Performance of the ICR 433 MHz RFQ Linac

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Abstract

In the 7 MeV proton linac at ICR, the RFQ linac is operated very stably and the beam transmission efficiency of 80 % is obtained. We have developed the compact beam analyzing magnet and the emittance monitor and measured the RFQ output beam. The unnormalized 90 % emittance is 42 π·mm·mrad and 30 π·mm·mrad on the x-plane and y-plane, respectively. The center energy of the output beam is 2.0 MeV and the energy spread is 80 keV FWHM.

I. Introduction

At Institute for Chemical Research (ICR), 7 MeV proton linac consisting of an RFQ and DTL (Alvarez) types, has been constructed [1]. The layout of the accelerator is shown in figure 1. It is operated at 60 µsec pulse width, 180 Hz repetition rate. The operating frequency of 433 MHz is chosen to be 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.

The proton beam is extracted from an ion source with multi-cusp magnetic field by the 50 kV extraction voltage. The 4-vane RFQ is the initial stage of the linac system. It is designed to accelerate the proton beam up to 2 MeV and inject it into the Alvarez linac. The main specification of the RFQ is shown in table 1.

Table 1. Main specification of the RFQ linac

Ion species	H^+
Input energy	50 keV
Output energy	2 MeV
Resonant frequency	433.0 MHz
Duty factor	1 % (maximum)
Vane length	2195 mm
Characteristic bore radius	3.0 mm
Minimum bore radius	2.0 mm
Intervane voltage	80 kV (1.8 Kilpatrick limit)

II. RF characteristics

To realize the flat field distribution in the cavity, 6 plug-tuners are installed in each quadrant [2]. The field distribution is measured by six pickup loops in each quadrant. The distribution was tuned under the low RF power condition. The field distribution in the RFQ cavity is shown in figure 2. The normalized field unbalance between quadrants is within ±2.5 % and the field deviation in the cavity is within ±6.0 %. The un-

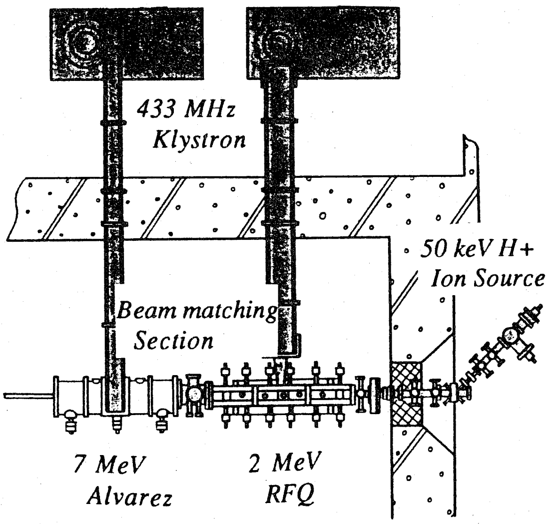

Figure 1. Layout of the accelerator system.

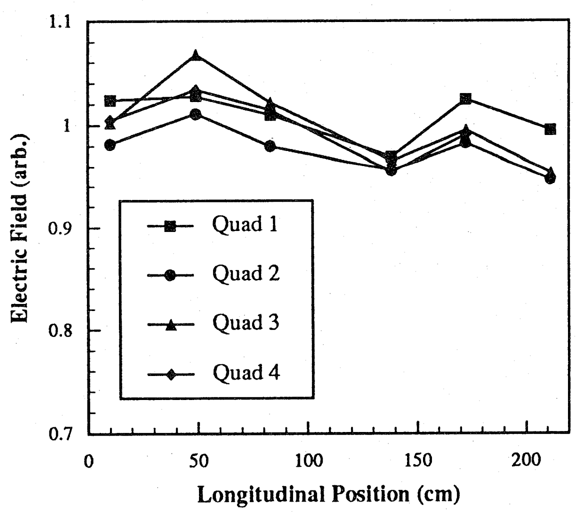

Figure 2. Relative field distribution in the RFQ cavity

loaded Q value is 5100.

The RF high power is delivered from the klystron (Litton, L-5773) through the waveguide (WR2100) and coupled into the cavity by a drive loop. The designed vane voltage is 80 kV (1.8 Kilpatrick limit) and the required RF peak power is 540 kW. We succeeded in feeding the 670 kW stably after the RF conditioning. The vane voltage is the 2.0 times of the Kilpatrick limit. The degree of vacuum is less than 2.0×10^{-6} Torr with the RF high power at the accelerator temperature of 35 °C.

The change of the field distribution is not found even if the input RF power level and the duty factor vary. The resonant frequency shift is observed as a function of the input RF power level. The frequency shift is 6 kHz at the 5.4 kW average input power. It is within a tunable range for the linac operation.

III. Beam measurements

The beam transmission efficiency of the RFQ is about 80 % at the designed RF power. It is supposed that the much of the beam loss is caused by the mismatching at the beam injection. The transverse emittance and the energy spectrum of the RFQ output beam were measured at the beam matching section between the RFQ and the Alvarez cavity. The beam current was low for the measurements, usually about 200 μA.

3-1 Transverse emittance

The emittance monitor consists of a fluorescent screen (Desmarquest, AF995R) and movable slits. A schematic diagram of the monitor is shown in figure 3 [3]. The x-slit and y-slit define the transverse position and the transverse spread of the beam is measured by the screen that is located at the downstream of the slits. Because of the high position sensitivity of the screen, we can get the high resolution of the transverse momentum. The distance between the slits and the screen is 315 mm. The resolution is 0.5 mm for the position and 1 mrad for the angle. The screen can be also used for the profile monitor without slits.

The fluorescent material is an alumina ceramic (99.5 % - Al_2O_3) in which a little chromium oxide is homogeneously doped. The fluorescence is observed by a CCD camera (PULNIX model TM720) which is placed 80 cm away from the axis. The γ value of the camera is set to be 1.0 and the shutter timing is synchronized to the pulse operation of the linac. The output signals from the CCD are digitized and stored by an image freezer. The digitized image is displayed on a TV monitor and transferred to a personal com-

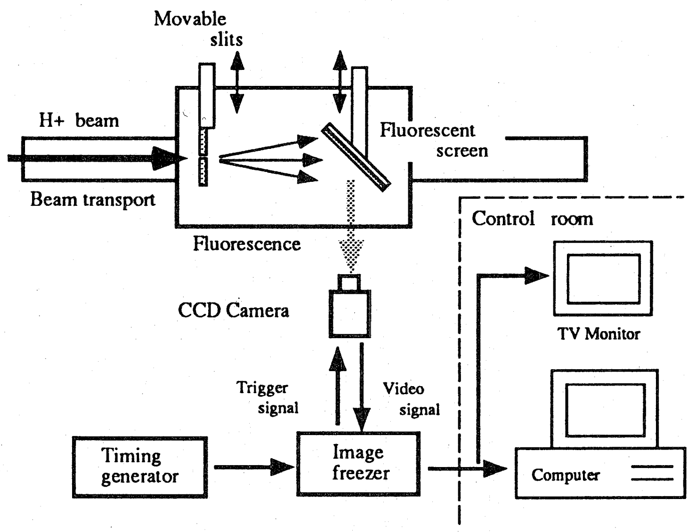

Figure 3. Schematic diagram of the beam emittance monitor system.

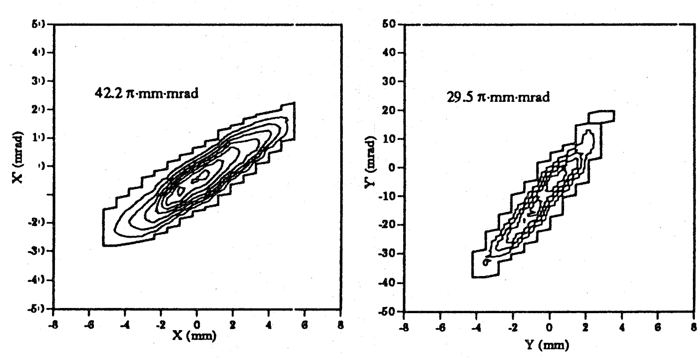

Figure 4. Measured unnormalized 90 % emittance of the RFQ output beam at the 540 kW input RF power.

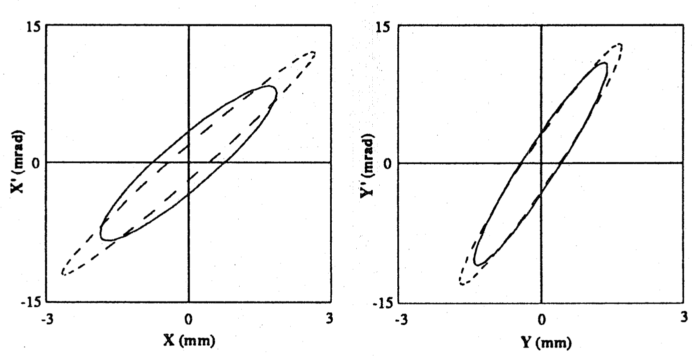

Figure 5. Comparison between the measured (solid line) and calculated (dotted line) unnormalized rms emittance.

puter. It calculates the beam profile and the emittance.

The measured unnormalized emittance are shown in figure 4. The emittance is for 90 % of the beam intensity and measured at 180 mm behind the vane end of the RFQ. The input RF power is 540 kW, which is the designed RF power. Figure 5 shows the comparison between the measured unnormalized rms emittance and the calculated one. The x-plane and y-plane rms emittance are 6.4 π·mm·mrad and 4.7 π·mm·mrad, respectively. The inclinations of the ellipse are well consistent in both figures but the x-plane emittance is larger than the simulation. The dependence of the emittance on the input RF power is within 5 % for the power level higher than the designed power.

3-2 Energy spectrum

A compact analyzing magnet was devised to measure the energy spread of the RFQ beam [4]. It can generate the magnetic field of 1 Tesla at 8 mm gap through the 100 mm length. The deflection angle is 30 degree. The beam is detected by the Faraday cup with collimator which is 210 mm away from the poles. The magnetic field is swept from 0 to 1 Tesla in 180 seconds and the energy spectrum is measured. The energy resolution is 20 keV at 2 MeV.

The measured energy spectrum is shown in figure 6 (a). Figure 6 (b) is a result of the PARMTEQ simulation. The input RF power is 540 kW. The center of the beam energy is just 2.0 MeV. The FWHM of the energy spread is 80 keV.

IV. Summary

We can operate the RFQ linac at the designed RF power very stably. The field deviation in the cavity is ±6.0 % and the beam transmission efficiency is about 80 %. We have developed the compact analyzing magnet and the emittance monitor using the fluorescent screen. The output beam of the RFQ was measured by the devices.

The matching elements between RFQ and Alvarez linacs have been improved based on the measurement results. They consists of the 4 permanent magnetic quadrupole lenses and the quarter wave-length resonator buncher [5]. The beam test of the linac system with the matching elements has been performed and the improvement of the low energy beam transport is scheduled.

V. References

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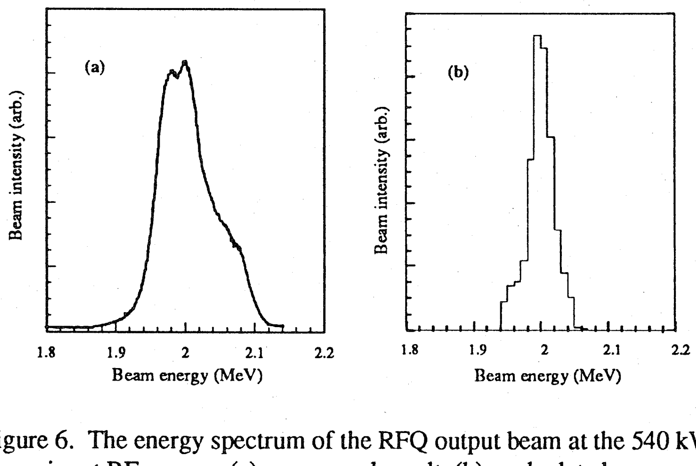

Figure 6. The energy spectrum of the RFQ output beam at the 540 kW input RF power. (a) : measured result, (b) : calculated one.