ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-WEPRB056

DESIGN STUDY OF 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, and Eun-San Kim†,Korea University, Sejong, South Korea
[1]also at Pohang Accelerator Laboratory, Pohang, South Korea

Abstract

We present the design study of the RF input power coupler for 325 MHz superconducting cavities. The power coupler, based on a conventional coaxial transmission line, provides RF powers to the cavity up to 12 kW in CW mode. The thermal interceptors are considered as 4.5 K and 40 K or 4.5 K and 77 K corresponding to the usage of liquid Helium only or both liquid Helium and Nitrogen for cryogenic temperature to reduce the thermal load. The transition box (T-box), which is assembled with power coupler, is designed and applied for impedance matching and inner conductor cooling.

INTRODUCTION

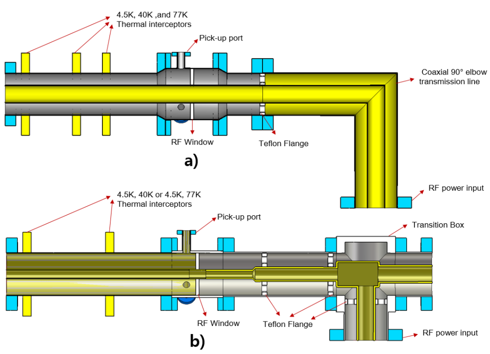

Figure 1: General view of the prototype power coupler a) 1st Version b) 2nd Version.

The power coupler is based on conventional coaxial transmission line. Both couplers have three diagnostic ports for vacuum, arc, and electron pick-ups to monitor RF breakdowns. The number of thermal interceptor-'s has been changed for the diversity of cooling gas (liquid Helium only or both liquid Helium and Nitrogen) used for thermal shield in cryo-module of various institutions. Figure 1 shows the prototype design of power couplers and the design requirements are listed in Table 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	12	kW
Q_{ext}	4×10^6	-

† eskim1@korea.ac.kr

The main feature of changes from the 1st version to the 2nd one is the reduced diameter of the outer conductor at the RF window section, the presence of the transition box and copper plating on the inside of the outer conductor. The reduced outer diameter decreases the size of coupler port in cryo-module and in accordance with assembling procedure, the RF window must be inside the outer wall of cryo-module, which requires a hole that is larger than the height of the pick-up port. The main purpose of transition box is impedance matching for difference between RF window section and conventional 50 Ω coaxial transmission line. The cooling gas can be inserted at the end of the T-box through the inner conductor to reduce the temperature increase of the antenna tip and RF window due to RF power. Engineering design for production is in progress.

SIMULATION

Electromagnetic Simulation

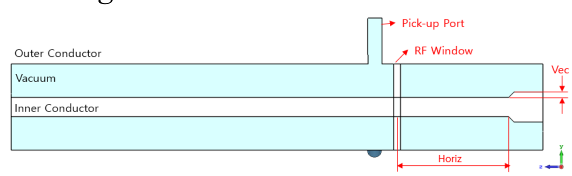

Figure 2: Geometric change of ceramic part (Vec and Horiz).

Figure 2 shows variations of both diameter (Vec) and length (Horiz) of the outer conductor at the RF window to minimize reflected powers at 325 MHz. The antenna diameter is 17.1 mm and was determined by multi-pacting analyses. We performed simulations to check effects of the inner conductor diameter changes from 8 mm to 15 mm. The horizontal length change affects the intensity variance of reflected powers (S_{11}) at 325 MHz. We performed the simulation to minimize reflected powers at operating frequency. The optimal value of vertical/horizontal length are 10 mm and 101 mm, respectively, as shown in Figure 3. As a result, the impedance of the antenna section is 90 Ω and the that of other section is 62.8 Ω [2].

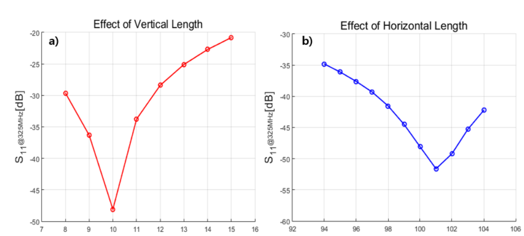

Figure 3: Effect of a) vertical length and b) horizontal length change.

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-WEPRB056

The outer conductor is composed of 0.8-mm-thick stainless steel with 15 μm copper plating at the vacuum section and the inner conductor is made of 1.5-mm-thick OFHC. The edges of the inner conductor at the impedance change section have 45 degree angles to avoid wake fields and multi-pacting effects in the coupler. The RF characteristics of the coupler prototype are shown in Figure 4. The geometry of the coupler was tuned to have the minimum reflection and maximum transmission occurred at operating frequency of 325 MHz, and their values are -56.25 dB and -0.0001 dB respectively. The pass band, which is frequency band with reflected power of -20 dB, is 47 MHz, so it is wider than the design requirement of 3 MHz [3]. Figure 5 shows the electric field distribution of the power coupler 1st version and 2nd one.

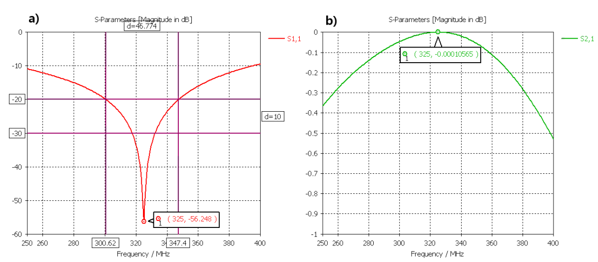

Figure 4: a) Reflected power (S_{11}) b) Transmitted power (S_{21}) of the power coupler 2nd version.

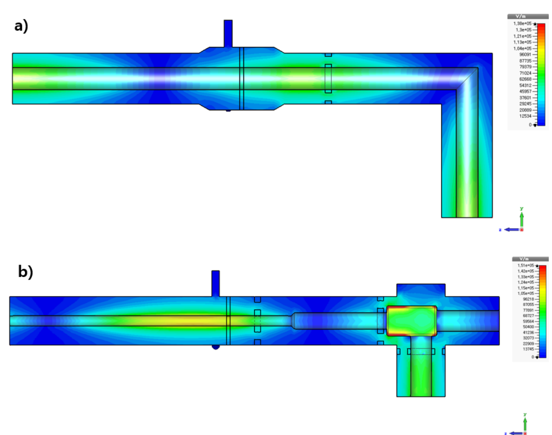

Figure 5: The electric field distribution of the power coupler a) 1st version and b) 2nd version.

Multi-pacting Analysis

The prototype version 1, for low power tests, didn't consider the multi-pacting effect at the design stage. However, multi-pacting is known to be a major cause of interference for power coupler and cavity operations. For coaxial lines, the 2-point multi-pacting effects occur in which electrons reciprocate between the outer and inner conductors. The change in the diameter of inner conductor of coaxial line makes the impedance difference that can reduce the intensity of multi-pacting [4]. Figure 6 shows the growth rate variation due to the impedance change in the power coupler.

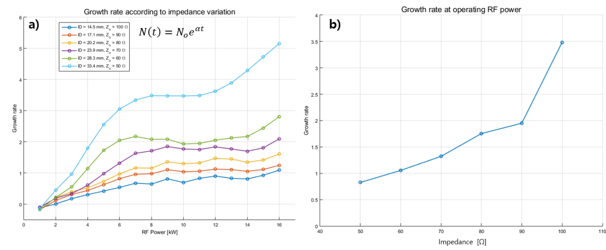

Figure 6: a) Growth rate variation due to impedance change, b) Growth rate at operating RF power.

The growth rate was the largest when the impedance was 50 Ω. When the impedance is increase, the rate is significantly decreased and the smallest can be seen at 100 Ω in Figure 6 a). However, the smaller the inner conductor, the harder it becomes to design and circulate the refrigerant for cooling the antenna tip and RF window. Thus, we chose the 17.1 mm for inner conductor diameter to minimize the multi-pacing and difficulty in engineering design.

Thermal Analysis

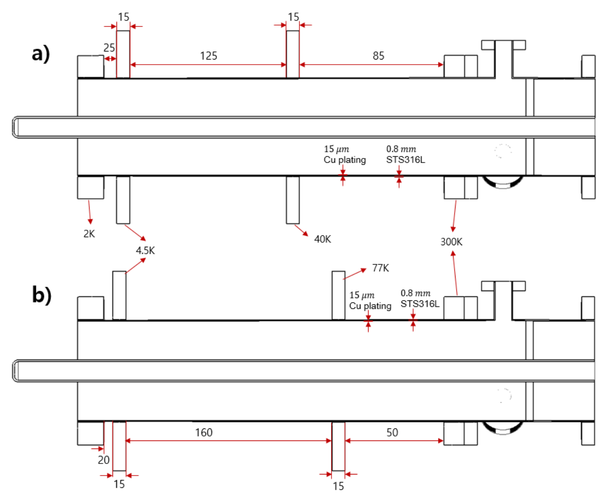

Figure 7: Schematic drawing of the 2nd version power couplers with a) 4.5K and 40K thermal interceptors. b) 4.5K and 77K thermal interceptors.

Figure 7 shows the optimized locations of each interceptors. The power coupler bridge between room temperature (300 K) and cryogenic temperature (2 K) and acts as a continuous heat source to the superconducting cavities. The optimal locations of the thermal interceptors connected to the outer conductor were chosen to minimize the static and dynamic heat loads. The thermal interceptors of 4.5 K and 40K are available for cavities use only liquid helium as cooling gas in cryo-module, and those of 4.5 K and 77 K can be used for cavities with liquid helium and nitrogen. Table 2 presents analytical thermal loads on each interceptor location.

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-WEPRB056

Table 2: Static Heat Load to Thermal Interceptors

Interceptor Temp. (K)	4.5K, 40K	4.5K, 77K
	Values (W)	Values (W)
2K	0.3070	0.3838
4.5K	1.5459	1.3602
40K	0.5189	-
77K	-	0.3445

Mechanical Analysis

Figure 8 shows the stresses, strains and deformations at the ceramic window when three times of the gravity force are applied to the inner conductor and ceramic window [5].

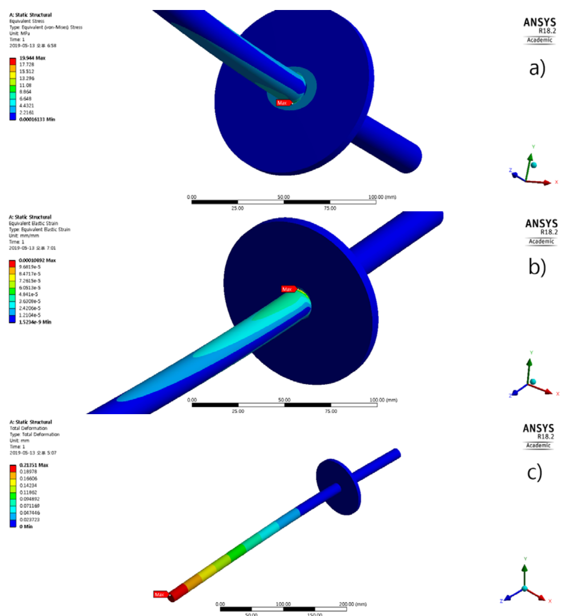

Figure 8: a) Stress, b) Strain, and c) Deformation of inner conductor and ceramic window.

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

The modal analysis was also performed to avoid vibration modes due to ground vibrations and harmonics of the AC electric power frequency of 60 Hz. The fixed point is same as previous analysis. Figure 9 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 [7].

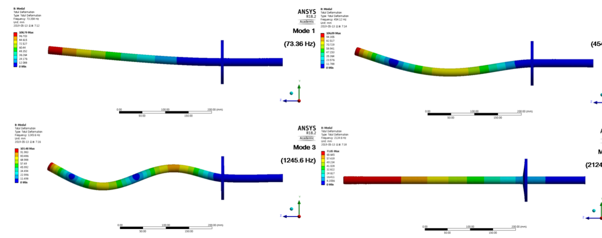

Figure 9: Four resonance modes of antenna.

Table 3: Resonance Mode Frequency of the Antenna

Mode	Frequency [Hz]
Mode 1	73.36
Mode 2	454.12
Mode 3	1245.6
Mode 4	2124.6

The mode 2 is close to the harmonics of 60 Hz, so we need to avoid those frequencies by changing the geometry of the antenna inner part.

CONCLUSION

We studied prototype designs of the 325-MHz input coupler for proton/heavy-ion superconducting cavities. The 1st version has already been fabricated and is in the test preparation stage. It has the advantages of minimize the multipacting effects, cooling system for antenna tip and RF window.

REFERENCES

[1] Junyoung Yoon *et al*, "Design Study of a Prototype 325MHz RF Power Coupler for Superconducting Cavity", in *proc. 29th Int. Linear Accelerator Conf. (LINAC2018),* Beijing, China, Sep. 2018, paper TUPO052, pp. 451-453

[2] S.V. Kutsaev *et al*, "Design of RF power coupler for superconducting cavities", *Journal of Instr.,* vol. 7, p.11004, Nov. 2012, doi:10.1088/Jinst.7.11.P11004

[3] S. Kazakov *et al*, "Main Coupler Design for Project X", in *proc. 26th Int. Linear Accelerator Conf. (LINAC2012),* Tel Aviv, Israel, Sep. 2012, paper TUPB053, pp. 594-596

[4] E. Somersalo *et al*, "Analysis of Multipacting in Coaxial LInes", in *proc. 16th Particle Accelerator Conf. (PAC'95),* Dallas, TX. USA, May 1995, paper FAE08, pp. 1500-1502

[5] Y. Gómez Martínez *et al*, "Power Couplers for SPIRAL 2", in *proc. 15th Int. Conf. on RF Superconductivity (SRF2011),* Chicago, IL USA, July. 2011, paper FRIOA04, pp. 947-950

[6] Material properties, http://www.matweb.com

[7] Ilkyoung Shin *et al*, "Design of QWR Power Coupler for the Rare Isotope Science Project in Korea", in *proc. 17th Int. Conf. on RF Superconductivity (SRF2015),* Whistler, Canada, Sep. 2015, paper THPB082, pp. 1326-1329