COUPLING CAVITY DESIGNS OF THE RF INPUT COUPLER TESTS FOR THE IFMIF/EVEDA PROTOTYPE RFQ LINAC

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Abstract

For a transmitted RF power test of RF input coupler, a coupling cavity development is indispensable to connect with two RF couplers. For this purpose, two coupling cavities for a 175MHz ± 250kHz have been designed by HFSS code. One is co-axial coupling cavity, which has two coupling parts and has a pillbox structure using a 6 1/8 inch co-axial waveguide. The other one is a ridge-type coupling cavity with a ridge structure cavity. For two coupling cavities, RF properties and RF power dissipation are evaluated by HFSS code. From these calculation results, the usage of ridge-type coupling cavity was decided for the transmitted RF power test of RF input coupler.

INTRODUCTION

International Fusion Materials Irradiation Facility (IFMIF) is an accelerator-based neutron irradiation facility to develop materials for a demonstration fusion reactor next to ITER [1]. For providing materials to make a decision of IFMIF construction, Engineering Validation and Engineering Design Activities (EVEDA) under the Broader Approach agreement have been started. IFMIF/EVEDA prototype accelerator consists of Injector (output energy; 100keV), a 175MHz RFQ linac (0.1-5.0MeV), a matching section, the first section of Superconducting RF linac (5.0-9.0MeV), a high energy beam transport line and a beam dump(9MeV-125mA CW), and the acceleration tests by employing the deuteron beam of 125mA are planning in Rokkasho, Aomori, Japan[2].

In the design of prototype RFQ linac [3], a four-vane integrated cavity type of RFQ, which has a longitudinal length of 9.78m, was proposed to accelerate deuteron beam up to 5MeV. The operation frequency of 175MHz was selected to accelerate a large current of 125mA in CW mode. The driving RF power of 1.28 MW has to be injected to the RFQ cavity. In the RFQ design, the 8 couplers are used to share the required driving power and located at 4 different longitudinal positions. Each two couplers are arranged to have the same longitudinal position. For each coupler, nominal RF power of 160kW for CW mode and maximum transmitted power of 200kW for full reflection to be withstood up to 100μsec are required, and also maximum reflected power of 20kW has to withstand during RFQ operation with no beam.

As the RF input coupler design for CW mode, a suppression of RF losses is a key issue, an RF input coupler with water cooling port including an RF window, based on a 6 1/8 inch co-axial waveguide, was designed. For a transmitted RF power test of the RF input coupler, a new coupling cavity development is indispensable, since the operation frequency of 175MHz is a low frequency, and RF coupling is strongly dependent on geometric condition of the loop antenna. For the new coupling cavity, a co-axial waveguide coupling cavity and a ridge-type coupling cavity are designed by HFSS code, and the RF properties, the RF losses and electric filed strength are evaluated.

RF INPUT COUPLER DESIGN

A non-rotating CF100 flange (ϕ90mm-port) on the RFQ-body and an EIA 9 3/16” female standard connector of RF transmission line are given for mechanical interfaces, an RF input coupler with water cooling port, including an RF window based on a 6 1/8inch co-axial waveguide, was designed in Fig.1. In case that a 6 1/8 inch co-axial waveguide is employed, RF loss at 175MHz can’t be negligible for CW mode, since RF loss is to be a few 10W at the inner-conductor parts of RF window and support disk. Therefore, a cooling water port of a λ/4-long is employed for heat removal, as the inlet /outlet of cooling water can be set at the end cooling port. In this design, reflection coefficient can be also suppressed by the length of L=λ/4. In this RF design, S_{11} parameter to be lower than -40dB was calculated in the range of 174-176MHz between the 9 3/16” connector for the RF input part and the ϕ90mm-port part without a loop antenna. For a loop antenna size, RF coupling factors (Beta) were measured on Aluminum RFQ module [4] of INFN Legnaro, using loop antenna samples. From these results, the inserted length of 45mm was decided.

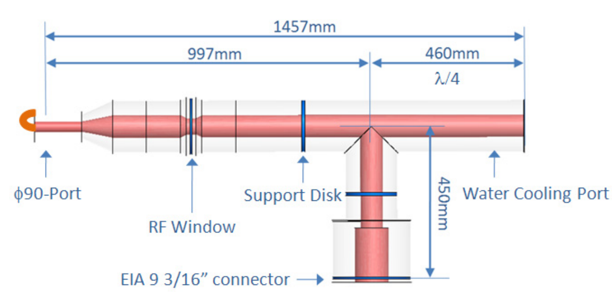


Figure 1: Schematic drawing of an RF input coupler with water-cooling port of λ/4.

COUPLING CAVITY DESIGNS

SINGLE COUPLING TYPE

A simple structure of coupling cavity is shown in Fig.2. This is a pillbox type, and RF power is coupled by inductance of L and capacitance of C between loop antennas, and reflection co-efficient due to mismatching impedance in pillbox is cancelled out by the pillbox axial length of L=λ/4. Therefore, the resonant frequency is defined by the pillbox axial length of L=λ/4. Since a loop length of L=45mm was designed for RF input coupler, the pillbox length is to be 90mm + the gap width of a few mm. In this case, the resonant frequency is closed to 830MHz, and the resonant frequency of 175MHz is not obtained from the geometric condition.

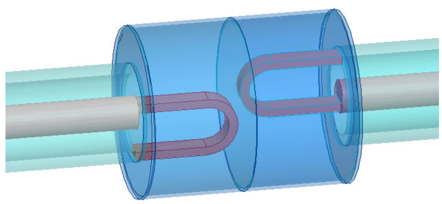


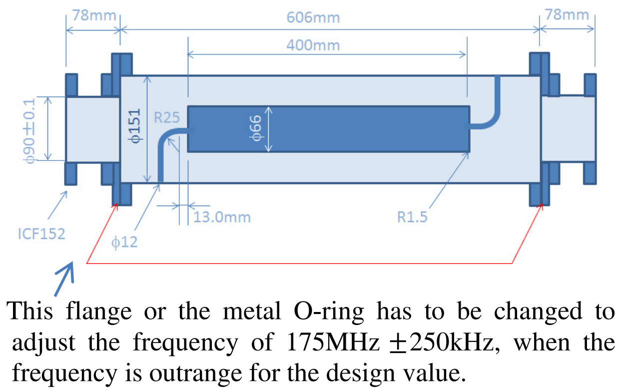
Figure 2: A pill-box coupling cavity

CO-AXIAL COUPLING CAVITY

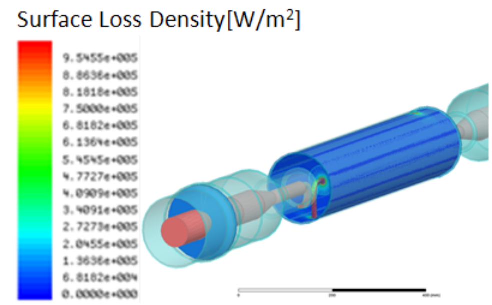
In Fig. 3(a), the mechanical design of co-axial coupling cavity is indicated. The axial length of 400 mm is designed for inner-conductor length, and it is to be about λ/4 for a 175MHz. In order to adjust the frequency, the flange or metal has to be exchanged to improve a gap width between the loop antenna and the coupling loop. The resonant frequency is strongly dependent on the gap length and the cavity length, and it is varied by a 400kHz per a 1mm. The bandwidth of 50 kHz for S_{11}< -20dB is calculated. For an RF input power of 200kW, the RF power dissipation is calculated to be 14.6 kW by S parameters.

RF surface loss density at the loop is evaluated in Fig.3 (b), and it is found that the maximum RF surface loss density reaches as 100W/cm^2 level. This loss density is also strongly dependent on the gap length between the coupling loop and the loop antenna. Since a pipe of 12mm-diameter is used for the coupling loop size, the heal load removal is possible by active water-cooling for the coupling loop and the inner-conductor using ϕ12mm-pipes. However, RF properties defects is expected by a vibration due to the water-cooling, since RF properties are sensitive for these dimensions.

For maximum electric field strength on RF power of 200kW, it is calculated to be 2MV/m between the outer-conductor and the inner-conductor, and it is less than Kilpatrick limit of 14MV/m at 175 MHz.



(a) Mechanical design of the Co-axial type cavity



(b) Surface loss density around the coupling loop

Figure 3: A co-axial coupling cavity with a 6 1/8 inch co-axial waveguide, (a) Mechanical design and (b) Surface loss density by HFSS code.

RIDGE-TYPE COUPLING TYPE

In Fig 4(a), the mechanical design of ridge-type coupling cavity is illustrated. This coupling cavity has a cylindrical structure of ϕ600mm, and the cross-section is a ridge-type. In center, a capacitive part, which has the gap width of 30mm and the diameter of 240 mm, is located. In Fig 4(b), the calculating result for resonant frequency vs. gap widths by the capacitive plates of ϕ257mm and ϕ58mm is indicated. By the ϕ257mm, it is found that resonant frequency is varied in the range of a few MHz by the gap width of ±1mm, and it is useful for a roughly tuning by exchanging the ICF306 flange. For the ϕ58mm, it is found that the frequency in the rage of ±250kHz is changed by the gap width of ± 5mm, and it is useful for a fine tuner. When an RF input power of 200kW is transmitted into the ridge-type coupling cavity, it is calculated that RF power dissipation is suppressed to be 7.2kW level by S parameters and RF surface loss density is to be 4 W/cm^2 level in Fig.4 (c). For a CW operation, a water-cooling channel, which has a flow rate of 5 liter/min. at the nominal pressure of ~ 0.3MPa, is needed for the around capacitive plate. The maximum electric field strength is also calculated to be 3MV/m at the gap of capacitive plate.

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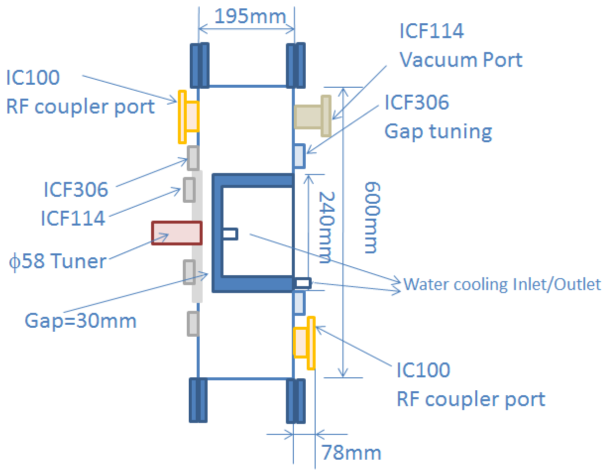
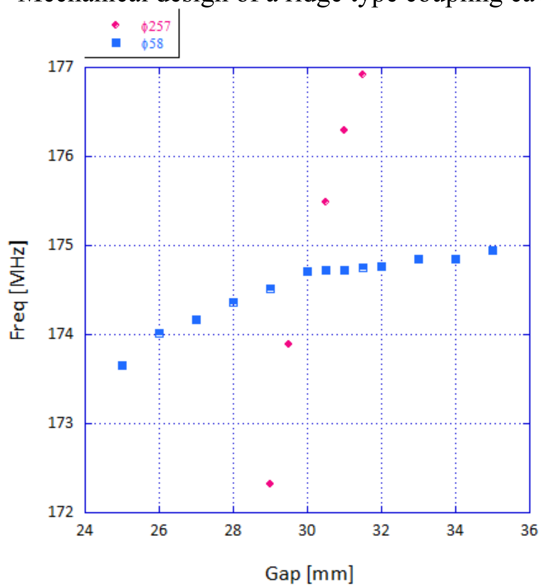
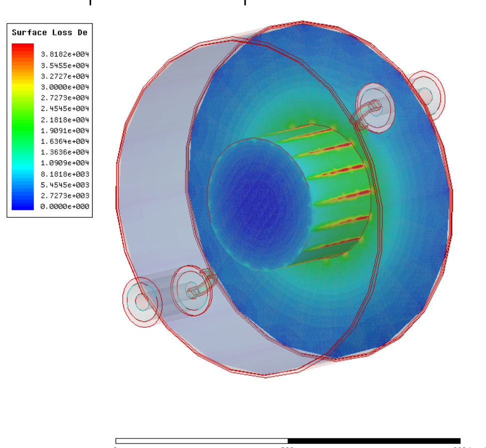


(a) Mechanical design of a ridge type coupling cavity



(b) Resonant frequency vs. Gap widths for capacitive plates of ϕ257mm and ϕ58mm



(c) Surface loss density at the inside of ridge cavity

Figure 4: Ridge-type coupling cavity; (a) Mechanical design, (b) Resonant Frequency vs. Gap width and (c) Surface loss density by HFSS code.

CONCLUSION

A co-axial coupling cavity with a 6 1/8 inch co-axial waveguide and a ridge-type coupling cavity for a 175MHz ± 250kHz, are designed by HFSS code. For the co-axial cavity, but it is a compact design, it is found that RF power dissipation and maximum RF surface loss density reach as 17.6kW and 100W/cm^2, respectively, when RF power of 200kW is transmitted. But these heat load removal is possible by water-cooling, RF defects due to a vibration of the inner conductor by water-cooling is expected. In the ridge type cavity, it is found that the power dissipation is suppressed to 7.2kW, and maximum surface loss density is improved to 4W/cm^2 level.

For maximum electric field strengths on RF power of 200kW for two coupling cavities, it is calculated to be less than 3MV/m, and it is less than the Kilpatrick limit of 14MV/m at 175MHz.

For the ridge-type coupling cavity, a fine tuning by the ϕ58 tuner is possible to adjust the frequency range of ± 250 kHz, but the flange or metal-O ring has to be exchanged for the co-axial coupling cavity. From these results, the usage of ridge-type coupling cavity was decided for a transmitted RF power test of RF input couplers.

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