DESIGN STUDY ON AN INTENSE HEAVY-ION LINAC SYSTEM

M. Okamura, Y. Oguri, Y. Takahashi and T. Hattori

Research Laboratory for Nuclear Reactors, Tokyo Institute of Technology

2-12-1, O-okayama, Meguro-ku, Tokyo, 152, Japan

O. Takeda, K. Satoh and Y. Tanabe

Toshiba Corporation, 2-4, Suehiro-cho, Tsurumi-ku, Yokohama, 230, Japan

Abstract

A four-vane RFQ cavity is designed for an intense heavy-ion linac system. RFQ-vanes with small tip curvatures are applied in order to improve the RF power efficiency. Beam optical and RF parameters are investigated by beams of numerical methods. Using a scale model, the cavity structure is experimentally optimized.

Introduction

An intense heavy ion linear accelerator system at Tokyo Institute of Technology (TIT), which consists of a four-vane RFQ linac and an IHQ[1] (Interdigital H structure with RF Quadrupole focusing) linac, is being designed for researches on high energy density in matter produced by heavy ion beams. The first stage linac, the four-vane RFQ, accelerates particles with charge to mass ratio (q/A) of 1/16 up to 200keV/amu. It is well known that four-vane cavities have high shunt impedunce compared with other RFQ structures. Nevertheless higher RF efficiency is still prefarable especially for operations with high duty factors and for accelerations of heavier particles. In many RFQs, the vane tip curvature ρ is designed to be equal to the quadrupole bore radius r_0. If vanes with smaller tip curvatures are applied, the intervane capacity is reduced, and higher shunt impedunce can be obtained.

In this note we present an outline of the design work on the RFQ cavity loaded with these "thin" vanes. Some new technical developments concerning the RFQ vanes are presented. Preliminary results on a scale model cavity are also reported.

Design Parameters[2]

The output energy of the RFQ has been designed to be 200keV/amu, because this value is the minimum acceptable input energy for the second stage linac. The computer code GENRFQ[3] was used for the optimization of vane parameters. The computer code PARMTEQ[4] was used to simulate the particle motion in the RFQ.

The parameters ware optimized in order to obtain a high particle transmission and a small cavity length. The obtained design parameters are summarized in Table 1. In Fig.1 parameters are plotted as a function of the cell number. The total vane length is 394 cm, which corresponds to 272 cells

including the radial matching section with 20 cells. The beam transmission is expected to be 92% for the beam current of 0mA and 72% for 10mA. Fig.2 shows results of a PARMTEQ calculation for beam current of 10mA.

Table 1
Parameters Designed Using PARMTEQ and GENRFQ

Charge-to-mass ratio	$\geq 1/16$
Operating frequency(MHz)	80
Input energy(keV/amu)	5
Output energy(keV/amu)	200
Normalized emittance(cm·mrad)	0.05π
Vane length(cm)	394
Total number of cells	272
Characteristic bore radius, r_0(cm)	0.49
Minimum bore radius(cm)	0.30
Margin of bore radius, a_{min}/a_{beam}	1.1
Maximum modulation, m_{max}	2.1
Focusing strength, B	3.2
Maximum defocusing strength, Δ_b	-0.048
Synchronous phase, ϕ_s(deg.)	$-90 \rightarrow -30$
Intervane voltage(kV)	84
Maximum field(Kilpat.)	2.2
Transmission(%)	(0mA input) 92
	(5mA input) 83
	(10mA input) 72
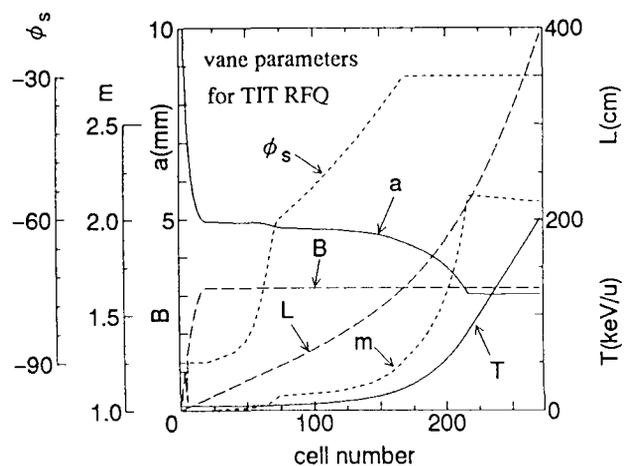
Fig. 1   Vane parameters for TIT RFQ as a function of cell number

TIT OXYGEN RFQ   (10 MA)

X VS. CELL NO.

PHI-PHIS (DEG) VS. CELL NO.

W-WS (MeV) VS. CELL NO.
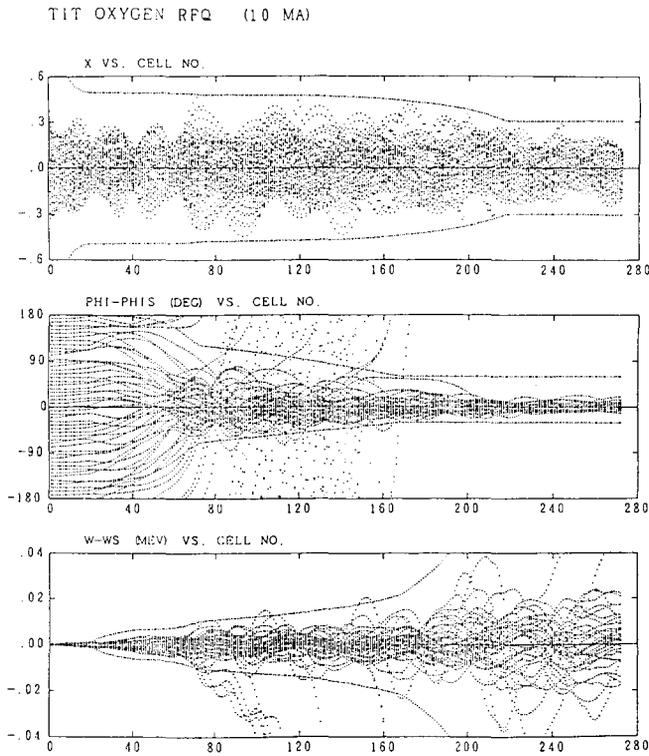
Fig.2 Results of the PARMTEQ Simulation

Top: Particle position is given in cm. The dashed lines are the envelope of the minimum aperture.

Middle: Phase oscillation. The dashed lines show the phase width of the longitudinal separatrix.

Bottom: Energy spread. The dashed lines show the energy width of the separatrix.

New Vane-Tip Configuration

A high RF power efficiency is required because the available RF power is limited to 120kW including beam load. In order to obtain a high shunt impedance and a high sparking limit between vanes, thin vanes with small vane-tip curvatures are preferable. We are planning to 0.75 times of characteristic bore radius ($\rho = 0.75r_0$) as the curvature. The vane-tip is machined with a numerically controlled (NC) mill. Two dimensional machining will be adopted in order to reduce time and cost of machining. These two-dimensionally machined thin vane configuration, however, can distort the linearity of the intervane electric field.

We are now investigating the beam dynamical effects of higher-order harmonics including longitudinal terms.

Table 2
RF Parameters Obtained Using SUPERFISH

Resonant frequency(MHz)	80
Calculated Q factor(SUPERFISH)	21600
Wall loss(at nominal intervane voltage, kW)	81.0
Shunt impedance(MΩ/m)	29.8
Maximum field(Kilpat.)	2.0
A_{01}	0.97
A_{03}	0.033

Vane-tip radius(cm)	0.37
Cavity diameter(cm)	76.6
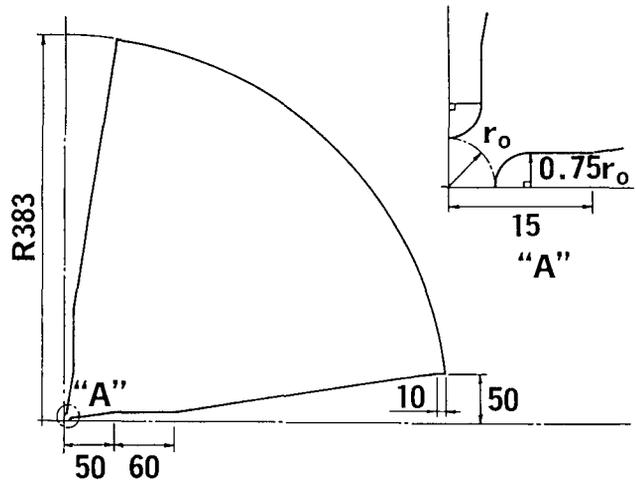
Fig.3   Cross sectional view of a quadrant of the TIT RFQ

Cavity Design

A cross-sectional view of one quadrant of the cavity is shown in Fig.3. The cross-sectional shape of vane was determined as shown in the figure considering further reduction of wall loss and easiness of machining. Main RF parameters of the RFQ linac is summarized in Table 2. A high shunt impedance and allowable peak surface electric field of 2.0 times the Kilpatrick limit have been achieved without any increase of A_{03}. It seems to be difficult to machine the 4m long vane with sufficient geometrical accuracy. Therefore, the cavity will be divided into two tanks with 2m long vanes.

Cold Model Design[6,7]

A 1/2.4-scaled cold model without any longitudinal vane modulation was constructed to examine the field stabilization and to determine end structures. Fig.4 illustrates the model cavity. The vanes are made of aluminum, while tanks are made of commercially available steel pipe for cost reduction. The vanes, the tanks and the lids of the tanks are plated with copper. The tank length and diameter are 1.7m and 32cm, respectively. The same two-tank structure in the actual cavity was applied in order to investigate the influence of connection of the tanks. The vertical gaps between vanes in different modules have theoretically no electromagnetic effect, because no current flows across the gap owing to the symmetry.

The vanes with ρ of 1.55mm were two-dimensionally machined using a numerically controlled mill. An geometrical accuracy within ±0.02mm was obtained for the
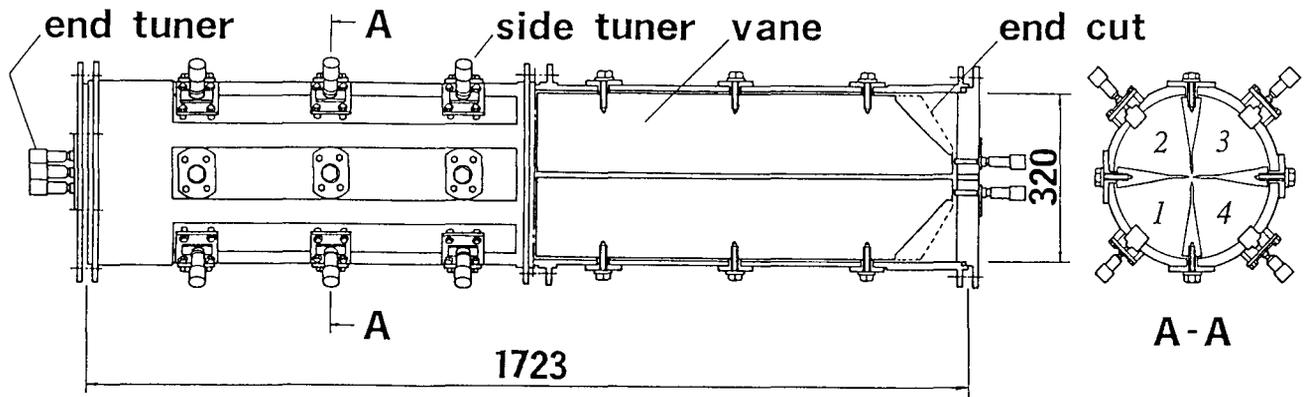
Fig.4 Schematic drawing of the 1/2.4 sdale model.

vane tips. The vanes are bolted to the tank with RF contacts. The vane end cuts are triangular and tuning plates can be attached as shown by dotted lines in the figure. Four capacitive end tuners (C-tuner) are also inserted from each end plate.In addition to the C-tuners, each quadrant has six inductive side tuners to tune the RF field distribution more precisely. A loop type antenna is employed and each quadrant has one pick-up for monitoring internal field strength.

Scale Model Measurement

A preliminary alignment of four vanes is carried out using two end jigs and reamer pins. The measurement of the intervane distance, which is designed to be 1.96mm, has shown an unexpected large assembly error. At the end of the vane the error is ±0.04mm and at the middle of the vane it is ±0.17mm. Improvement of the alignment is now being done intensively.

The electric field strength near the beam axis is measured with bead-perturbation method. Through two halls bored at the center of both end plates, a perturbator, a ceramic bead with a diameter of 10mm, is introduced into the cavity. The perturbator slides on the surfaces of neighboring two vanes by means of a guiding thread. This measuring technique allows exact positioning of the perturbator without special holding devices. The diameter of center halls is reduced to be 12.5mm in proportion to beam halls of the actual cavity. The end lids have other four halls near the bottom of vanes to measure the magnetic field in each quadrant cavity.

Conclusion

An 80MHz RFQ linac was designed to achieve the intervane voltage of 84kV with the limited available RF power of 120kW. According to the SUPERFISH analysis, the structure with two dimensionally machined $\rho = 0.75r_0$ vanes has shown an improvement of shunt impedance. In order to study the field stability of this RFQ, a 1/2.4-scaled cold model without vane modulation and a radial matching section was successfully fabricated, and preliminary RF

properties were obtained. Not only the beam dynamical analysis with higher-order harmonics, but also structural and thermal designs are in progress including the R&D concerning machining procedure.

Reference

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