Performance of the RFQ and Alvarez Linac at Kyoto University

T.Shirai, H.Dewa, H.Fujita, Y.Iwashita, S.Kakigi, H.Okamoto, A.Noda and M.Inoue
Accelerator Laboratory, Institute for Chemical Research, Kyoto University
Gokanosho, Uji-city, Kyoto 611, Japan

Abstract

The 7 MeV proton linear accelerator which consists of an RFQ and an Alvarez has been developed at Kyoto University. The operating frequency is chosen at 433.3 MHz to make the cavity size compact. Klystrons are used as RF power sources. High power operation tests were carried out and the required RF power, i.e 530 kW for the RFQ and 330 kW for the Alvarez, was successfully fed. In beam acceleration test, 7 MeV output beam was detected.

I. Introduction

We have developed a proton accelerator that consists of a 2 MeV RFQ (Radio Frequency Quadruple) and a 7 MeV Alvarez linac [1,2,3]. The layout of the accelerator is shown in Fig. 1. This linac has been developed as a prototype for a proposal in which an 800 MeV proton linac of 200 μA is planned [4]. It is composed of RFQ, Alvarez and coupled cavity linacs and will be used for research in physics, isotope production and cancer therapy. The 7 MeV linac is also to be used for nuclear science and proton irradiation.

The main specification of the linac is shown in Table 1. It is operated at 60 μsec pulse width, 180 Hz repetition rate. The operating frequency of 433.3 MHz is about twice higher than that of conventional proton linacs, because the cavity size becomes compact and klystrons are available as RF power sources in this frequency range.

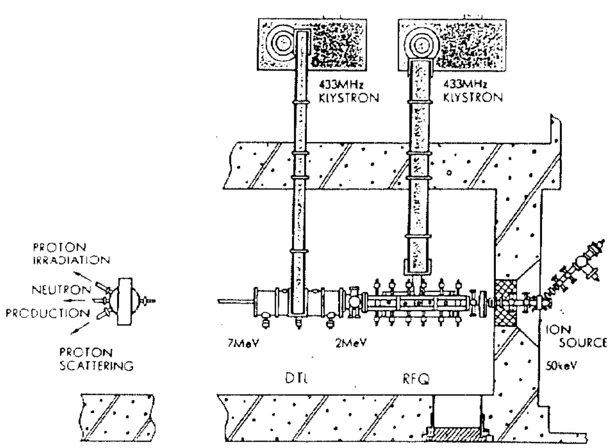

Figure 1 Layout of the accelerator system.

Table 1 Main specification of the linac.

Multicusp ion source	
ion species	H^+, H^-
extraction voltage	50 kV
RFQ linac (4-vane)	
vane length	2195 mm
characteristic bore radius	3.0 mm
minimum bore radius	2.0 mm
intervane voltage	80 kV (1.8 Kilpatrick limit)
output beam energy	2 MeV
transmission efficiency	95 % (at 30 mA)
Alvarez linac	
tank length	1868 mm
number of drift tube	28
Q magnet	NdB permanent magnet
maximum surface field	26 MV/m (1.3 Kilpatrick limit)
output beam energy	7 MeV
RF power source	
klystron	L-5773 (Litton)
output peak power	1.2 MW
frequency	433.3 MHz
duty factor	1 % (maximum)

II. RFQ linac

Figure 2 shows the inside view of the RFQ tank. The vanes are made of CrCu (Cr 0.75, Zr 0.08) with cooling water channels of 20 mm diameter. Each vane tip was cut with the concave cutter and the transverse curvature is 3.0 mm.

The RF power from the klystron, delivered through the waveguide (WR2100), is coupled into the cavity by a drive loop. To realize the flat field distribution, 6 plug-tuners are installed in each quadrant. The field distribution was measured by six pickup loops in each quadrant. The picked up power was calibrated by the results of bead perturbation measurements [5]. After the tuning, the field distribution in the RFQ cavity is shown in Fig. 3. The normalized field unbalance between quadrants is within ±2.5 % and the longitudinal field tilt is within ±5.5 %. The resonant frequency is 433.01 MHz, which is slightly lower than the designed value. The measured unloaded Q value is 5100 by a network analyzer (HP 8753C), while SUPERFISH prediction is 6600.

The designed vane voltage is 80 kV (1.8 Kilpatrick limit). The required RF power estimated from the SUPERFISH calculation and the measured Q value, is 540 kW. For the RF conditioning, the RF power was supplied at the low repetition rate of 18 Hz, 60 μsec pulse width [6]. Figure 4

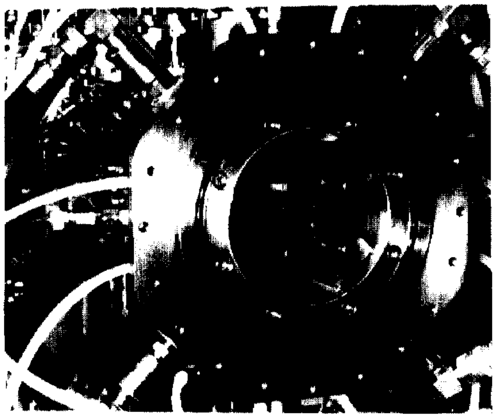

Figure 2 Inside view of the RFQ tank

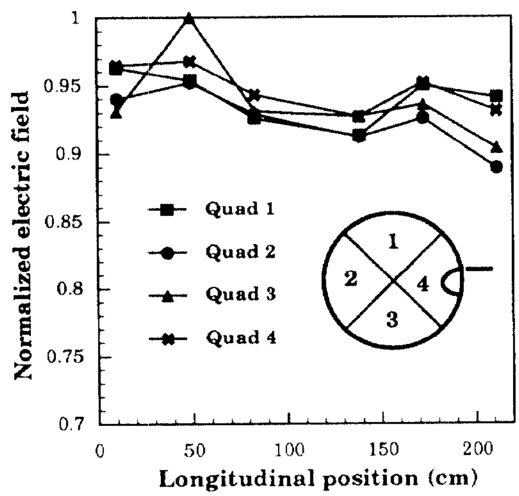

Figure 3 Normalized field distribution in the RFQ cavity.

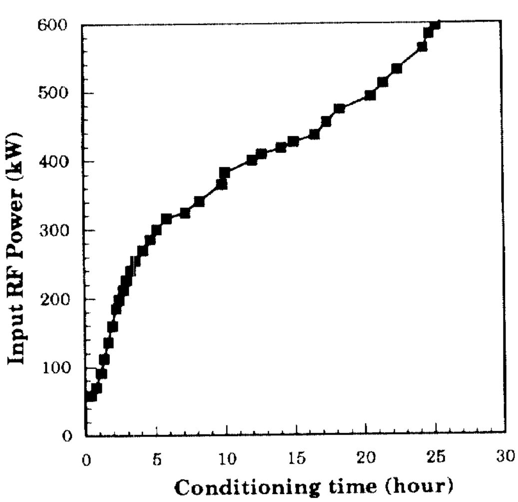

Figure 4 RF conditioning time for the RFQ cavity.

shows the RF conditioning time. We succeeded in feeding the 600 kW after 25 hours conditioning. In 1 % high duty operation, the field distribution was also unchanged and the observed resonant frequency shift was -20 kHz, which was within a tunable range for the linac operation. Three turbo molecular pumps with pumping speed of 500 l/s, 270 l/s and 340 l/s and a cryogenic pump with 2100 l/s (at H_2O) are used for the RFQ tank. The vacuum pressure was less than 1.1×10^{-6} torr at 35 °C.

The X-ray from the RFQ is due to the bremsstrahlung of field emission electrons on the vane tip surface. The maximum energy of the X-ray corresponds to the vane voltage. So, we estimated the vane voltage from X-ray energy spectrum. The spectrum is measured with a pure Ge counter and an MCA (Multi Channel Analyzer). The measured energy spectrum of the X-ray is shown in Fig 5. The vane voltage of 80 kV was obtained when the input RF power was 530 kW.

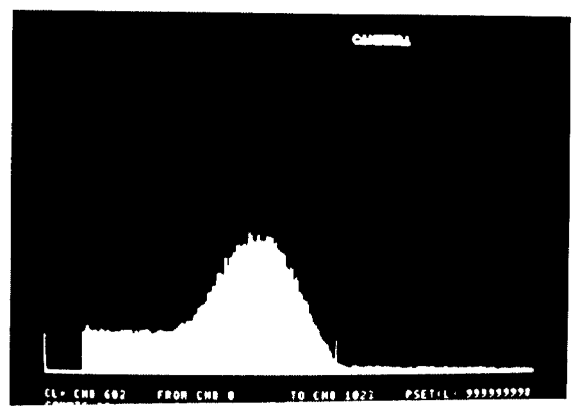

Figure 5 Energy spectrum of the X-ray from the RFQ cavity with the input RF power of 530 kW.

III. Alvarez linac

Figure 6 shows the inside view of the Alvarez tank. 28 drift tubes are supported by stems on a bottom plate that is demountable from the tank. The drift tube diameter and the bore radius are 55 mm and 5.0 mm, respectively. PMQs (Permanent magnetic quadrupoles) installed into the drift tubes. The bore radius is 5.5 mm and the magnetic field gradient is around 17.5 kG/cm. The magnet material is Nd-Fe-B (HITACHI METALS, Ltd.).

RF power from a klystron is coupled through a slot into the cavity. By using five block tuners of 10 cm diameter, (three of them are movable and others are fixed,) the longitudinal field variation is made flat and the resonance frequency is tuned to that of the RFQ cavity. The field distribution was measured with 5 pickups in the cavity in the same way as for the RFQ. The longitudinal field variation is within ±3 % after the tuning. The unloaded Q value is 40000, while SUPERFISH prediction is 52000.

The effective shunt impedance of the Alvarez linac estimated with a bead perturbation measurements is 100 MΩ and the required RF power is 330 kW. The RF conditioning was carried out in the same way as for the RFQ. After 15 hours RF conditioning, the RF peak power of 330 kW was successfully fed into the cavity. A main vacuum pump is a cryogenic pump having the pumping speed of 2100 l/s (H_2O) and the vacuum pressure was less than 7×10^{-7} torr at 35 °C.

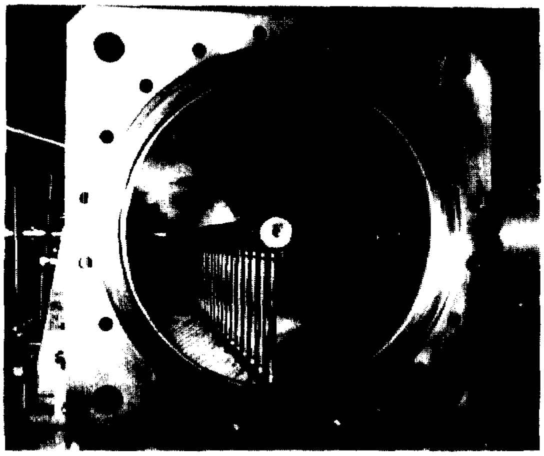

Figure 6 Inside view of the Alvarez tank

IV. Beam acceleration test

A multicusp ion source produces 50 kV proton beam. It is transported to the RFQ cavity through an Einzel lens, an triplet electrostatic quadrupole lens and a solenoid magnet.

The output beam of the RFQ linac is monitored by a Faraday cup at the exit of the tank. Figure 7 (a) shows the dependence of the output beam current on input RF power. No output beam current could be detected when the intervane voltage is about 80 % of designed value. It is consistent with the result of PARMTEQ simulation.

4 PMQs and a buncher are set in order to match the beam parameters to an acceptance of the Alvarez linac between the RFQ and Alvarez [7]. The PMQ is the same as used in the drift tubes of Alvarez linac. The buncher is a quarter wave resonator and now in construction. Beam tests were carried out without the buncher and the calculated reduction of the beam transmission rate is about 20 % due to the longitudinal mismatching.

Figure 8 shows the RF pulse shapes from pickup loops in the RFQ and Alvarez tanks and the 7 MeV output beam pulse. The dependence of the output beam current from the Alvarez on the input RF power is shown in Fig. 7 (b). Al foils with various thickness were set at the exit of the tank to evaluate the output beam energy and energy spread. The estimated output beam energy and energy spread were 7.0 MeV and ±0.2 MeV, respectively. We have confirmed the beam acceleration of the linac in the test and more detailed performance is being measured after beam matching elements installation.

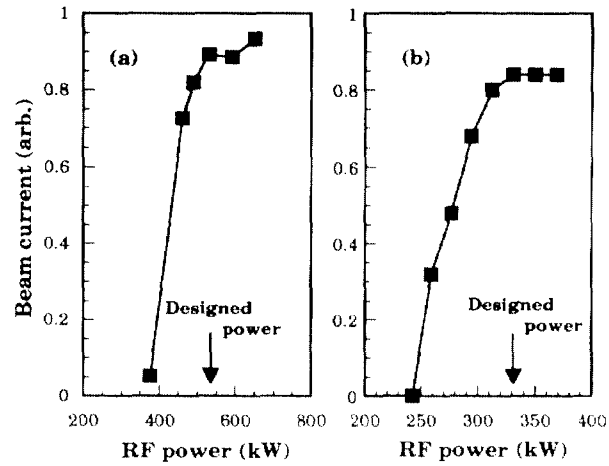

Figure 7 Input RF power dependence of the output beam currents from the RFQ (a) and Alvarez (b).

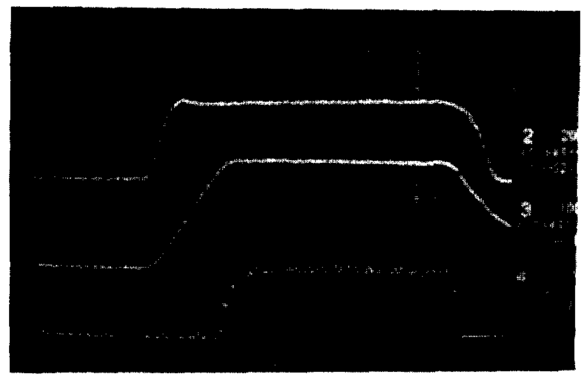

Figure 8 RF pulse shapes from pickup loops in the RFQ and Alvarez tank and the output beam from the Alvarez. (top to bottom).

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