DESIGN OF A 2-BEAM TYPE IH-RFQ LINAC FOR HIGH INTENSE HEAVY ION BEAM ACCELERATIONS IN LOW ENERGY REGION

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Abstract

For generating high intense ion beams from a linear accelerator (linac) stably, it is necessary to suppress the defocusing force between the charged particles. The defocusing force is extremely strong in low energy and high intense beams. Therefore, high intense ion beam acceleration in the low energy region is one of the most difficult conditions to achieve. One of the solutions is to suppress the defocusing force by dividing the high intense beam into several beams. Thus, a multibeam IH type Radio Frequency Quadrupole (IH-RFQ) linac has been proposed for the low energy and high intense beam acceleration. In particular, we have been developing a 2-beam type IH-RFQ cavity as a prototype of the multibeam type IH-RFQ.

INTRODUCTION

High intense ion beam acceleration in the low energy region is one of the most difficult conditions to achieve due to the space charge effect. As a solution for this problem, an idea has been proposed to divide a single, high intense beam into several beams, and merge these beams into a single high intense beam with higher energy. Toward this end, an accelerator technology for a heavy ion inertial confinement fusion driver has been studied [1-3].

There is a HIBLIC in Japan that serves as a conceptual design of the inertial confinement fusion reactor [1]. The design requires 16 RFQ linacs for the first acceleration stage because the maximum output current limit is estimated to be 35 mA in the conventional RFQ linac. In this case, a beam is accelerated in a cavity conventionally. Thus, if several beams can be accelerated in a cavity towards a cascade acceleration, this method would be better than the existing systems in terms of space and cost economy.

Therefore, multibeam type linacs, which consist of several beam channels in one cavity, have been studied. For instance, a multibeam type RFQ linac with an IH structure was proposed at GSI in Germany [4]. However, there have been no previous cases in which the actual machine was manufactured. Consequently, we have developed an IH-RFQ linac with two beam channels in one cavity as a prototype for the multibeam type linac.

DESIGN AND PARAMETERS

The external appearance of the 2-beam type IH-RFQ cavity is shown in Fig. 1, which consists of two sets of quadrupole electrodes. The RF electromagnetic field is stimulated by the TE_{111} mode as well as the IH cavity. The RFQ electric field is generated by four rods installed in each of the stems taking the polarity into consideration. We adopted a structure separated into three parts, a main frame and two semi cylinders, for ease in fabrication and modification of the electrodes.

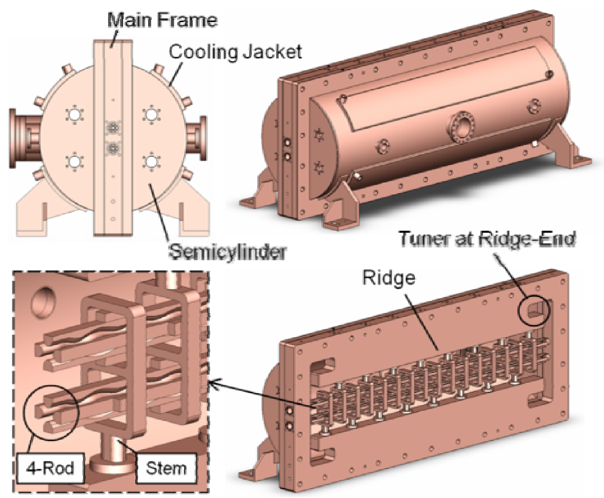

Figure 1: External appearance of the 2-beam type IH-RFQ.

The RFQ cavity can replace a resonance circuit equivalently, and the four gaps between the quadrupole electrodes in the RFQ are represented as the electrical capacitance in the resonance circuit. The resonance frequency is proportional to $(LC)^{-0.5}$. L and C are inductance and electrical capacitance in the cavity respectively. The electrical capacitance of the 2-beam type IH-RFQ cavity increases compared to the single beam type because the 2-beam type structure has two sets of quadrupole electrodes. This allows a comparatively low frequency to be achieved within a small cavity diameter. The cuts at the end of the ridge adjust the resonance frequency by changing the area of the magnetic flux surface and the inductance in the cavity.

Acceleration properties of the 2-beam type and the single beam type IH-RFQ linac were simulated [5]. The results demonstrated that the cavity diameter and length of the 2-beam type cavity are more compact than those of the single beam type cavity. The transmission of the 2-beam type cavity is 34% larger than that of the single beam type cavity, which has double the cross section of the beam channel in the 2-beam type. However, the beams from the multibeam type cavity need to be merged because the total emittance of the several output beams is too large for most applications to handle. There is a

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possibility that a portion of the ion beams are lost due to beam funneling, so beam funneling technology with efficiency is required for multibeam acceleration.

The accelerated particles were set to q/A≥1/6, and C^{2+} beams will be accelerated in the test of this linac. The resonance frequency in this cavity is 46.2 MHz in MW-Studio calculation. The input energy is 5 keV/u considering beam dynamics simulations and the voltage at which the beam will be extracted from an ion source. Taking into consideration the maximum output of the RF power source, the wall loss is saved less than about 80 kW including beam loading. A Kilpatrick factor of the maximum field at inter-rod is 1.8 which is the ratio of electric field to the Kilpatrick criterion.

Table 1 shows the main parameters for the 2-beam type IH-RFQ linac. The computer code RFQUICK was used to generate the cell parameters for the PARMTEQM calculation [6]. The RFQUICK is suitable for the design of RFQ linacs whose output beam currents exceed 10 mA. The computer code PARMTEQM was used to simulate the beam dynamics in the RFQ. The electromagnetic simulation software MW-Studio was used to calculate the resonance frequency, the Q value and the wall loss of the cavity.

Table 1: Main Parameters for the 2-beam Type IH-RFQ

Chargh to mass ratio (q/A)	1/6
Input energy (keV/u)	5
Output energy (keV/u)	60
Resonance frequency (calculated by MW-Studio) (MHz)	46.2
Rod-tip type	$0.75r_0$
Modulation type	Standard
Average bore radius, r_0 (cm)	0.76
Minimum bore radius, a_{min} (cm)	0.41
Cavature radious of rod-tip (cm)	0.57
Focusing strength, B	8.754
Defocusing strength (at exit of the gentle buncher section), $\|\Delta\|$	0.216
Synchronous phase, ϕ_s (degree)	-90 → -30
Rod length (cm)	148.12
Total number of cells	104
Cavity length (cm)	150
Cavity diameter (cm)	49.2
Maximum field at inter-rod (Kilpat.)	1.8
Q value (calculated by MW-Studio)	7500
Wall loss (at normalized inter-rod voltage, 80% Q) (kW)	25

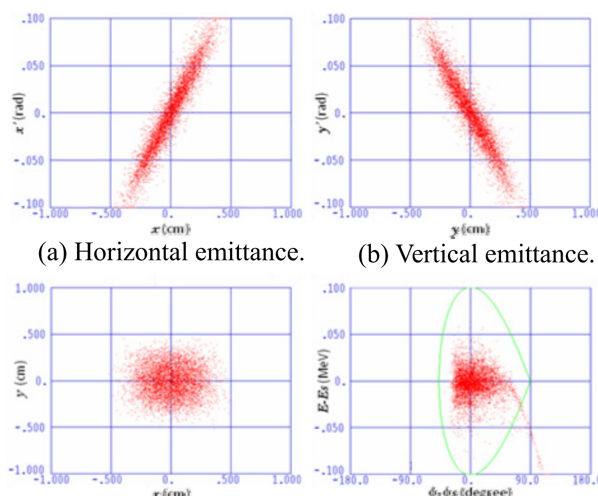
BEAM DYNAMICS SIMULATION

Table 2 shows the parameters of the input beam for the beam dynamics simulations. α_t and β_t refer to twiss parameters, and ε_t refers to the emittance at the transverse direction. The parameters were determined under the assumption that a laser ion source with a direct plasma injection scheme would be adopted as the injection system for the linac [7]. The particle distribution of the 4-D waterbag exhibits a uniform phase and a random energy spread [6].

Table 2: Parameters of the Input Beam for the Beam Dynamics Simulation

Beam current (mA)	60
Number of particles	10000
α_t	3.4
β_t (cm/rad)	12.7
ε_t (π mm.mrad, RMS, normarized)	0.1
Distribution	4-D waterbag
phase	uniform
energy	5keV/u, random

Figure 2 shows the output beam profile at the end of the 4-rod. The emittance and the twiss parameters at the end of the rods are shown in Table 3. When a beam current of 60 mA from an ion source is injected into a beam channel, the 2-beam type IH-RFQ linac accelerates an output current of 43.6 mA per beam channel. As a result, when the total beam current of 120 mA is injected into the two beam channels, the total output current from the cavity will be 87.2 mA.



(a) Horizontal emittance. (b) Vertical emittance. (c) Particle distribution on the real plane. (d) Longitudinal emittance.

Figure 2: Beam profile at the end of the 4-rod.

Table 3: Parameters of the Output Beam from a Beam Channel

Transmission (%)	72.7
Output current (mA)	43.6
α_x	1.8
β_x (cm/rad)	14.8
ε_x (π mm.mrad, RMS, normarized)	0.25
α_y	-1.6
β_y (cm/rad)	10.5
ε_y (π mm.mrad, RMS, normarized)	0.23
α_z	0.69
β_z (degree/MeV)	1473
ε_z (π MeV.degree, RMS, normarized)	0.33

The output current against the input current in this design is shown in Fig. 3. The output current saturates when the input beam current reaches 120 mA and above. Figure 4 shows the output current against the Kilpatrick factor at the inter-rod. The output current can rise to about 8% by increasing from 1.8 to 2.2 Kilpatrick factor.

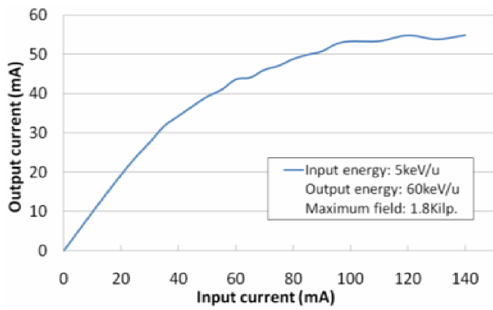


Figure 3: Output current versus the input current per beam channel.

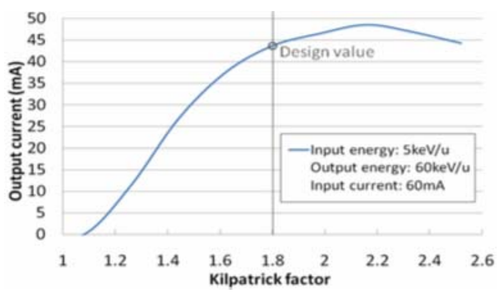


Figure 4: Output current per beam channel versus Kilpatrick factor.

RF MEASUREMENT

As shown in Fig. 5., the actual machine of the 2-beam type IH-RFQ cavity was manufactured, and the low power RF property of the cavity in room air was measured by using a network analyzer (E5070B made by Agilent Technologies, Inc.). At the time of the measurement, the room air temperature, the cavity temperature and the humidity were 31.2°C, 30.4°C and 51.5% respectively. The S_{21} parameter in TE_{111} mode is shown in Fig. 6. The resonance frequency and the Q value were about 46.99MHz and about 5900 respectively.

Figure 5: Low power RF measurement of the 2-beam type IH-RFQ cavity.

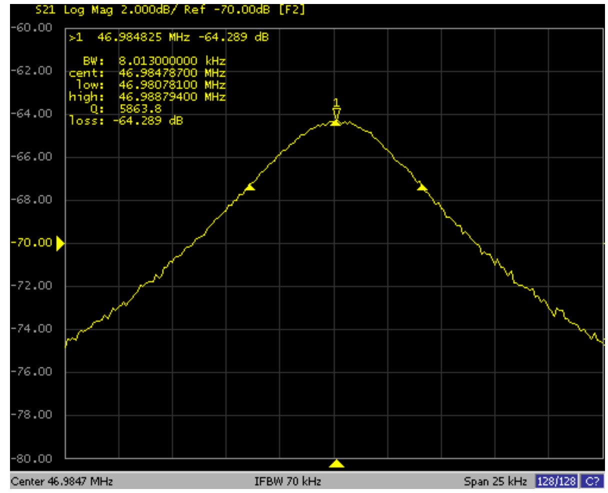


Figure 6: S_{21} parameter in TE_{111} mode.

The Q value in the real cavity goes down to about 80% from the calculated value because electrical contacts and surface roughness of the elements in the cavity are less than perfect. In the case of a 2-beam type RFQ with a π-0 mode structure, the Q value in the real cavity was 2000-3000 [8]. This indicates that the 2-beam type IH-RFQ is more power-efficient than the type with the π-0 mode structure because the power loss per RF cycle in the cavity is in inverse proportion to the Q value.

CONCLUSION

We have studied a multibeam type IH-RFQ linac that is a practical and efficient method to accelerate high intense and low energy ion beams and developed a 2-beam type as the prototype. The actual machine of the 2-beam type IH-RFQ has been manufactured, and the RF property has been measured.

The results of the beam dynamics simulations demonstrated that the total output current from the 2-beam type IH-RFQ linac is 87.2 mA to yield a total input current of 120 mA in q/A=1/6 particle acceleration. The output current from the 2-beam type IH-RFQ can exceed that from the conventional RFQ.

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