BEAM DYNAMICS OF A 175MHz RFQ FOR IFMIF PROJECT

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Abstract

For a 12.5m-long 175MHz RFQ design, application of coupled cavity technique have been investigated to suppress higher modes in a longitudinal length. In order to divide into segments with an optimum length, frequency differences between the operation mode and the nearest higher mode for various longitudinal lengths were calculated by MW-studio. The optimal length was found to be a 4.1m-long which is equivalent to division by three by installing two coupling plates. Beam dynamics analysis for this configuration was performed by TOUTATIS code, and the deterioration of transmission coefficient within 1% was attained by employing the gap width of less than 4mm.

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[4-5] and drift tube linac (DTL) are designed to be 0.1, 5.0 and 40.0 MeV, respectively[6]

In the RFQ linac, the 12.5m-long RFQ was designed to accelerate deuteron beam up to 5MeV. The operation frequency of 175MHz was selected to accelerate the large current of 125mA. To suppress higher modes in the longitudinal RFQ length, application of a coupled cavity technique which had been developed for 350MHz RFQ system in APT/LEDA of LANL [7-10], is indispensable.

For this technique, the 12.5m-long RFQ is divided by installing coupling plates into segments with a length to be optimized not to affect the operation mode by the nearest higher mode. For this purpose, resonant frequency dependences on the segment length were calculated by MW-Studio code [11]. As a gap between RFQ vanes is indispensable for the coupled cavity, deterioration of emittance and transmission coefficient due to the gap is anticipated. These beam dynamics issues were analyzed by TOUTATIS code [12].

HIGHER MODE ANALYSIS

Parameters of a 175MHz RFQ which were calculated by PARMTEQ code [13], is shown in Table 1. The parameters were optimized to obtain a high transmission coefficient. A maximum vane voltage of 86.2kV using Kilpatrick limit factor of 1.8 was assumed, and a beam bore-radius of 4mm was used. It was found that a total RFQ length of 12.54 m is needed to accelerate up to 5MeV.

Table 1: Parameters of a 175MHz RFQ

Frequency	175 MHz
Current (Deuteron)	125mA
RFQ Injection Energy	100keV
Beam Injection Emittance	0.2πmm-mrad
Vane Voltage	86.2kV (1.8E_k)
Synchronous Phase	-90° → -34°
Max. Modulation Factor	1.42
Focusing Force Factor	5.60
Total RFQ Length	12.54m
Radial Matching Section	0.035m
Shaper Section	0.900m
Gentle Buncher Section	0.980m
Accelerator Section	10.610m
Transmission Co-efficient	87.2%

In Fig.1, resonant frequency dependence on a longitudinal length which was calculated by MW-Studio, is indicated. The resonant frequencies of higher modes are close to that of operation mode as the longitudinal length becomes longer. In our previous works, resonant frequencies of a 175MHz RFQ mock-up module had been measured, and the following knowledge was obtained for the behavior of the operation mode influenced by the frequency difference to the nearest mode.

1) For the case of ~ 600kHz,
phase differences are degraded at the level of 180°± a few 10°
2) For the case of ~1MHz,
a new mode is excited between the operation mode and the nearest mode.
3) For the case of more than 1 MHz,
the unwanted behavior described above is not seen.

From these results, it is decided that a frequency difference of more than 2MHz is needed not to affect the operation by higher modes.

In Table 2, typical frequency differences from the calculated results are indicated. Longitudinal lengths of 3.1m, 4.1m and 6.1m are correspond to the divisions of RFQ into four, three and two segments, respectively. Frequency differences for 3.1m and 4.1m are satisfied with the 2MHz, but that for 6.1m is not satisfied. For 3.1m and 4.1m, three coupled cavity and two coupled cavity are needed, respectively. Because few coupled cavity should be applied to reduce complicated cooling system and beam deterioration, 4.1m segment length is appropriate for the 12.5m-lomg RFQ design.

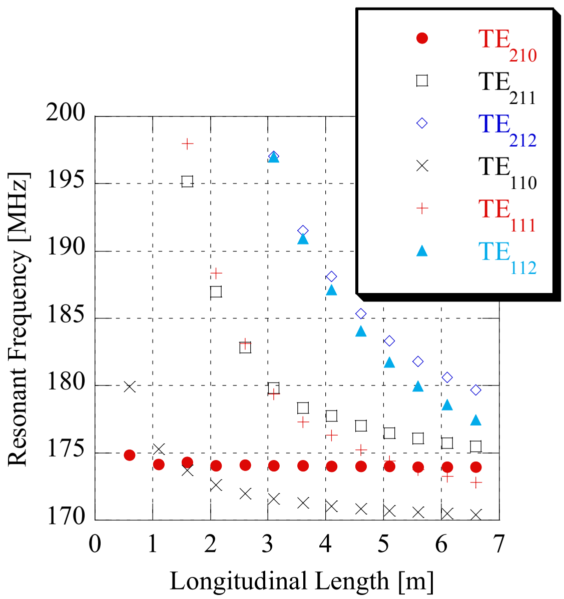

Figure 1: Dependence of resonant frequencies on a longitudinal length for a 175MHz RFQ is calculated by MW-Studio code.

Table 2: Frequency difference between operation mode and the nearest higher mode

Longitudinal Length [m]	Nearest Higher Mode	Frequency Difference
3.1 m	TE_{110}	2.495 MHz
4.1 m	TE_{111}	2.225 MHz
6.1 m	TE_{111}	0.609 MHz

BEAM DYNAMICS

Configuration of a coupled cavity is shown in Fig.2. A longitudinal length is divided by installing a coupling plate, and a gap is needed between RFQ vanes. Electric fields are locally distorted by the gap, and then deterioration of beam quality is anticipated. Therefore, beam dynamics in the 175 MHz RFQ with two coupled cavities has been analyzed by TOUTATIS code.

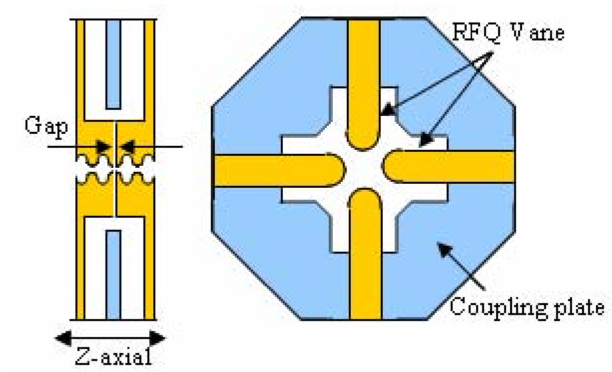

Figure 2: Configuration of a coupled cavity.

In Fig.3, beam envelopes (a) with no coupling plates and (b) with two coupling plates are indicated. The horizontal and vertical axes indicate the longitudinal length and the transverse radial size, respectively. Gap widths of 8mm are used, and coupled cavities are installed at the lengths of 4.220m and 8.475m, respectively. In this case, it is clear that beam envelope is perturbed by two gaps.

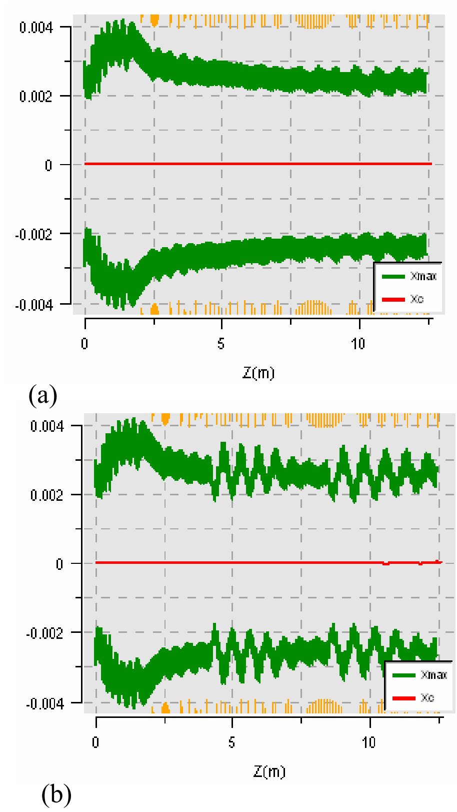

Figure 3: Beam envelopes (x: positive axis; y: negative axis) (a) with no coupling plates and (b) with two coupling plates (gap widths:8mm).

The beam emittances at RFQ exit for no gap, 4mm and 8mm gap widths are shown in Table.3. The same widths are used for two couplings. It was found that beam emittance is deteriorated by gap width. In the case of gap width of 8mm, the deterioration is 25 % for a transverse direction, but 7% for a longitudinal direction.

Table 3: Normalized Emittance (rms) at RFQ exit

	gap width		
	None	4mm	8mm
Transverse	0.270	0.289	0.338
Longitudinal	0.514	0.516	0.557

unit:πmm mrad

Transmission coefficient depending on gap width is shown in Fig.4. No coupled cavity, gap widths of 4mm and 8mm are indicated by circle, square and triangle, respectively. In case of no coupled cavity, transmission coefficient of 86.1% was obtained by TOUTATIS code, but it was 87.2% by PARMTEQ code. The results of TOUTATIS codes were in a good agreement and PARMTEQ within 1% level. In the cases of using gap widths of 4mm and 8mm, coefficient of 85.7% and 83.5% were calculated, respectively. By a gap width of less than 4mm, it was found that a deterioration of transmission coefficient can be suppressed within 1%.

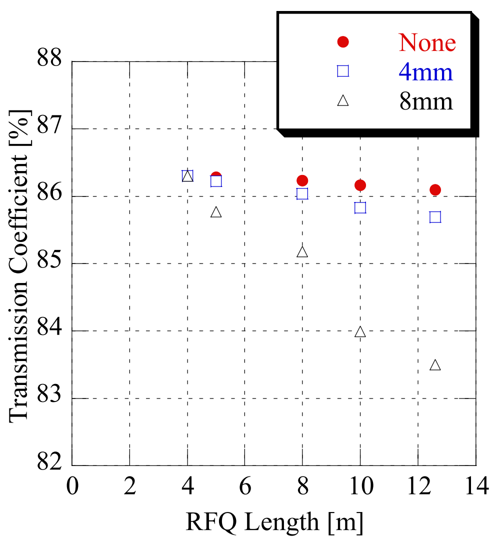

Figure 4: Transmission coefficient for a 175MHz RFQ with two coupled cavities.

SUMMARY

For a 12.5m-long 175MHz RFQ, resonant frequencies of the operation mode and higher modes in various lengths are analyzed by MW-Studio code. From frequency difference between the operation mode and the nearest higher mode, application of two coupled cavities was selected not to be affected the operation mode by higher modes. In the 12.5m-long RFQ with two coupling plates, beam dynamics were analyzed by TOUTATIS code. The beam emittance in a transverse direction is deteriorated conspicuously, in the case of gap width of 8mm and the deterioration in a transverse direction is about 3 times worse than that in a longitudinal direction. As for transmission coefficient, deteriorations of 0.4% and 2.4% were obtained in the cases of gap widths of 4mm and 8mm, respectively. In order to attain a deterioration of less than 1%, a coupled cavity design with a gap width of less than 4mm is indispensable.

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