COUPLING FACTOR EVALUATION OF THE RF INPUT COUPLER FOR THE IFMIF/EVEDA RFQ LINAC

S. Maebara, Tokai-JAEA, Ibaraki, Japan
M. Ichikawa, Rokkasyo-JAEA, Aomori, Japan
A. Palmieri, INFN-LNL, I-3520 Legnaro(PD), Italy

Abstract

RF coupling factor on beam loading is evaluated with based on the measured S_{11} parameter and Q value on Aluminum RFQ module. In order to fulfill the acceptance Q_0 value of 9000 for the RFQ, the RF coupler has to be at least critically coupled to the cavity for such Q_0 value. The chosen insertion depth is equal to L=45mm. By this loop antenna size, magnetic field strength around the loop and surface loss density on the loop are evaluated, it is found to satisfy with the RF coupler acceptance values.

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, a beta (RF coupling factor) on beam loading for the IFMIF/EVEDA prototype RFQ linac were evaluated with based on the measured S_{11} parameter and the Q value in Aluminum RFQ module [4] of INFN Legnaro, using loop antenna samples. From these results, a loop antenna size for this RF input coupler engineering design was decided, and two RF coupler tip modules at vacuum side were fabricated.

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.

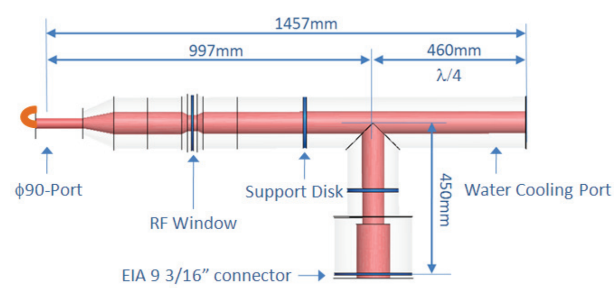

Figure 1: Schematic drawing of an RF input coupler with water-cooling port of λ/4.

COUPLING FACTOR MEASUREMENTS

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, 45, 40 and 27mm, S_{11} parameter dependences for the rotating angles were measured on Aluminum RFQ module [4] in

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Fig. 2, and beta (RF coupling factor) on beam loading in the IFMIF/EVEDA RFQ were evaluated as indicated in the Fig. 3.

Figure 2: Photograph of real size Aluminum RFQ module; the axial length of 9.78m-long.

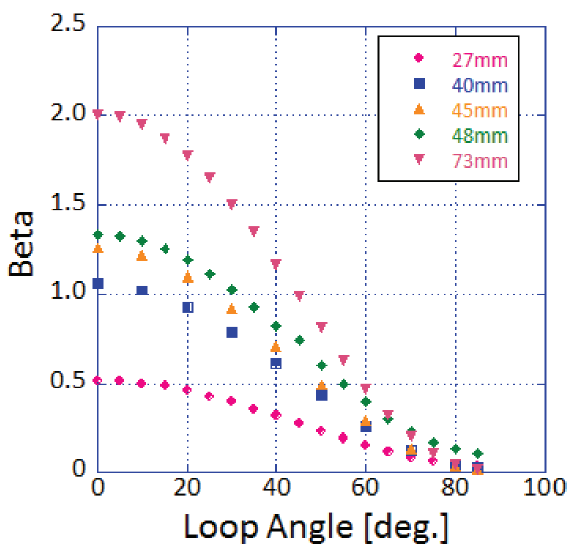
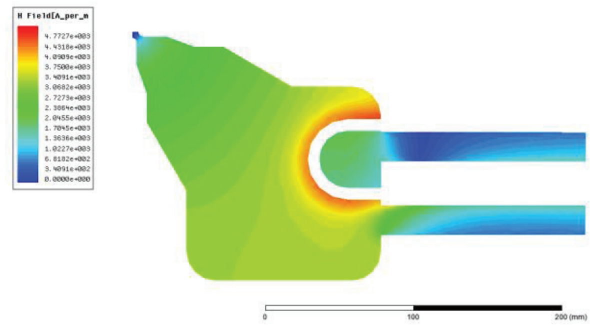


Figure 3: Evaluation of beta (RF coupling) on beam loading in IFMIF/EVEDA prototype RFQ; beta vs. Loop angle for the inserted depth of 27, 40, 45, 48 and 73mm.

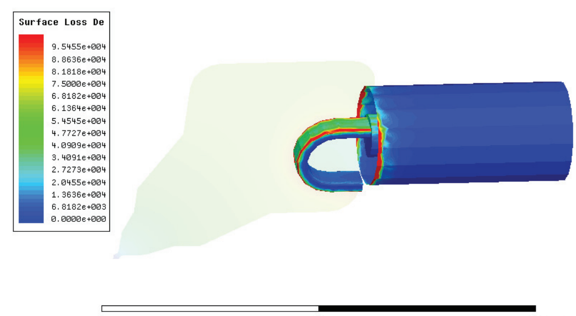
In Fig. 3, these beta values on beam loading rescaled with RFQ length per 8 couplers, Q_0 value, beam loading and H field strength with based on the measured S_{11} parameter and the Q value. Here, the Q_0=9000 is assumed for a minimum RFQ acceptance value. For the loop length L=40mm and L=45mm, the beta at the angle of 0 deg. are evaluated to be 1.06 and 1.26, respectively. An RFQ field distortion by the insertion due to one loop antenna, was evaluated by Bead Pull Measurement (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 the RFQ, the field distortions by L=45mm seem to be less than ±1%, since the field distortion is expected to be cancelled out.

MAGNETIC FIELD ANALYSES

By this loop antenna size of L=45mm; the cross-section of 16x8mm, the inner-radius of 19.5mm, magnetic field strength around the loop and surface loss density on the loop are evaluated by HFSS code. In Fig. 4(a) and Fig. 4(b), the magnetic field profile and the loss density profiles are indicated on the RF power of 153kW in normal case.



(a) Magnetic field profile around the loop length of L=45mm



(b) RF loss density profile on the loop length of 45mm

Figure 4: Magnetic field analyses by HFSS code; (a) Magnetic field strength around the loop length of L=45mm and (b) RF loss density on the loop antenna on the RF power of 153kW.

On RF power of 153kW in nominal case, the magnetic field strength of 3.3kA/m is calculated, it is satisfied with the acceptance value of 3.2kA/m. For the surface loss density, it is evaluated to be a100-200W level by the loop surface area of 48.5cm^2.

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 the 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. 5. The inlet/ outlet is set around the outer-conductor. In Fig. 6, photograph of the fabricated RF coupler tip module, with based on these design results, is indicated. By this RF coupler tip module, the cooling water flow rate in the loop antenna of more than 5liter/min was performed at the pressure of 0.3MPa, it is expected to suppress the temperature rise in CW operation.

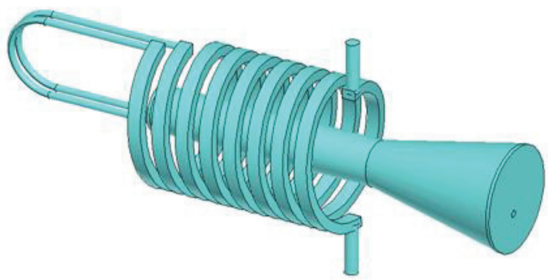


Figure 5: Schematic drawing of cooling channel at the RF input coupler tip.

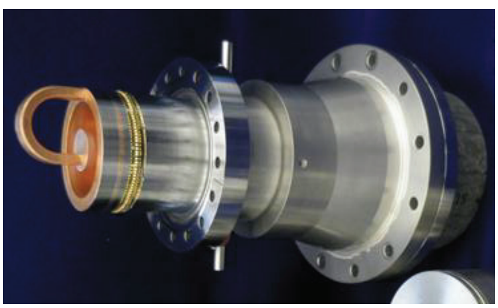


Figure 6: Photograph of the fabricated RF coupler tip module.

CONCLUSION

To evaluate RF coupling factor (beta) on beam loading, S_{11} parameters and Q value are measured using the real size Aluminum RFQ module of INFN Legnaro. The RF coupling factor on beam loading dependence on the loop angle in the loop length of L=27, 40, 45, 48 and 73mm is obtained. To satisfy a minimum RFQ acceptance value of Q_0=9000, the beta of 1.14 is indispensable for the IFMIF/EVEDA prototype RFQ linac. From these result, the loop antenna size of L=45mm was decided for the RF input coupler engineering design. For this loop antenna size, magnetic field strength around the loop and surface loss density on the loop are evaluated to be 3.3kA/m and 100-200W, respectively, it is found to satisfy with the RF coupler acceptance values. Based on these evaluation results, RF coupler tip module was fabricated. In 2013, a transmitted RF power test of RF coupler is planning at RF Test Bench in EU.

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REFERENCES

[1] IFMIF-CDA Team (Ed.) M. Martone, "IFMIF Conceptual Design Activity Final Report", *ENEA Frascati Report*, RT/ERG/FUS/96/17 (1996).

[2] A. Mosnier, et al., "The Accelerator Prototype of the IFMIF/EVEDA project", IPAC10, Kyoto, May 2010, MOPEC056, p. 588 (2010); http://www.JACoW.org.

[3] M. Comunian, A. Pisent, E. Fagotti, "The IFMIFEVEDA RFQ: Beam Dynamics Design", LINAC'08, Vancouver, Sept. 2008, MOP036, p. 145(2008); http://www.JACoW.org.

[4] A. Palmieri, et al., "The IFMIF RFQ Real-scale Aluminium Model: RF Measurements and Tuning", IPAC10, Kyoto, Japan, May 2010, MOPEC061, p. 603 (2010); http://www.JACoW.org

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