THERMAL ANALYSES OF AN RF INPUT COUPLER FOR THE IFMIF/EVEDA RFQ LINAC

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Abstract

RF losses for an RF input coupler with water cooling port, an RF window and a coupling cavity needed for RF transmission power test were evaluated by HFSS code. For the loop antenna size, coupling factors were measured on Aluminium RFQ module. The cross section of 16 x 8 mm and an inner radius of 19.5mm were used, and it is found that the loop length of L=40 mm could be an optimized length. From this result, it is expected that the total heat load surrounding the RF coupler tip part, reaches 100W level at least. Since heat removal is indispensable for CW mode, a water cooling method was decided for this RF 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 the RF input coupler, the RF window and the coupling cavity, RF losses were evaluated by a 3-D electro-magnetic code (HFSS). For a loop antenna size, RF coupling factors (Beta) were measured on Aluminium RFQ module [4] of INFN Legnaro, using loop antenna samples. From these results, a cooling channel at the RF coupler tip part was designed.

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.

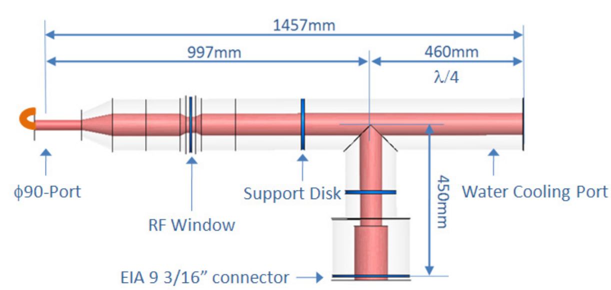

Figure 1: Schematic drawing of an RF input coupler with water cooling port of λ/4

THERMAL ANALYSES

RF Input Coupler Design

For an input power of 200kW, the RF loss of 165 W was evaluated using the $1\text{-}P_{11}\text{-}P_{21}$ between the 9 3/16" connector and the ϕ90mm-port without a loop antenna. For a loop antenna, the RF loss due to skin effects can be calculated to be 28W, using the skin depth of 5 μm and current of 63 A, when the loop length of 100 mm and the cross-section of 16 x 8 mm are assumed. For the loop antenna, the RF loss due to electromagnetic field of RFQ

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has to be also evaluated, but it is strongly dependent on cavity Q_0 value. For both RF losses of 165W and 28W, with assumption of a reflected power of 20kW, the RF loss becomes 334W. In Fig.2, RF loss density profile of the inner conductor surface is indicated. The heat load surrounding the ϕ90mm port part is the largest in the RF couplers, since the coaxial waveguide size is the smallest. For the RF loss densities, it was calculated to be a maximum of 1.6kW/m^2, and the heat load reaches 21W by the surface area of 134cm^2. For the total heat load surrounding the ϕ90mm port part, including heat load due to the outer-conductor and cavity Q_0, it is expected to be 100W level at least.

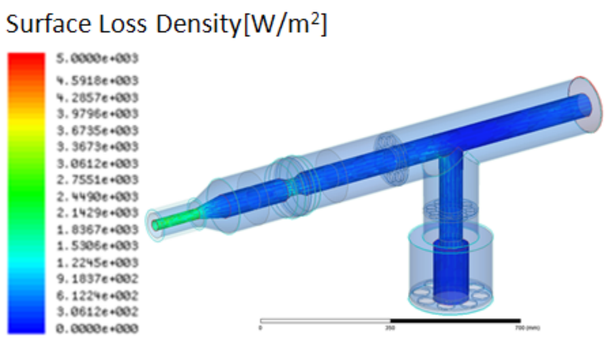


Figure 2: RF loss density of the RF input coupler

RF Window

For the ceramic disk, Al_2O_3; ε_r:9.4, tan δ: 6x10^{-3} (default value), thickness: 8mm, was considered. The volume loss density was calculated as shown in Fig.3. It is found that 85W is lost in the alumina disk surrounding the inner-conductor for an input power of 200kW. However, it can be decreased below heat load of 14W at least, by the tanδ value of less than 1x10^{-4}. In reflected power of 20kW, the RF loss reaches 24W. It is expected that heat load of 24W can be removed easily by employing active water cooling surrounding the inner/outer conductor of alumina disk.

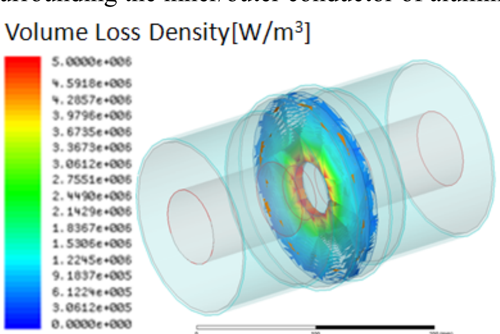
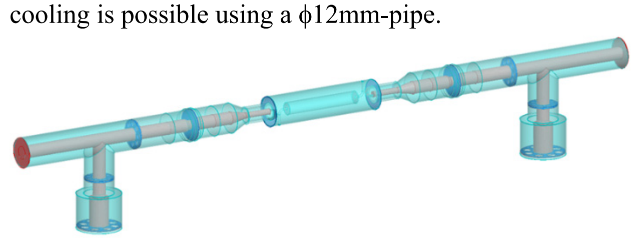


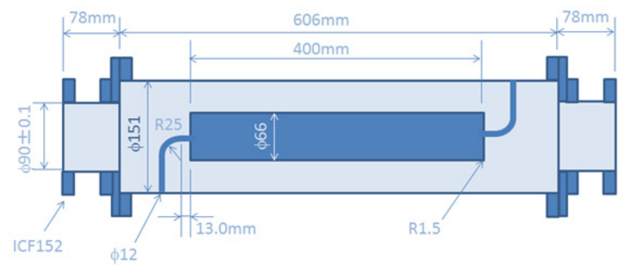
Figure 3: Volume loss density of Al_2O_3 ceramics

Coupling Cavity

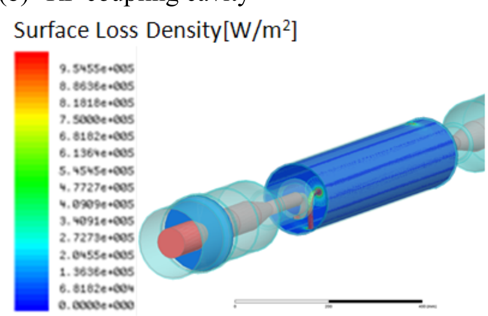
As shown in Fig. 5(a), coupling cavity is used for an RF transmission power test to connect with RF source and RF dummy load at both EIA 9 3/16 inch connectors, respectively. In Fig. 5(b), a schematic drawing of the coupling cavity is indicated. The axial length of 476 mm was designed, and it is to be about λ/4 for 175MHz. In this design, a bandwidth of 50 kHz for S_{11}< -20dB was obtained. For an RF input power of 200kW, surface loss density at the loop is evaluated in Fig.5 (c), and it is found that surface loss density reaches 100W/cm^2 level. This loss density is strongly dependent on the gap length between cavity loop and coupler loop. Since a 12mm-diameter is used for the cavity loop size, active water cooling is possible using a ϕ12mm-pipe.



(a) RF transmission power test system



(b) RF coupling cavity



(c) Surface loss density of the coupling cavity loop

Figure 4: RF transmission power test system using coupling cavity

LOOP ANTENNA

A cross section of 16 x 8 mm and an inner radius of 19.5mm were used for coupling factor measurements. Using the loop lengths from RFQ wall of 73, 48 and 27mm, S_{11} parameter dependences for the rotating angles were measured on Aluminium RFQ module [4], and beta of RF coupling factor on beam in the IFMIF/EVEDA RFQ were evaluated as indicated in the Fig.2. Here, cavity Q_0=9000 is assumed for nominal beam power and minimum RFQ acceptance value. It is found that the loop length of L=40 mm could be an optimized length. RFQ field distortions due to the installation of one loop antenna were also evaluated by Bead Pull Measurement of Perturbation Method. In case of L=48mm, it is measured to be ±3% and ±2% for Dipole component and Quadrupole component. When two loop antennas are installed symmetrically into RFQ, field distortion is expected to be cancelled out. Field distortions, therefore, seem to be less than ±1%.

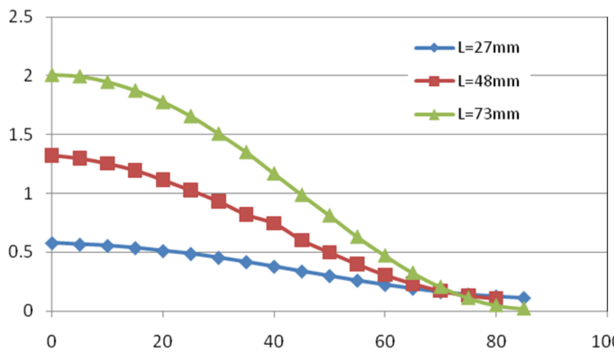


Figure 5: Evaluation for beta (RF coupling) on beam in IFMIF/EVEDA RFQ; beta vs. loop angle

WATER COOLING CHANNEL DESIGN

In the RF input coupler with water cooling port, there are three water cooling parts; the ϕ90-port including loop antenna, the inner-conductor of RF window and the support disk, and the outer-conductor surrounding the RF window. Two cooling channels of ϕ4.0mm-diameter are installed into the loop antenna of the 16x8 mm cross section. In order to make two cooling channels, the R&D was performed, and fabrication technique was successfully established. The minimum bend radius of 19.5 mm can be produced for the cross section of 16 x 8 mm. From this result, both inner/outer conductors are cooled by cooling water as shown in Fig.6. The inlet/ outlet of cooling water are set around the outer-conductor. In current design, the flow rate of 2~3 litter/min in pressure of ~0.3MPa is calculated.

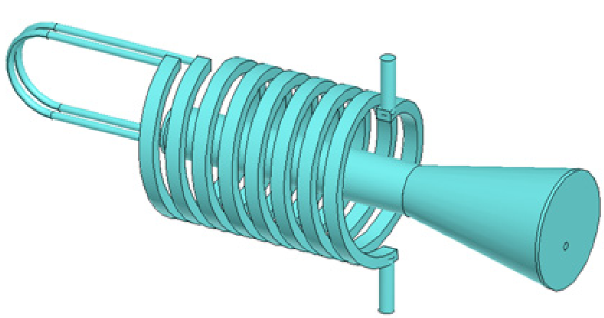


Figure 6: Schematic drawing of cooling channel at the RF input coupler tip

For inner conductors at RF window and support disk, the inlet/ outlet of cooling water are set at the water cooling port end. Two ϕ8 mm-pipes are connected with each cooling channels, the temperature rise will be suppressed below 100° for CW mode. Into the outer-conductor surrounding the RF window, a ϕ8 mm-pipe is also installed, and the inlet/ outlet of cooling water are set.

CONCLUSION

In an RF input coupler with water cooling port, RF loss in the input power of 200kW was evaluated by HFSS code. For the total heat load at the ϕ90mm-port part, including heat load due to the outer-conductor and cavity Q_0, it is expected to be 100W level at least. The heat removal is indispensable for CW mode. For the RF window, it is found that the RF loss reaches 24W in case of a reflected power of 20kW, by employing the tanδ value of less than $1\text{x}10^{-4}$. This heat load can be removed easily by active water cooling surrounding the inner/outer conductor of alumina disk. For a loop antenna size, it is found that the cross section of 16 x 8 mm, the inner radius of 19.5mm and the installed of 40mm could be optimized for the RF input coupler, by coupling factors measurements. From this result, two pipes of ϕ4.0mm-diameter were installed into this loop antenna, and the inner/outer conductors at the ϕ90-port part and the loop antenna could be cooled by cooling water. For this cooling channel, it is found that the flow rate of 2~3 litter/min in pressure of ~0.3MPa was obtained. Base on this cooling channel design, the production is started in October, 2011.

AKNOWLEDGEMENT

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