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

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Abstract

For the IFMIF/EVEDA RFQ linac, two RF input couplers with/without a cooling port (L=λ/4), based on a 6 1/8 inch co-axial waveguide, were designed, and the RF properties were evaluated using a 3-D electro-magnetic code. From the analysis results, it was found that a total RF loss of 273 W is lost for an input power of 200kW and a reflected RF power of 20kW. For an RF coupling coefficient, it was also found that the required specification of less than S_{11}= -20dB is obtained by a loop size of D8mm x W16mm and a penetration depth of 45mm.

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.

In the design of prototype RFQ linac, 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.

As the RF input coupler design for CW operation, a suppression of RF losses is a key issue, two kinds of RF input couplers including an RF window, based on a 6 1/8 inch co-axial waveguide, were designed, and their RF losses were evaluated by a 3-D electro-magnetic code (MW-studio). For a loop antenna design, RF coupling coefficient with varied penetration depth was calculated using an RFQ model.

REQUIRED SPECIFICATION

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 coupling at different positions, the minimum H fields of 3100, 3400, 3800 and 4100 [A/m] are required by two couplers, respectively. The required coupling values are achieved by the rotation of the loop with respect to the beam axis (0 to 90 °) and /or by the penetration inside the RFQ cavity.

The schematic drawing of an RF input coupler is indicated in Figure 1. A non-rotating ISO 100 flange (φ90mm-port) on the RFQ and an EIA 9 3/16" female standard connector are given for the mechanical interface, an "RF input coupler" component. The dimension in transverse direction of the component from the beam axis is within 2000mm.
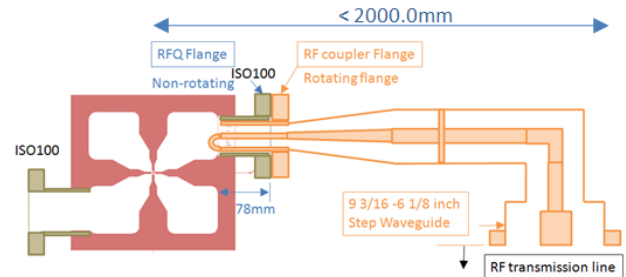

Figure 1: Schematic drawing of an RF input coupler

The target performances of 8 RF couplers after RF conditioning are summarized in Table1.

Table 1: Target performances

Requirement	Target value	Comment
Nominal frequency	175 MHz	
Duty cycle	100 %	Pulsed operation possible
Max. transmitted power	200 kW	Full reflection to be withstood up to 100μs.
Nominal power	160 kW	To be used to dimension the RF couplers
Max. reflected power in operation	20 kW	Value that each coupler has to withstand during RFQ operation with no beam
Line impedance	50 Ohm	RF network impedance
Max. power lost in the coupler	0.5 %	Insertion loss
Max. reflected power from the coupler	1%	$\mid S_{11}\mid^2$=0.01 for any frequency in the interval [174MHz, 176 MHz] on matched load

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RF Input coupler Designs

Two RF input coupler designs are considered for water cooling method as shown in Figure 2; (a) RF input coupler without water cooling port, and (b) RF coupler with water cooling port. The case (a) can be applicable when heat dissipation at the loop antenna and at the inner conductor of coaxial waveguide is not so high even for CW operation. However, a two-way cooling channel inside the loop is needed, a precise fabrication technology to maintain shape of the loop antenna is necessary. In the case (b) as the inlet /outlet of water cooling channels can be set at the end cooling port, a two-way cooling channel for heat removal at the loop antenna can be avoided. Reflection coefficient can be also suppressed by the length of L=λ/4.
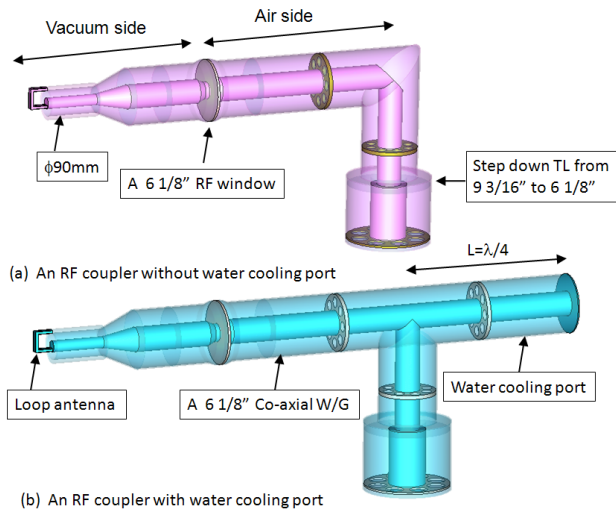

Figure 2 Two RF input coupler designs with/without water cooling port

RF window design

The schematic drawing of a "standard" RF window is shown in Figure 3(1). In this case, both outer and inner conductors are cylindrical, and the line impedance of 50Ω is distorted by the ceramics window. In order to avoid this mismatching, the geometry of the coaxial line surrounding the ceramics is optimized as shown in Figure 3(b). A 6 1/8" RF window was designed by using MW-studio code and the simulation result is indicated in Table 2 by comparing power reflection coefficient P_{11} at the inlet of the circuit, and power transmission coefficient P_{21} at the outlet of the circuit, where dissipation power loss (circuit RF loss) can be expressed by $1-P_{11}-P_{21}$.

For the ceramic disk, Al_2O_3 (ε_r:9.9, tan δ: 4×10^{-4}) was considered. For the improved type, the reflection coefficient was decreased but the circuit RF losses were decreased significantly. The P_{21} of alumina disk was calculated, and it was found that a 11 W is lost in the

alumina disk for an input power of 200kW. In case of a reflected power of 20kW, the RF loss reaches to 19W. It is expected that this heat load of 19W can be removed easily by employing active water cooling surrounding the outside of alumina disk.
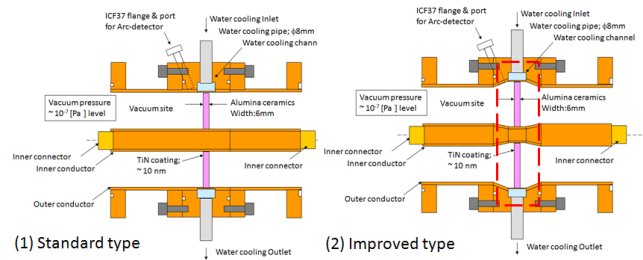

Figure 3 Schematic drawing of RF window design: (1) Standard type and (2) Improved Type

Table 2: Calculation result for RF window

A 6 1/8 " RF window	P_{11}[%]	P_{21}[%]	$(1-P_{11}-S_{21})$[%]
(1) Standard type	9.5×10^{-1}	99.04	8.63×10^{-3}
(2) Improved type	8.8×10^{-5}	99.99	5.60×10^{-3}

Muti-pactoring discharge phenomenon is expected in the RF power range of 150-300kW for a 6 1/8" RF window, based on analytical result [2]. However, the frequency of occurrence may be restricted after the sufficient RF aging, since the operation of a 6 1/8" RF window at 500MHz has been already demonstrated at a power up to 500kW CW in the operation [3]. A 10 nm TiN-coating on ceramics has been applied for the production, but the effect has not been well understood experimentally. Since multi-pactoring discharge strongly depends on the surface condition and the quality of ceramics, a high power tests are planned using a high-Q load circuit for product mock-up of the RF window. In this high-Q load circuit, an electric field being equivalent to a transmitted power of 160-200 kW or beyond can be generated.

P_{11} & P_{21} parameters of the RF couplers

For both RF couplers, (a) and (b) in Figure 2, P_{11} and P_{21} parameters were calculated between the input of the waveguide step 9 3/8" and the outlet of φ90mm without the loop antenna tip using MW-Studio code. Calculation hypotheses and results are given in Table 3 and Table 4.

For an input power of 200kW in both models, the total RF losses of 138 W in case (a) and 165 W in case (b) were evaluated using the $1-P_{11}-P_{21}$, respectively. For a loop antenna part in RFQ, it was calculated to be 20W using the coupling condition of β=1(no reflection power), where the coupling factor β is defined as the external RF power by the ratio with the power in the RFQ inside including RFQ wall loss and the beam power. In case (a), the total RF loss becomes 273 W with assumption of a

reflected power of 20kW. The heat load surrounding the ϕ90mm port is the largest in the RF coupler, since the coaxial waveguide size is the smallest. For the RF loss density of the inner conductor surface, it was calculated to be 5W/m^2 for an RF power of 200kW and no reflection.

Table 3: Calculation hypotheses

Materials	Values	
Copper as inner/outer conductor	Electrical conductivity: 5.8×10^7 S/m	
Alumina ceramics as RF window	ε_r: 9.9	(@175MHz)
	tan δ: 4×10^{-4}	(@175MHz)
Polyethylene as Support disk	ε_r: 3.5	(@175MHz)
	tan δ: 0.003	(@175MHz)

Table 4: Calculation results (@175MHz)

RF coupler model	P_{11} [%]	P_{21} [%]	(1- P_{11}-P_{21}) [%]
(a) Without cooling port	0.226	99.7	0.0688
(b)With cooling port	0.082	99.8	0.0824

Dependence of S_{11} parameter in the RFQ module on loop antenna tip

In Figure 4 and 5, illustration of the analysis model with MW-Studio code and the results are indicated. For an analysis model of RFQ, a longitudinal length of L=2450 mm was considered. In this calculation, the S_{11} is evaluated at the inlet of ϕ90 mm port, which is 78 mm away from the RFQ wall. The S_{11} is reverse of RF coupling coefficient β, and the matching condition of β=1 means no reflection power. For the size of loop antenna tip, three examples of D8mm xW8mm, D8mm x W16mm and ϕ 8 mm are used.

As indicated in Figure 5, the S_{11} parameter of less than -20 dB (or β=0.99 or higher) at the penetrate depth around 45 mm was obtained by the loop antenna size of D8mm xW16mm, but the results for the small loop sizes of D8mm x W8mm and ϕ8mm were inferior to that. From this result, it was found that an optimization of loop antenna size (cross section) is also a key factor to satisfy with the matching condition, the margin to be less than -20dB is not so much, and the deformation of the loop antenna shape due to heat load does not affect coupling coefficient so much. In the next step, this simulation result will be compared with low RF power tests by Network Analyzer on RFQ test module prepared by JAEA.
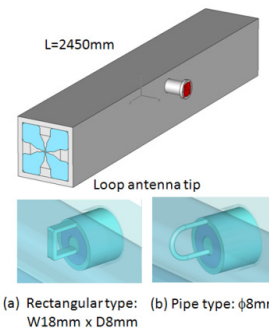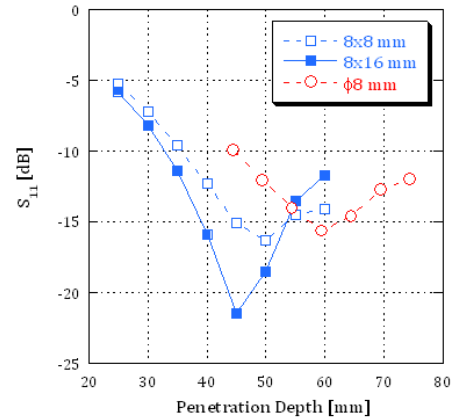

Figure 4 Illustration of the analysis model

Figure 5 Dependence of the S_{11} parameter in the RFQ module on the penetration depth of the loop antenna tip

CONCLUSION

Two RF input couplers with/without cooling port were designed, and their total RF losses were evaluated to be 158W and 186W for an RF power of 200kW in the β=1, respectively. In case of reflected power of 20kW, the total heat load reaches to 273W at least. Because the margin, furthermore, has to be considered, active cooling for both the inner/outer conductor at the ϕ90mm port is indispensable. Investigations on the cooling technique and the fabrication technique for both RF input coupler designs are in progress.

AKNOWLEDGEMENT

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