DESIGN AND CONSTRUCTION OF A HEAVY ION RFQ LINAC

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Abstract

A full-scale 4-rod type heavy ion RFQ linac is constructed and the measurements of the RF characteristic are completed at low power level with un-modulated electrodes. The measured resonant frequency of the RFQ is 33. 0527 MHz and un-loaded Q-value is found to be about 5000. These values agree well with what we expect from the results of our 1/3 scale model; the design values are 33.3 MHz and 4700 for the resonant frequency and the un-loaded Q-value respectively.

Introduction

Although current industry applications of ion implantation are mostly performed with conventional electrostatic accelerators and is limited to low dose implantation with ion energies ranging from one to several MeV, RFQ has its several appealing points to be recognized by industrial accelerator users as a high current and high energy accelerator. RFQ's weight and its easy radiation-shield requirement are other advantages over existing commercial MeV ion implanters. Furthermore when a compact ECR ion source becomes available, which is capable of producing a high-current multiply-charged ion beam, an RFQ linac will have a remarkable advantage in its small size and power efficiency. We summarize in this paper our work on 4-rod RFQ linac : 1/3 model study, an RF power amplifier system, and design considerations and the initial RF tests on full-scale machine.

Model Study of RFQ

The purpose of this model study is to search for the final dimension of the RFQ in reasonable size and to check its RF characteristics. All the measurements were done with un-modulated electrode.[1]

RF Characteristics

Fig.1 shows the unloaded Q-values as a function of the post height in 150 mm and 190 mm diameter tank. The number of the post is six - this means a pair of RFQ electrode is supported by three posts. The width and thickness of the post are 80 mm and 15 mm, respectively. The posts are evenly spaced by 150 mm from each other. The electrode is un-modulated and its length is 793 mm. The aperture radius is 2.7 mm. RF contact between the tank and the base-plate of the RFQ assembly is made by commercially available "RF shield fingers". The tendency is that the Q-value is basically irrespective to the height of the post, but will deteriorate as the electrodes come close to the wall of the tank. This result indicates that the beam optic-axis and the center of the cavity don't need to be aligned; they can be eccentric and it still gives "normal" RF characteristics that we require as an accelerator cavity. As a result the manufacturing costs of the cavity will be greatly reduced in the full-scale machine.

Fig.2 is a typical on-axis longitudinal electric-field distribution obtained from the experiments. The perturber's length is 10 mm and it is made just to fit in the aperture of the RFQ model. The results are that the variation of field along the axis is within 5 %. To achieve this degree of flatness, the electrode alignment tolerance must be as good as 0.05 mm.

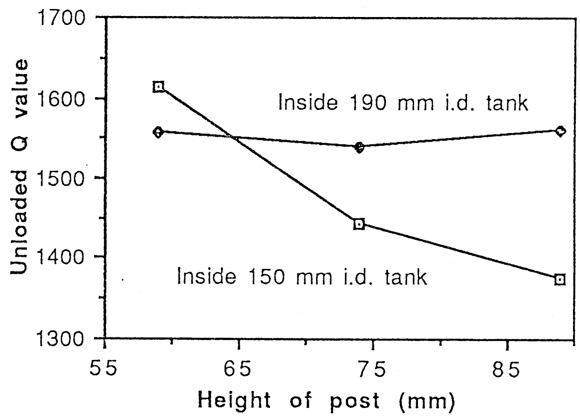

Fig.1. Unloaded Q-value as a function of post height.

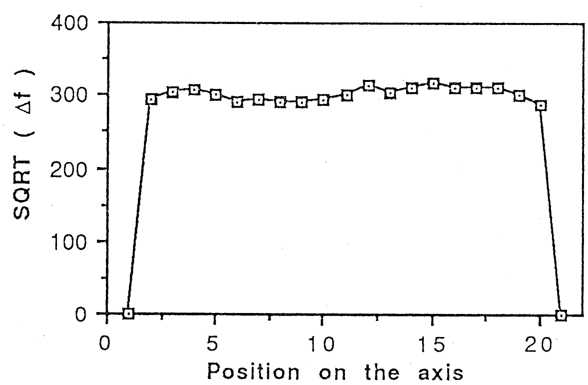

Fig. 2. Typical on-axis electric field distribution of 4-rod RFQ 1/3 scale cold-model. The resonant frequency is 94.72 MHz.

3-D electrode cut

This work is to check the 3-D cut of a 1/3 model RFQ electrode. Because of the nature of profile, only the profile in the mid-plane of the electrode along the longitudinal axis and the transverse plane at particular points - the valley and ridge of the profile - are measured. Those will be sufficient to understand how well machining is performed and also to check the method and programs we have used.

Measurements and data analysis are not trivial because of the rod-electrod's rather week strength. Error correction associated with bending of the electrode is done carefully in such a way that it eliminates the the distortion of the rod-electrode by taking many reference points. In over all, the inspection of analysis shows that machining is performed within 40 micron of accuracy in both longitudinal and transverse directions. Those results will be satisfactory for our present purpose and assure us that the methods are correct. Fig.3 shows a comparison of calculated and the measured transverse electrode profile of a 1/3 model electrode at 371 mm from the start of radial matching section.

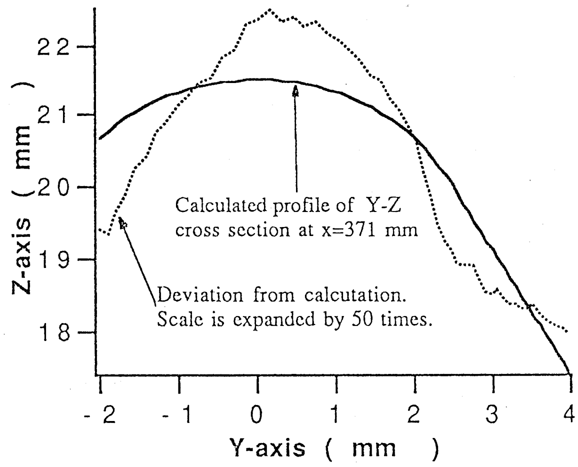

Fig. 3. Cross section plot of 1/3 scale RFQ electrode of calculated and measured profile . Dotted plot shows deviations from the calculation, brew up in scale by 50 times.

RF power system

Configuration

Fig. 4 is the block diagram of the RF P.A. system. Both the 50 kW P.A. and the 5 kW P.A.s have a local as well as a remote controller. The RF P.A. system is installed in the Ryushisen-Hassei-Kiki Shitu except for a signal generator, a 360 degree phase-shifting unit, and the remote controllers.

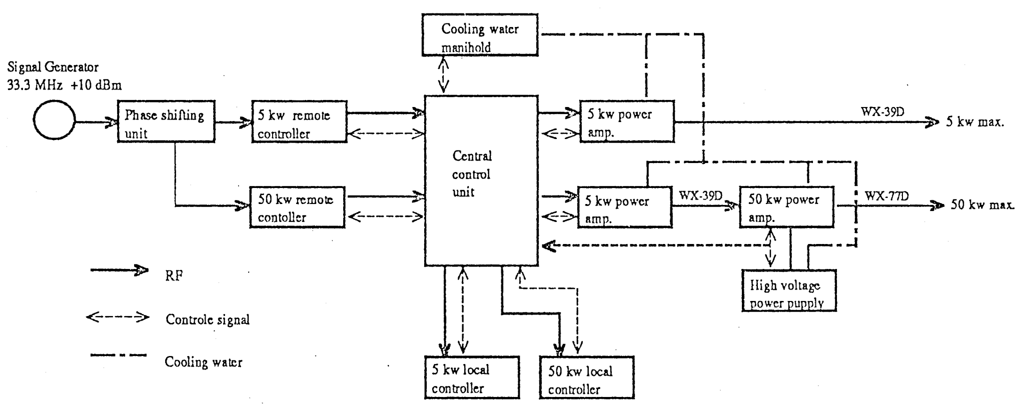

Fig.4. Block diagram of 33.3 MHz RF P.A. system.

They are installed in the remote control room located south of the experiment room. The two 5 kW P.A. s are identical : one is used as a driver amp. for the 50 kW P.A. and the other is going to be used as a final-stage P.A. for the post accel./decelerator resonator. Each P.A. consists of a 500 W solid-state amplifier and a Siemens RS3021 CJ triode P.A. The 50 kW P.A. is also a tube-amp. equipped with a Siemens RS 2058 CJ tetrode. RS3021 CJ and RS 2058 CJ have the maximum anode dissipation of 20 kW and 90 kW, respectively. The reason we have chosen such large tubes is that a small-size circulator is not available in this frequency regime. It can be thought as one practical way of protective measures for the expensive tubes.

The total power required for the full power operation of the 50 kw and 5 kW system is approximately 140 kVA. A 150 kVA 200 volts 3 phase power line is newly installed in the experimental area. The P.A.s also require 100 liters/min. of deionized-water for cooling. A 400 liters/min. deionized cooling water circulator system (called "Sokutei-kei") supplies cooling medium for the RF P.A. system as well as for the RF accelerator cavities. This is one of four deionized cooling systems in the building and it has more than adequate specifications for our purpose : a 230 kW heat exchanger, a 70 m total-head pump, and a 450 kW cooling tower.

This P.A. system is expandable to meet for a multi-post accel./decelerator linac by adding the phase shifting units to the existing P.A. system. An upgrade in the linac's maximum energy or its energy range can be accomplished without major change in the P.A. system configuration.[2]

50 kW final stage power amplifier

This P.A. is classified as cathode-driven class AB grounded control- and screen-grid RF amplifier. The driver amp.'s output is fed to the cathode via WX-39D and the output is transmitted to the RFQ cavity in WX-77D coaxial tube. The forward power calibration is done with -60dB directional coupler that is installed in the WX-77D coaxial line and the results are compared with the values obtained by the calorimetric measurements of the 50 ohm water-cooled dummy load. The power efficiency that is defined as RF power output divided by power fed to the RS-2058 CJ's anode is approximately 70 % at 50 kW output. The calorimetric measurement gives 48.5 +/- .3 kw at the same output.

The output ripple is suppressed to less than +/- 2% at the maximum power output by a feed-back loop. Higher harmonics are kept below -30 dB at the same output. The cabinets of P.A.s are properly RF shielded to satisfy the applicable regulatory standard. This is checked with a commercial RF survey meter and by more sensitive electric field strength measurement with an antenna and a spectrum analyzer. At 50 kW output loaded into a dummy, E-field power density is undetectable anywhere in the vicinity even in the lowest range (full scale being 2.65 E-2 mW/cm^2) of the survey meter. An alternative E-field strength measurement with a spectrum analyzer gives below 40 dBμ/m in both horizontal and vertical direction 12 meter off the 50 kW P.A. cabinet.

Full scale RFQ linac

Design outline

The key parameters of our RFQ is listed in table 1. To be accepted in industry use and to lower the manufacturing costs , the cavity length should be limited around 2 m. Also as described in model study, the beam optic axis is not the center of the cavity - they are eccentric - in order to reduce the cavity diameter to 60 cm. This reduces the costs of the cavity and consequently, the costs of vacuum system , too.

Table 1. Key RFQ Parameters

Frequency	33.3 MHz
Characteristic bore radius	0.8 cm
Focusing strength	6.79
Inter-electrode voltage	54.9 kV
Charge to mass ratio	1/11 ~ 1/16
Injection energy	2.73 keV/n
Output energy	63.6 keV/n
Total length	222 cm
Cavity i.d.	60 cm
RF power , min. requirement	~36 kW cw

The total length of the cavity is 2340 mm and it consists of two identical tanks joined together at the center. Each tank has five ports for a vacuum pump, a view window, a RF power drive, a RF monitor, and a loop tuner. The material of the cavity is oxygen-free copper. The thickness of the wall is 35 mm. A portion of the inner surface at the bottom-side of the cavity is machined flat so that the RFQ electrode assembly can be positioned in place and it gets a good electrical contact with the cavity wall.

The tank has four cooling pipes half embeded and silver-brazed in the exterior surface. Assume there is 10 kW of RF power loss in the half-length of the RFQ cavity and constrain the max. temp. variation on the tank wall to be less than 5 degree and the max temp. rise of the water to be also less than 5 degree, then those requirement are met with the following conditions: temp. of water=27 degree Celsius, water flow rate=14 liters/min., number of pipes in one quadrant=3. The head-loss in the pipe is about 0.03 kgf/cm^2 per meter with relative surface roughness of 0.00385. The RFQ electrode assembly is also cooled by water. There are three independent cooling-water channels allocated for the RFQ electrode assembly: two for the electrodes and one for the electrode-supporting structure. The bore of the electrode cooling channel is made such that the pressure drop is about 0.18 kgf/cm^2 per meter at water flow rate of 21 liters/min.

The vacuum system comprises of two 900 liters/min. oil-rotary pumps and 2000 liters/min. turbo molecular pumps. A gate valve and an RF shield are installed between the turbo pump and the accelerator cavity. The initial test of the vacuum system is quite successful, being able to pump down to 4.8 E 10^{-7} torr when the RFQ assembly is out of the cavity.

Low power RF characteristics

The measured resonant frequency with un-modulated electrode is 33.0527 MHz and measured un-loaded Q-value is 5000. The two loop-tuner is able to increase the resonant frequency by 23.5 kHz to 33.0762 MHz.

Acknowledgments

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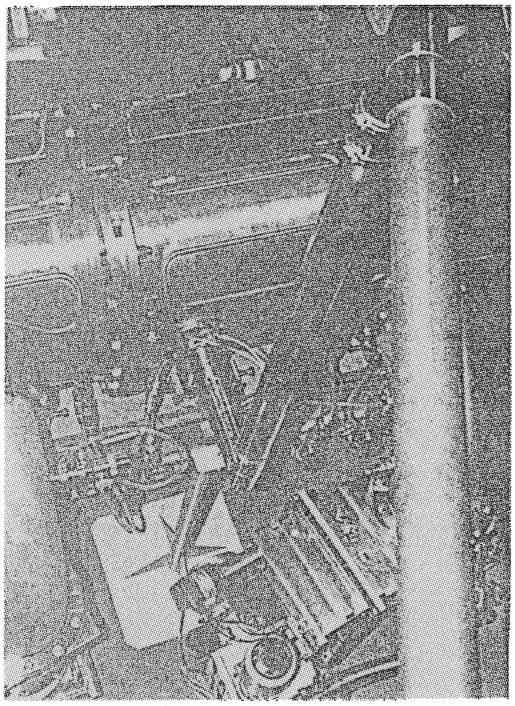

Photo. 1. A picture of full-scale RFQ cavity.

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2. For more information, refer to: Hiroshi Fujisawa, " The RF Power Amplifier System for a Heavy Ion RFQ Linac ", *Bull. Inst. Chem. Res., Kyoto Univ.*, Vol.69, No.1, (1991) 11-14.