A 175MHz RFQ DESIGN FOR IFMIF PROJECT

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Abstract

An RF power-balance effects by a multi-drive loop antenna and a slug tuner have been investigated for a 175MHz RFQ design. For the multi-loop antenna, a good power balance with four-loop antenna was measured by a low power test using a 175MHz RFQ mock-up module, in comparison with those with a single loop and two-loop antennas. For the four-loop antenna, it was also found that the electric field distortion in beam bore is less than 1% from calculation results. As for the slug tuner, it was found that RF power-balance up to 80% can be controlled without overlap of modes from the low power test. The calculation results suggested that the RFQ design requirement of a distortion factor limit of 1% can be attained by employing a 1cm slug tuner with the insertion depth of 1cm or less.

INTRODUCTION

International Fusion Materials Irradiation Facility (IFMIF) is an accelerator-based neutron irradiation facility to develop materials for a demonstration fusion reactor after ITER project [1-3]. For this purpose, materials have to be studied in radiation of more than 80 dpa, an intense neutron field equivalent to D-T fusion reactor environment using a deuteron-lithium (D-Li) stripping reaction.

In this system, 40MeV deuteron beam with a current of 250mA is injected into liquid lithium flow with a speed of 20 m/s, Neutron field similar to D-T fusion reactor(2MW/m^2, >20 dpa /year for Fe) is produced by the D-Li stripping reaction. The required current of 250mA is realized by two beam lines of 125mA, and the output energies at injector, radio-frequency quadrupole (RFQ) linac[4-6] and drift tube linac (DTL) are designed to be 0.1, 5.0 and 40.0 MeV, respectively[7]. CW operation is required to obtain a high neutron fluence accumulation.

For the RFQ linac, a 12m-long four-vane RFQ was designed to accelerate the deuteron beam up to 5MeV, an operation frequency of 175MHz was selected to accelerate the large current of 125mA. In the 12m length, two septum plates are installed into the RFQ in order to suppress higher modes, and central modules about 4m-long are connected through the septum plates. In each central module, RF power is supplied by each RF source. An RF power of 800kW level has to inject into one central module, a development using a multi-drive antenna is needed from a withstanding voltage.

For the operation frequency of 175MHz, a rectangular waveguide of 1.0 x 0.5 m for a transmission line, and a tapered ridged waveguide length of ~5λg are needed to reduced cut-off frequency in order to inject RF power through small aperture. Accordingly, an RF-Input coupler using Iris type also becomes large. Therefore, an RF Input-coupler using a multi-drive loop antenna with co-axial waveguide has been developing. In the case that the loop antenna has to be installed into the RFQ cavity, quadrupole operation mode (TE$_{210}$) will be affected by the loop antenna structure and positioning of the loop antenna. The operation mode will be also affected by the fabrication error of the 12m-long RFQ. Therefore, an RF power-balance control by a slug tuner is indispensable for tuning the RFQ[8-10].

In this study, an RF power-balance due to a multi-drive loop antenna and a slug tuner have been investigated. The power-balance effects in a 175MHz RFQ mock-up module have been measured by network analyzer. An electric field distortion in beam bore has been also calculated by 3D electromagnetic simulation code of MW-Studio[11].

MOCK-UP MODULE

A four-vane RFQ mock-up module was designed by MAFIA[12] code before[13]. The RFQ module consists of two end-plate modules and central module, and each end-plate module is connected to each side of central module. For this mock-up, the vanes have no modulation. The beam bore diameter and vane radius were designed by beam dynamics simulation, and they were specified to be 8mm and 4mm, respectively. The resonant frequency was analyzed by changing each cavity dimension. After the cavity dimensions were finalized, the central module and the two end-plate modules were fabricated with aluminum. Photographs of the central module and the end-plate module are shown in Fig. 1.

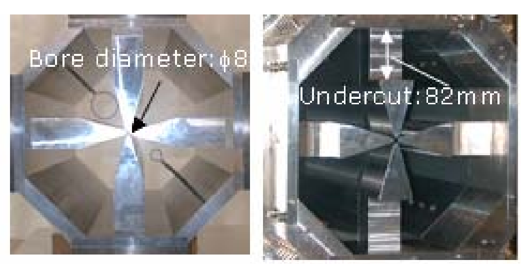

Figure 1: Photograph of central module(left) and end-plate module(right).

The resonant frequency of the 1.1m-long RFQ module was measured by network analyzer. The resonant frequency of 175.65 MHz for quadrupole operation mode (TE210) was obtained in Fig. 2, and it was in good agreement with the calculated value of 174.36MHz. This difference was less than 1% of the operation mode frequency. This difference is supposed to be caused by

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misalignment at the connection between central module and end-plate modules.

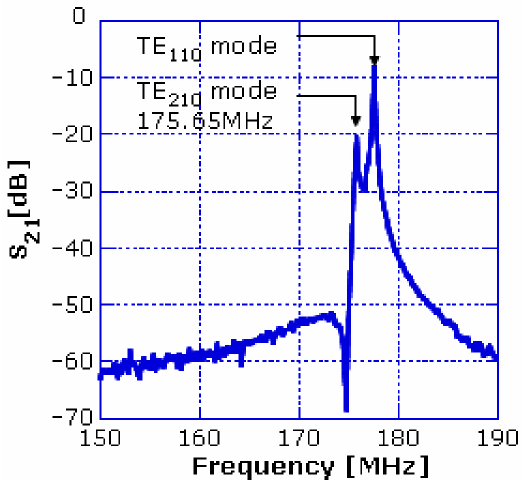

Figure 2: Measured resonant frequency of the 1.1m-long RFQ module.

MULTI-DRIVE LOOP ANTENNA

Several mock-up loop antennas using a pipe diameter of 10mm have been fabricated, and power balances and phase differences in a 175MHz RFQ mock-up modules were measured by network analyzer. When a loop antenna which has a diameter of ϕ90mm was installed into the RFQ module, phase differences for the operation mode (TE_{210}) was affected by the loop antenna structure, and dipole mode (TE_{110}) overlapped with the TE_{210}. To avoid this effect, small loop antennas were tested. It was found that the installed depth has to be shorted by 3 cm to make phase difference small(Fig. 3 (left)). But, due to voltage limits, it is difficult to couple multi-MW using a single coupler. RF coupling using two-loop or four-loop antenna is better than one-loop antenna. Phase differences and power balances were also measured in both cases (Table 1). When the four-loop antenna was installed into the RFQ(Fig. 3(right)), a good average phase difference of 180º and a good RF power balance within 8% variation was obtained. This 8% is within almost an error of measurement due to pick-up coil. In any cases, the operation mode (TE_{210}) was not be affected by these antenna configuration

Table 1 Measured Phase difference and Power variation.

	Average <Phase Diff.>	Power Balance
Single loop	180.0 deg	13%
Two-loop (Adjacent Inj.)	180.2 deg	23%
Two-loop (Diagonal Inj.)	179.4 deg	16%
Four-loop	179.7 deg	8%

The electric field profiles in the beam bore were also calculated by MW-Studio. In Fig. 4, the schematic drawing of beam bore peripheral is indicated. The electric field profiles were calculated along field lines for each cavity. It was found that distortion of electric field is less than 1% for the four-loop antenna.

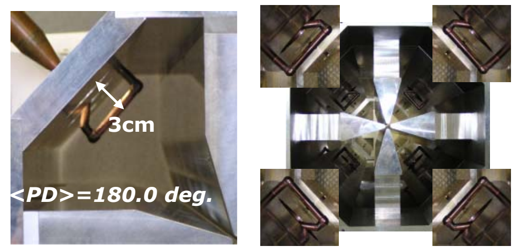

Figure 3. Photograph of small loop antenna (right) and RF-input coupler using the 4-loop antenna (left).

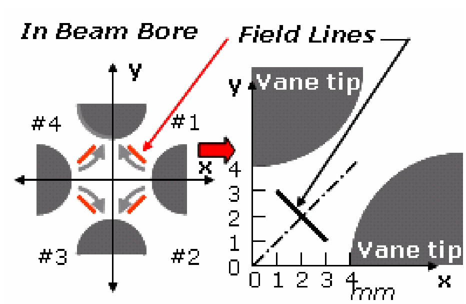

Figure 4: Schematic drawing of beam bore peripheral.

SLUG TUNER

It is important to measure an RF power-balance by slug tuners in the RFQ cavity. Since the operation mode (TE_{210}) will be affected by the installation depth of slug tuners and may not be separable with dipole mode (TE_{110}). For the three kinds of slug tuner with diameters of 3cm, 4cm and 5cm as shown in Fig. 5, RF power-balance and phase difference in each cavity was measured using the 175MHz mock-up module. It was found that operation mode is not affected by the 5cm slug tuner up to the 7cm-depth and the power-balance up to 80% variation can be controlled.

Figure 5: Photograph of slug tuners.

Electric field profiles in beam bore were also calculated by MW-Studio. From the calculation results, it was found that the design requirement of the distortion limit of 1% can be attained by employing the 1cm slug tuner with the insertion depth of 1cm, slug tuners with the diameter of

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more than 1cm and the insertion depth of more than 1cm were not appropriate for beam dynamics. When the 1cm slug tuner with 1cm-depth is installed into cavity #1, electric field profiles of #1 and #3 are indicated in Fig. 6. Electric field profile(E_{noSlug}) without slug tuner is indicated by black line. The field strength ratio of E_{Slug}/E_{noSlug} at the peak value are 0.989 and 1.010, respectively. From this result, the RF power-balance of 2% in the 1.1m-long RFQ can be controlled. In the case that the RF power-balance of 10% variation is assumed, the 5x4 slug tuners for the 1.1 m-long RFQ are needed.

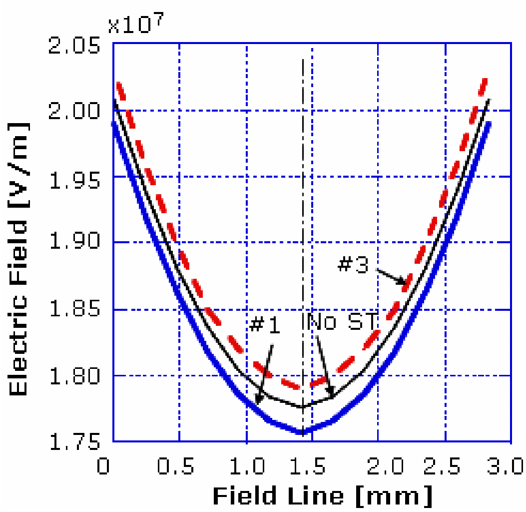

Figure 6: Electric field profiles of #1 and #3 in the case of distortion factor of 1%.

SUMMARY

Mock-up loop antennas for a high RF power have been fabricated, and these RF power-balances in a 175MHz RFQ mock-up module have been measured by network analyzer. By a small loop antenna with a pipe diameter of 10mm, the operation mode (TE_{210}) was not affected by the loop antenna structure, it was found that the installed depth by 3cm is a key technology in order to make the phase differences small. In the multi-drive loop antenna tests, a good RF power-balance with four-loop antennas was obtained in comparison with those with the single loop and the two loop antennas. For the four-loop antenna, electric field profiles in beam bore were calculated, and it was fond that the filed distortion factor is less than 1%. On the other hand, RF power-balance effects by slug tuners have been tested, it was found that operation mode is not affected by the 5cm slug tuner up to the 7cm-depth and the power-balance up to 80% variation can be controlled. From simulation results, however, it was found that the RFQ design requirement of a distortion limit of 1% can be attained by employing a 1cm-diameter slug tuner with the insertion depth of 1cm or less. These obtained results will be a good data base for a 175MHz RFQ design.

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