modelled as exponential [4]:

$$N = N_0 e^{G\frac{\Delta t}{T}}$$

Where:

- N: the number of electrons after $\Delta t$ time
- N0: the initial number of electrons
- T: the radio frequency period
- G: defined as the average growth rate of secondary electrons in a period.

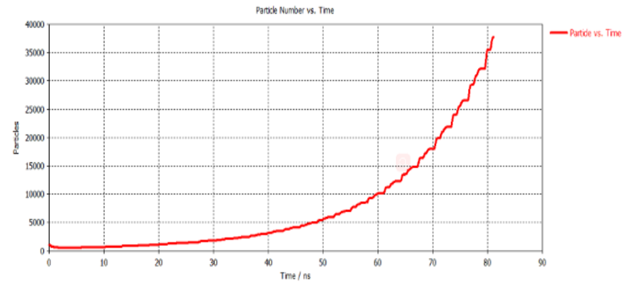


Figure 3: Particle number vs. time.

Figure 3 shows the particle number increasing over time due to multipacting. At the level of the ladder, electrons fly between the inner and outer conductors, and the number does not increase. At the rising edge of the ladder, electrons collide with the metal wall to produce more electrons, and the secondary electrons grow each time. Figure 4 shows the secondary electron growth rate of window and coaxial line calculated at different power. G<0, particles disappear after several periods; G>0, particle number increases periodically.

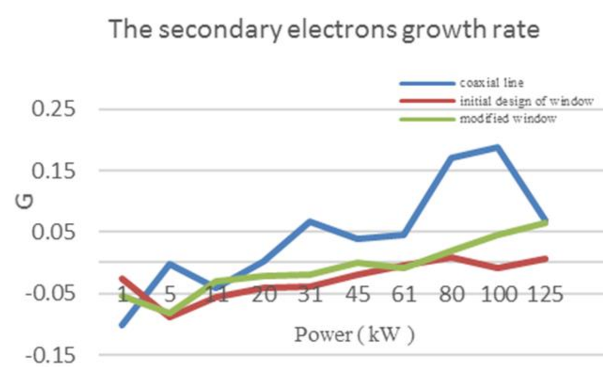


Figure 4: The secondary electron growth rate at different input power.

It was found the MP occurred between the inner conductor and the choke structure at 125 kW by observing the trajectories of the particles (Figure 5). Considering it is not safe for ceramic and overweight form is not conducive to the overall welding in the subsequent form processing, so the choke structure has been adjusted. The MP growth rate of adjusted form is slightly higher than the initial design, but MP mainly occurs between the inner and outer conductors, avoiding the direct collide with the ceramic. The secondary electron growth rate is approximately to 0.04 at 100 kW.

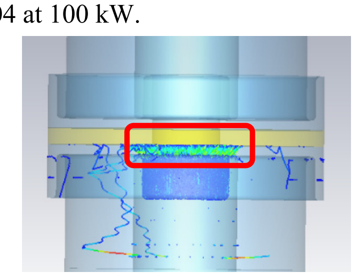

Figure 5: The MP trajectory occurring between the inner conductor and ceramic.

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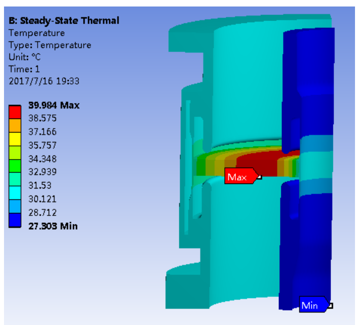
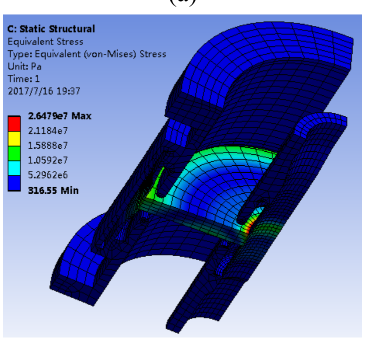
## THERMAL ANALYSIS OF THE RF WINDOW

Ceramic is an insulating material with a certain dielectric loss. The great dielectric loss on the ceramic leads to high temperature, and the thermal stress beyond the limit will result in ceramic window crack. Therefore, the window cooling design is essential to decrease the temperature. Figure 6 shows the window temperature contour and thermal stress contour. The inner window frame shares water cooling with inner conductor, and the maximum temperature is 40 ℃ distributed on the centre of the ceramic (at 200 kW). The maximum thermal stress is 26.5MPa distributed at the weld of the inner conductor and the ceramic.



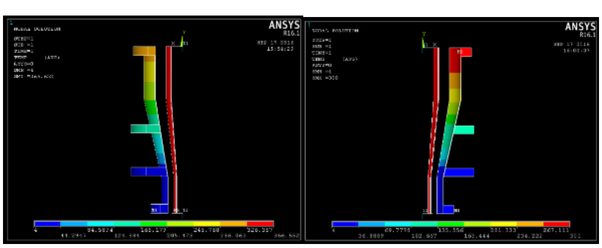

(a)




(b)

Figure 6: (a) temperature distribution with 200kW RF power (b) thermal stress distribution.

Compared the temperature of inner conductor with or without water cooling, the inner conductor shows an excessive heating at 100kW RF power. The 25 °C water cooling is efficient and the temperature of inner conductor decreased dramatically (Figure 7).




(a) (b)

Figure 7: Temperature contour of the inner and outer conductor at 100 kW (a) without cooling, (b) with water cooling.

## HEAT LOAD ANALYSIS

The fundamental power coupler is connected to the 2K temperature at cavity side and room temperature outside the cryomodule, which significantly affects the cryogenic heat load. There are two main approaches to reduce the heat load of the coupler. Firstly, plate a certain thickness of copper layer on the inner surface of the stainless steel outer conductor where RF current flows. The optimal value of the coating properties is a compromise of coating thickness, purity, residual resistivity and low-temperature thermal conductivity, ensuring that the RF loss of the coupler is reduced and the static loss can be accepted [5]. Secondly, thermal anchors or helium gas flow is used to cool the coupler outer conductor, where its position and geometric as well as the helium flow are optimized by simulations [6].

Based on simulations and copper coating technology, the plating thickness is 15um. Two thermal-anchors at 4K and 80K are attached to the outer conductor. The location of the thermal anchors is optimized to minimize total cryogenic load. Figure 7 shows the temperature contour of outer conductor with optimal anchors. The heat loads of the coupler are listed in Table 2.

Table 2: Heat Loads with 4K and 80K Thermal Anchors

| Heat load | 2K (W) | 4K (W) | 80K (W) |
|---|---|---|---|
| Static | 0.1385 | 5.413 | 4.5122 |
| Dynamic (100 kW CW) | 0.8193 | 8.224 | 5.6726 |

The simulation shows that the heat loads to 2 K flange and 4 K are too high for the cryogenic system. The helium gas to cool the out conductor may reduce the heat load properly. It will be calculated next.

## SUMMARY

A new high power input coupler for 325MHz Spoke cavity has been designed. The results of the simulations would offer great assistance in the manufacturing and in the later RF conditioning of the prototype coupler in the near future.

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