EMITTANCE MEASUREMENT AT THE ICR 7 MeV PROTON LINAC

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Abstract

At ICR, Kyoto University, an emittance monitor for beams from the DTL has been developed and installed in the beam line. With beam current of 0.6 mA, typical rms emittance for x direction is measured to be 4.5 πmm•mrad. Dependence of emittance on beam current and RF power fed to the DTL are measured. Beam distribution in phase space is found to be affected by the strength of the RF power fed to the DTL. The variation of emittance within the macro pulse is also measured and the beam distribution in phase space is found to have more complicated structure within the macro pulse than expected.

1. Introduction

At ICR (Institute for Chemical Research), Kyoto University, the 7 MeV proton linac which consists of an RFQ linac and a DTL has been operated since 1992[1] and it is now under improvement to get higher beam current[2][3].

In these days, acceleration of intense charged particle beams in a linear accelerator is of considerable interest for variety of application. Beam evolution in the high current linac is strongly affected by the nonlinearity caused from space charge forces and resulting emittance growth limits the quality of the output beams. Theoretical treatment of the effect in an actual machine is, however, quite difficult. So, it is important for practical purpose to measure the effect of beam current on emittance growth in an actual machine. The measurement also provides valuable information on the effect of space charge forces in view of beam dynamics' studies.

From that point of view, we have developed an emittance monitor for beams from the DTL and installed it in the beam line. Dependence of emittance on beam current and RF power fed to the DTL is measured. Variation of emittance within the macro pulse is also measured.

In this paper the main feature of the emittance monitor and the results of the recent measurements are presented.

2. Emittance monitor

We adopt the conventional two-slit method and modify it to measure the emittance of the pulsed beam with the duration and repetition rate of 50 µs and 18 ~180 Hz, respectively[4]. A schematic diagram of the emittance monitor is shown in Fig. 1 and its main specifications are shown in Table 1. The emittance monitor has front and rear slit and the beam passed through the two slits is collected by the beam collecting plate. This current is amplified by the current amplifier, held by the sample and hold circuit and led to 12 bit A/D converter. The measurements of the beam current are synchronized to the RF timing signal applied to the DTL with use of the sample and hold circuit. Changing the hold timing, we can measure the variation of emittance within the macro pulse.

The distance between front and rear slit is 1 m and the

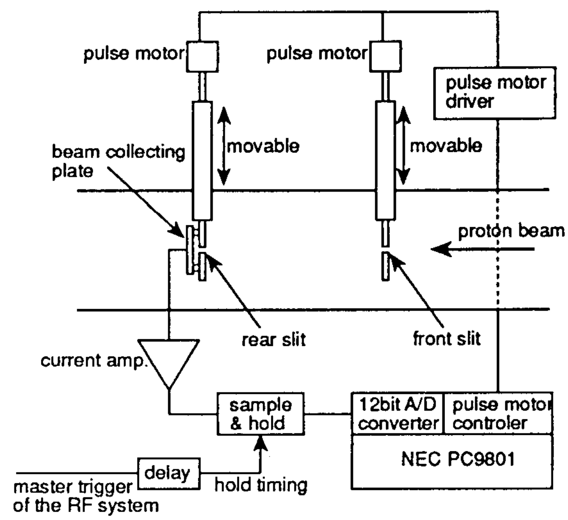

Fig. 1 A schematic diagram of the emittance monitor

slit width	0.2 mm
slit thickness	10 mm
distance between front and rear slit	1 m
resolution of position	0.2 mm
resolution of inclination angle	0.2 mrad
desplacement of slit	- 20 mm ~ + 80 mm (in steps of 0.2 mm)
measurement range	± 10 mm x ± 10 mrad
measurement time	5 min (1 mm x 1 mrad interval)

Table 1 Main specifications of the emittance monitor

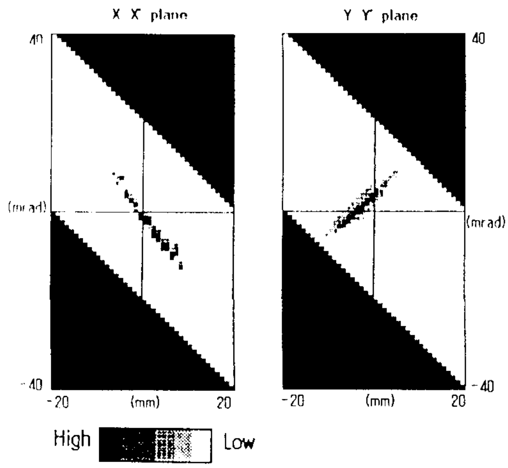

Fig. 2 An example of the contour plot in phase space (scanning all the measurable region)

widths and thicknesses of the collimating slits are 0.2 mm and 10 mm, respectively. These slits can be actuated in steps of 0.2 mm and their total displacement from the design orbit can be from -20 mm to + 80 mm. In this geometry, the maximum displacement and inclination angle of the beam to pass through the two slits is 20 mm and 40 mrad, respectively.

In the case of scanning the region of 10 mm x 10 mrad with 1 mm x 1 mrad intervals, it takes about 5 minutes to measure the contour plot of the beam intensity in the phase space and calculate rms emittance for both planes. In the case of scanning all the measurable region, it takes about 12 minutes. An example of the contour plot is shown in Fig. 2.

The accuracy of the measured emittance is mainly limited by the accuracy of the current measurement system. With beam current of 0.6 mA, we can measure the emittance with an accuracy of ± 1.0 πmm•mrad.

Two sets of the slits is installed in a vacuum chamber for x and y directions. The front slits for x and y directions are installed at positions of 1475 mm and 1325 mm downstream from the exit of the DTL, respectively.

3. Experimental setup

At ICR proton linac, output beam quality is strongly affected by the LEBT (low energy beam transport) parameters such as applied voltage on the electric quadrupoles and the Einzel lens. During the experiments, LEBT parameters are fixed to a set of values which enables us to accelerate relatively high current of beam.

Between the emittance monitor and the exit of the DTL a newly fabricated steering magnet and a quadrupole doublet are installed, and these magnets are used to steer the beam and get moderate focusing at the emittance monitor.

The emittance is measured scanning all the measurable region with 1 mm x 1 mrad intervals.

4. Measurement results

4. 1. Dependence on beam current

In our facility, improvements of the LEBT system to increase the beam current is now in progress[3], and beam current of 0.6 mA has been reached at the exit of the DTL. We examine the dependence of emittance on beam current and found that dependence of emittance on beam current is not apparent with beam current less than 0.6 mA. With beam current of 0.6 mA, rms emittance for x direction is measured to be 4.5 πmm•mrad.

While measuring the dependence of emittance on beam current, hold timing and RF power fed to the DTL is fixed to near the center of the macro pulse (In Fig. 4(a), the timing is shown as t_3) and the design value of 300 kW, respectively.

4. 2. Dependence on RF power

Dependence of emittance on RF power fed to the DTL is shown in Fig. 3. The figure tells us that emittance increases as the RF power is lowered, and at the same time, position of the beam centroid is shifted in phase space. These shifts can be explained by a displacement of the beam centroid at the entrance of the DTL. Beams having a displacement at the entrance of the DTL are evolved oscillating around the design orbit under an influence of the RF defocusing force. When the RF power fed to the DTL is lowered, RF defocusing force decreases and it causes the shifts of the betatron tune.

These results suggest that beam distribution in phase space may vary within the macro pulse without more careful adjustment of the MEBT (medium energy beam transport) and LEBT parameters. This subject is taken up in the next subsection.

While measuring the dependence of emittance on RF power fed to the DTL, hold timing and beam current is fixed to t_3 and 0.5 mA, respectively.

4. 3. Variation in the macro pulse

At ICR proton linac, beams have a macro pulse length of 50 μsec and RF power fed to the DTL vary within the pulse. Considering measured results of the previous subsection, this variation is expected to affect the beam distribution in phase space. From that point of view, we examine the variation of the emittance within the pulse changing the hold timing of the sample and hold circuit. Measured dependence of emittance on hold timing is shown in Fig. 4. In this figure, we can see a variation of emittance within the macro pulse. Though no apparent variation of the position of beam centroid is found, the variation of emittance is relatively large. So, it seems that the variation can not be explained only by the variation of the RF power within the pulse.

Because the current amplifier has a time constant of 6 μsec, measured emittance should be considered to be an averaged value over ± 3 μsec around the hold timing. So, it is difficult to examine the detailed structure with the current amplifier. We are now trying to shorten the time constant of the current ampli-

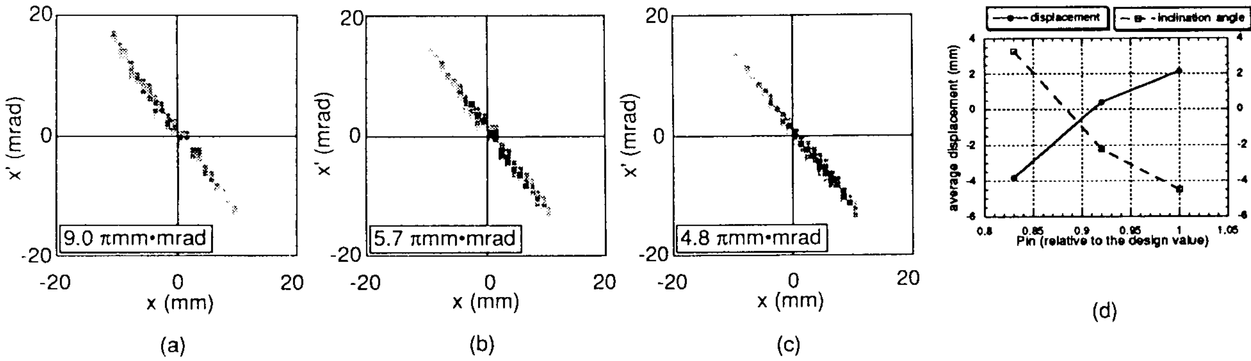

Fig. 3 Dependence of emittance on RF power fed to the DTL, P_{in}
(a) $P_{in} = 0.83$ (b) $P_{in} = 0.92$ (c) $P_{in} = 1.0$ (d) Position of the beam centroid in phase space
P_{in} is measured relative to the design value of 300 kW. In (a) ~ (c), rms emittance is shown in below left.

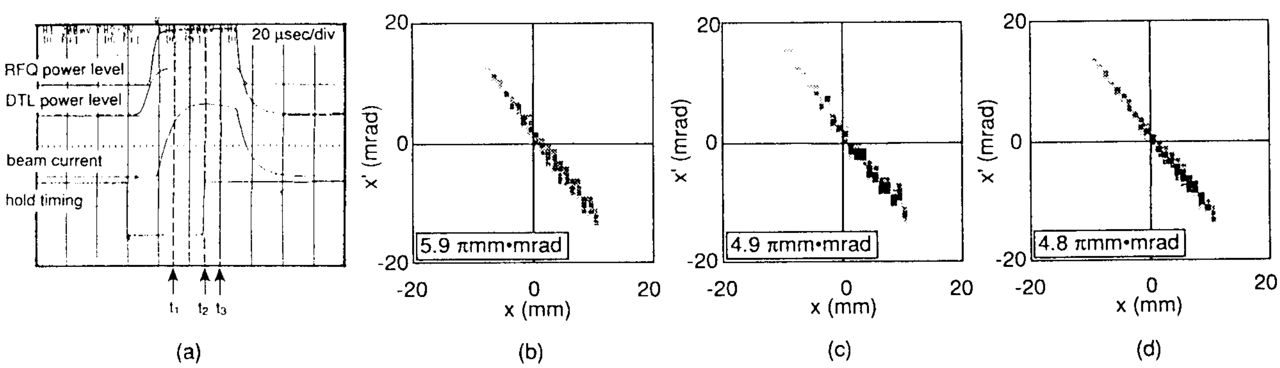

Fig. 4 Dependence of emittance on hold timing, t_h
(a) Difinition of $t_1 \sim t_3$ (b) $t_h = t_1$ (c) $t_h = t_2$ (d) $t_h = t_3$
In (b) ~ (d), rms emittance is shown in below left.

fier to measure the variation in better time resolution. More extensive measurements are needed to discuss quantitatively about the variation and understand the underlying physics of it.

While measuring the dependence of hold timing, beam current and RF power fed to the DTL is fixed to 0.5 mA and 300 kW, respectively.

5. Summary

We developed an emittance monitor for beams from the DTL. Dependence of the emittance on the beam current and other parameters is measured. Measurement results can be summarized as follows:

1) No current dependence of emittance is found with beam current less than 0.6 mA.

2) Beam distribution in phase space is found to have a dependence on the RF power fed to the DTL.

3) It is found that there is a variation of the beam distribution in phase space within the macro pulse.

In future experiments, we plan to measure the emittance growth in the linac quantitatively. For this purpose, we have a plan to develop an emittance monitor to measure the emittance at the entrance of the RFQ.

At ICR, the LEBT system is now under improvement to get higher beam current, and the experiments with beam current of more than 10 mA are expected to be performed in the near future.

References

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