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DESIGN STUDY OF A PROTOTYPE 325MHz RF POWER COUPLER FOR SUPERCONDUCTING CAVITY*

Junyoung Yoon, JungBae Bhang, Chong Shik Park, Hyuk Jin Cha, Si-Won Jang, Kyung-Ryul Kim[1], Seong Hee Park, Eun-San Kim† ,Korea University, Sejong, South Korea
Ilkyoung Shin, Institute for Basic Science, Daejeon, South Korea
Jonghwa Lee, Do Yoon Kim, Vitzrotech, Ansan, South Korea
Eiji Kako, KEK, Tsukuba, Japan
[1]also at Pohang Accelerator Laboratory, Pohang,South Korea

Abstract

We present design studies of a prototype RF input Power Coupler, which provides RF powers to 325MHz cavities up to 18.5kW in CW mode. The prototype power coupler is a coaxial capacitive type with single ceramic window. In order to optimize the RF coupler design, we performed multi-physics simulations, including electromagnetic, thermal, and mechanical analyses.

INTRODUCTION

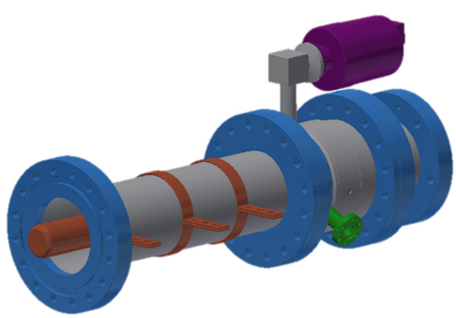

Figure 1: General view of power coupler.

The power coupler is based on conventional 50Ω coaxial transmission line. The prototype coupler has three diagnostic ports for vacuum, arc, and electron pick-ups to prevent RF breakdowns and three thermal interceptors for 4.5K, 40K, and 77K. Figure 1 shows a preliminary design of power coupler and the design requirements are listed in Ta ble 1 [1].

Table 1: Design Requirements of the Input Coupler

Parameters	Values	Unit
Operating frequency	325	MHz
Pass band ($S_{11} < 0.1$)	3	MHz
S_{11} at 325MHz	≤-30	dB
Operating Power	18.5	kW
Q_{ext}	4×10^6	-

† eskim1@korea.ac.kr

SIMULATION

The CST Microwave Studio (MWS) Frequency Domain solver [2] is used for electromagnetic simulations and Ansys Theramal, Structural, Modal solvers were used for the Thermal/Mechanical simulations. [3]

Electromagnetic Simulation

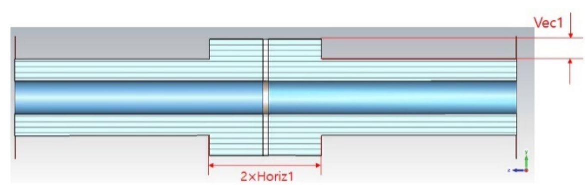

Figure 2: Geometric change of ceramic part.

Figure 2 shows variations of both diameter (Vec1) and length (Horiz1) of the outer conductor at the RF window to minimize reflected powers at 325MHz. We performed simulations to check effects of the diameter change from 8 mm to 10 mm. The optimal values of vertical length were between 8.6 mm to 9 mm shown in Figure 3. Considering engineering and manufacturing errors, we chose the 9 mm variation of the outer diameter at ceramic window.

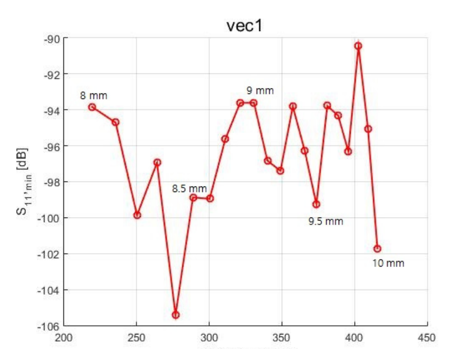

Figure 3: Effect of vertical length change.

The horizontal length change make a small frequency distribution in reflected powers (S_11) at 325MHz. Therefore, we performed the simulation in the narrow range to minimize reflected powers at 325MHz. Figure 4 shows that the optimal horizontal length is 117.2 mm.

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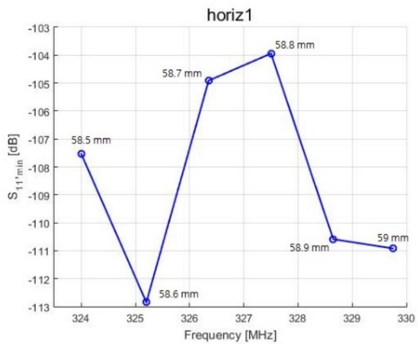

Figure 4: Effect of horizontal length change.

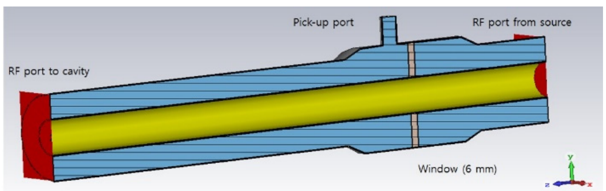

Figure 5: Electromagnetic model of the power coupler.

Figure 5 shows the prototype power coupler modelling in CST MWS. The outer conductor is composed of 0.8-mm-thick stainless steel and the inner conductor is made of 1.5-mm-thick OFHC. We constructed 60-degree angles to the edges of the outer conductor around the ceramic window because the sharp edges make the wake fields and increase the multipacting effect in the coupler [4].

While the changes of the pick-up port length does not significantly affect to the power transmission in the coupler, those of the pick-up port diameter had significant effects to the reflected power. Figure 6 shows the effect of pick-up port diameter change. We chose the 0.5 inch for the least deformation of the RF power transmission as well as consideration of connection with diagnostic devices.

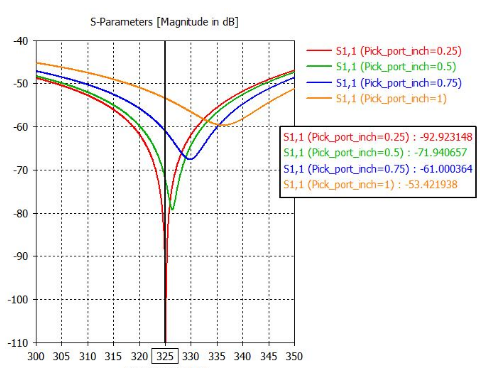

Figure 6: Reflected power (S_{11}) change due to diameter change of pick-up port.

The RF characteristics of the coupler prototype are shown in Figure 7. The point 1 is the minimum point of the reflected power, while and the point 2 is the operating frequency.

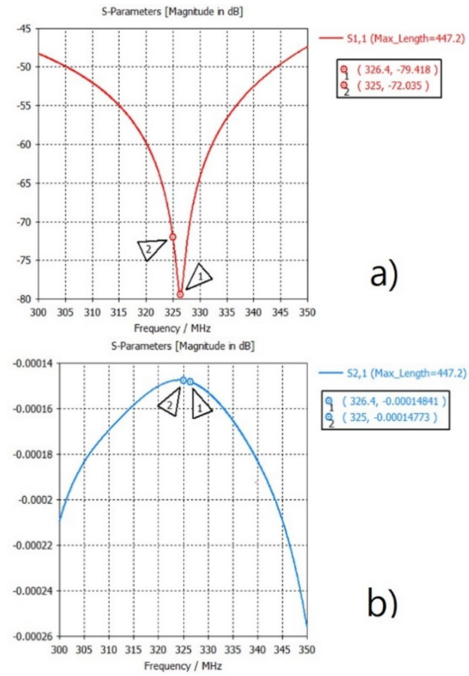

Figure 7: a) Reflected power (S_{11}) b) Transmitted power (S_{21}) of the power coupler.

Thermal Analyses and Simulation

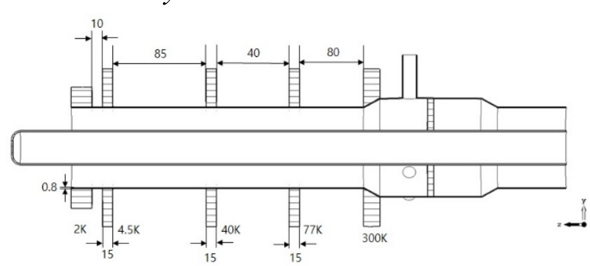

Figure 8: Scheme of a prototype power coupler for thermal analyses.

The power coupler bridged between room temperature (300K) to cryogenic temperature (2K) and acts as a continuous heat source for the superconducting cavities. Therefore, we optimize the thermal interceptor locations of the outer conductor to minimize the static heat loads. Figure 8 shows the locations of 3 interceptors and Table 2 presents analytical thermal loads on each interceptor location.

Table 2: Static Heat Load to Thermal Interceptors

Interceptor Temp. (K)	Values (W)
2K	0.0156
4.5K	0.1679
40K	0.0624
77K	0.1617

The temperature distribution and the heat flux of the coupler are shown in Figure 9.

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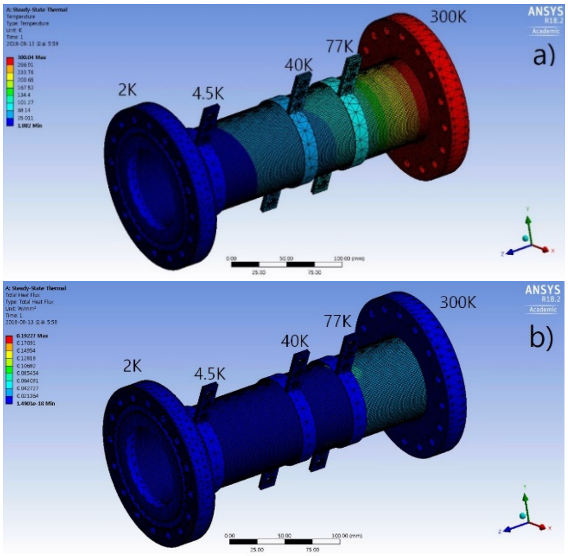

Figure 9: a) Temperature distribution and b) Heat flux result of static thermal load.

Mechanical Simulation

Figure 10 shows the stresses, strains and deformations at the ceramic window when a force of three times of gravity acts on the antenna tip in the opposite y direction..

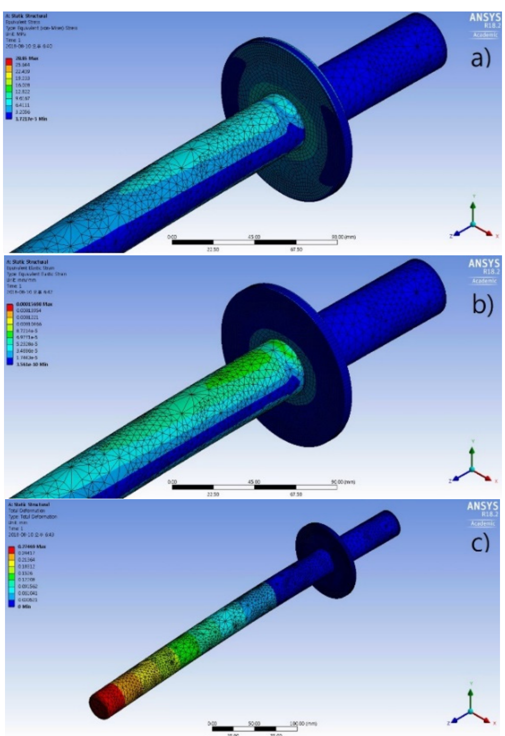

Figure 10: a) Stress, b) Strain, and c) Deformation of inner conductor and ceramic window.

The estimated stresses on the antenna (OFHC, $\sigma_{yield} = 33.3MPa$) and the window (99.7%-alumina, $t = 6$ mm, $\sigma_{yield} = 2350MPa$) are under than yield strength of the materials. [5]

The modal analysis was performed to avoid the vibration modes due to ground vibrations and harmonics of the AC electric power frequency. The fixed point is same as previous analyses. Figure 11 shows the four vibrational modes of the inner conductor connected with the ceramic window. The resonance frequency modes of the power coupler antenna are listed in table 3. [6]

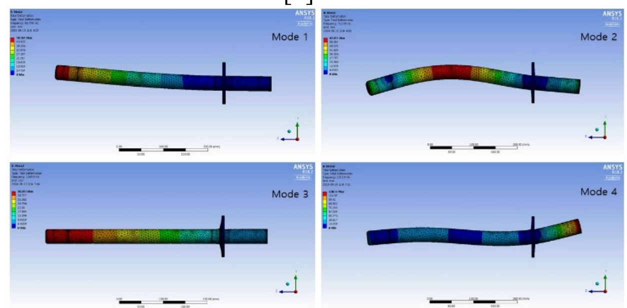

Figure 11: Four resonance modes of antenna.

Table 3: Resonance Mode Frequency of the Antenna

Mode	Frequency [Hz]
Mode 1	80.8
Mode 2	713.6
Mode 3	1349.9
Mode 4	1515.9

The modes 2 and 4 are close to the harmonics of 60Hz, so we need to avoid those frequencies by changing the geometry of antenna inner part.

CONCLUSION

We studied preliminary designs of the 325-MHz input coupler prototype for proton/heavy-ion superconducting cavities. The prototype will be fabricated and low-power tested in near future. Through such experiences, an upgraded version including a cooling scheme will be designed and fabricated.

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