DEVELOPMENT OF AN APPARATUS FOR MEASURING TRANSVERSE PHASE-SPACE ACCEPTANCE

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Abstract

An apparatus for transverse acceptance measurement has been developed in JAEA cyclotron facility. The apparatus consists of a phase-space collimator in the injection beam line and a beam current monitor after the cyclotron. The collimator consists of two pairs of position-defining slits and angle-defining slits to inject an arbitrarily small portion of transverse phase-space into the cyclotron. Measurement of the acceptance is made by injecting every portion in the whole phase-space which should be large enough to cover the acceptance. The acceptance can be estimated from the sum of the portions of the beam which pass through the system. The beam is measured by an uncooled Faraday cup or a scintillator because of the low beam current from a few picoampere to a few hundred picoampere in HEBT for acceptance measurement.

INTRODUCTION

A high-energy heavy ion microbeam project [1] has been proceeding in the cyclotron (K=110) facility at the ion beam irradiation research facility, TIARA (Takasaki Ion accelerators for Advanced Radiation Applications) for detailed analyses of biological cells [2], finely-structured semiconductor devices [3], etc.

Figure 1 shows a beam focusing system at the end of the high energy beam transport line (HEBT) for microbeam production. An accelerated beam is bent down to the vertical beam line by the 90 degrees dipole magnet. The beam emittance is collimated by two pairs of slits. The first pair of micro slits (their gap is a few micrometers) determines the object size of the beam, and the second pair of slits (their gap is a few hundred micrometers) defines divergence of the beam. The quadruplet quadrupole magnets focus the beam to the order of micrometer.

A beam with high brightness is required for the microbeam production because a beam only with very small emittance passes through the microbeam line. It is important to transport the high brightness region extracted from an ion source to the end of the microbeam line.

In addition to this, in normal operations it is required to reduce beam loss in the cyclotron to achieve higher transmission efficiency.

To satisfy these requirements, it is essential to match the injection beam emittance to the acceptance of the accelerator system. To improve the matching, measurement and evaluation of the matching between the emittance and the acceptance is needed. We are developing an apparatus for evaluating the transverse matching. In this paper, the apparatus for transverse acceptance measurement is reported.

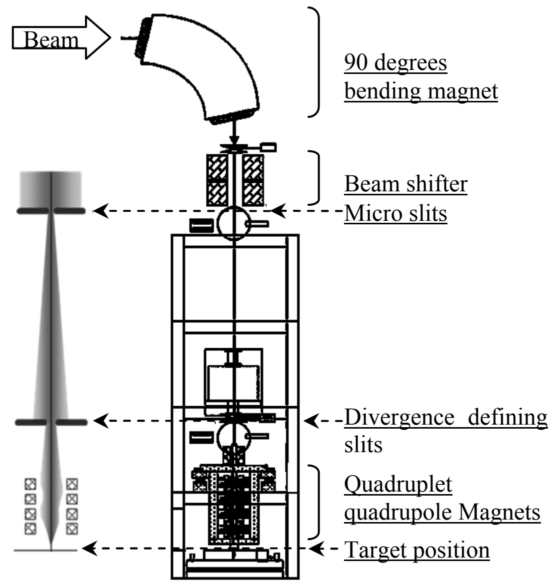

Figure1: Schematic view of microbeam system on the vertical beam line in high energy beam transport line.

APPARATUS FOR MEASURING TRANSVERSE PHASE-SPACE ACCEPTANCE

The acceptance is an area in phase space which is able to pass thorough accelerator components and/or transport lines. Various kinds of acceptances can be defined; an acceptance from inflector entrance to deflector exit in an AVF cyclotron, acceptance from one place in the low energy beam transport line (LEBT) to another in HEBT, etc.

Measurement of the acceptance is made by injecting every portion in the whole phase-space which should large enough to cover the acceptance. The acceptance can be estimated from the sum of the portions of the beam which pass through the system. Figure 2 shows the concept of a transverse acceptance measurement system. Arbitrary small portions in the phase space restricted by

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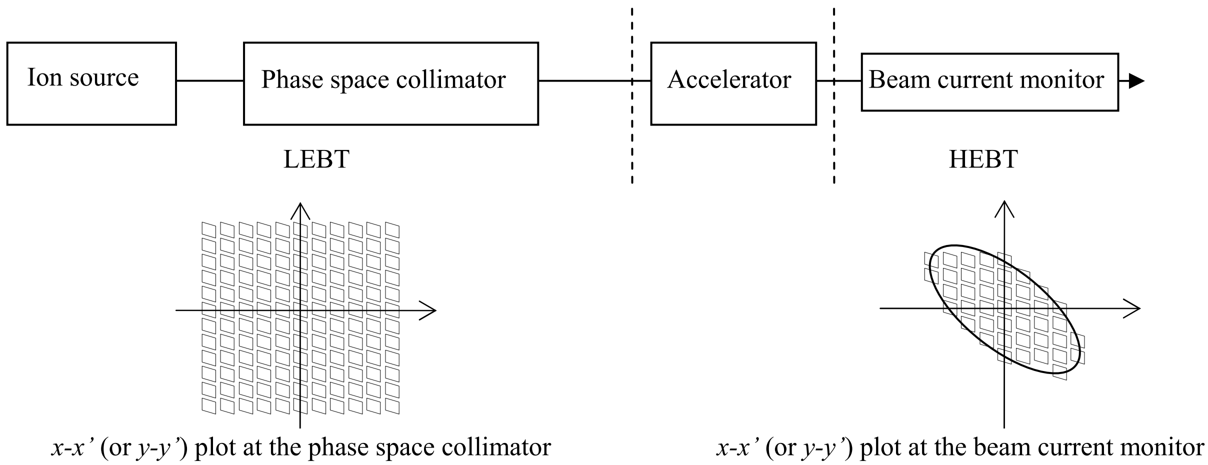

Figure 2: Concept of a transverse acceptance measurement system.

the phase space collimator in the LEBT are injected to an accelerator. The detector in the HEBT determines which portion can pass through the accelerator and the transport line. The acceptance from the phase space collimator to an arbitrary position is measured by the detector set at the position.

Phase Space Collimator

The phase space collimator consists of two pairs of position defining slits and angle defining slits. One pair collimates an area in the horizontal (*x-x'*) plane and another collimates in the vertical (*y-y'*) plane. Figure 3 shows the conceptual figure of the phase space collimator and an example of its defined phase-space area.

The position-defining slit limits a beam to a certain position range. The subsequent angle defining slit limits the range of the beam divergence angle. The position and the opening of each slit gap can be varied according to the area and areal resolution of the phase space for the acceptance to be measured respectively.

The simultaneous inequality (1) shows the coordinate (*x, x'*) confined in a parallelogram area in transverse two dimensional phase space which is limited by the phase space collimator.

$$\begin{cases} x_p - \dfrac{w_p}{2} \le x \le x_p + \dfrac{w_p}{2} \\ \dfrac{-x + x_d - \dfrac{w_d}{2}}{L} \le x' \le \dfrac{-x + x_d + \dfrac{w_d}{2}}{L} \end{cases} \qquad (1)$$

x_p: the center of the position defining slit gap
w_p: the opening of the position defining slit gap
x_d: the center of the angle defining slit gap
w_d: the opening of the angle defining slit gap
x: x-coordinate at the position defining slit
L: the distance between position and angle slit

The whole acceptance should be overlapped with the beam emittance, which can be enlarged effectively by means of beam steering just before the collimator.

The phase space collimator installed in the LEBT of JAEA cyclotron and the designed phase space distribution of the beam at the phase space collimator is shown in Figs. 4 and 5 respectively. The beam is oblate ellipsoid in phase space at the phase space collimator and; therefore, the beam has a large diameter (about 100mm) and a small divergence angle (about ±10mrad).

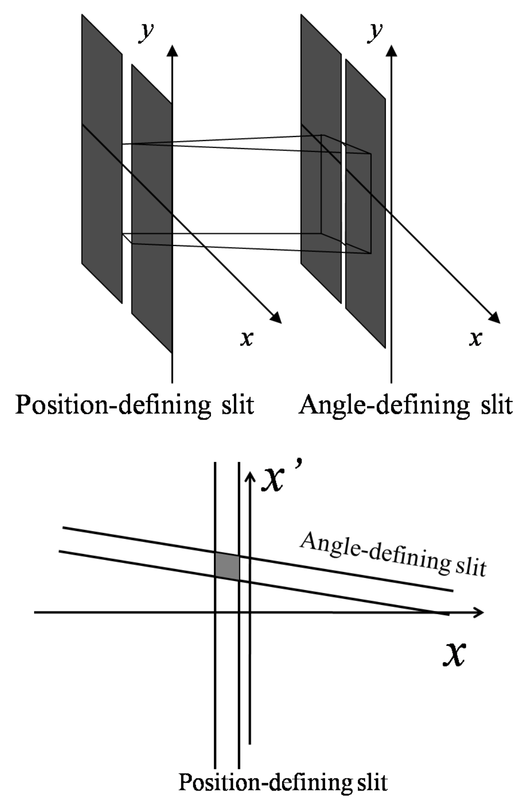

Figure 3: Conceptual figure of phase space collimation.

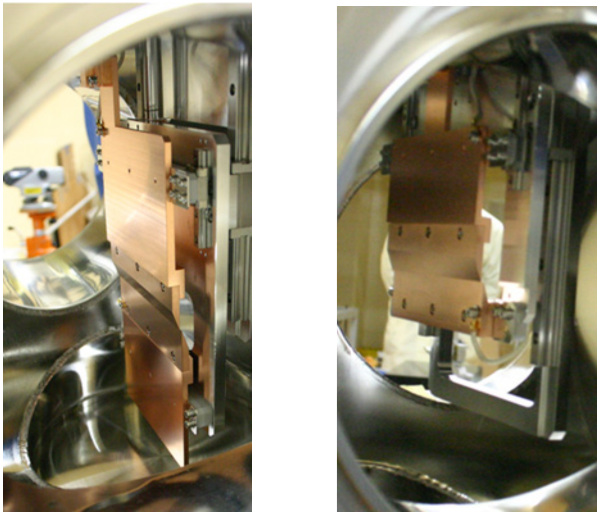

Figure 4: The phase space collimator for y direction: position-defining slit (left), angle-defining slit (right)

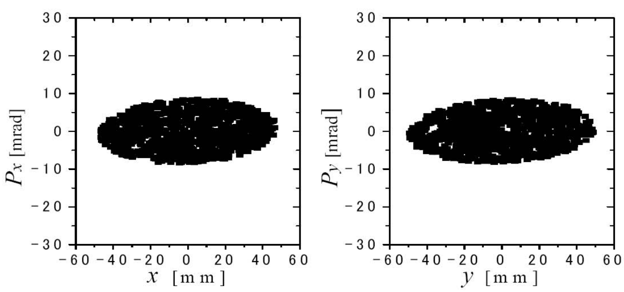

Figure 5: The designed phase space distributions at the phase space collimator.

Beam Current Monitor

The beam current passing through the phase space collimator is estimated to be a few picoampere to a few hundred picoampere. Our water-cooling Faraday cups in HEBT, however, cannot measure the beam current below 1 nA because its noise level is about 1 nA. Uncooled Faraday cups or scintillators are used as beam current monitors.

In the case of using a scintillator, the beam intensity is measured by analysing the height of the pile-up pulse which is amplified by a photomultiplier. Figure 6 shows an example of the pulse train. A preliminary experiment with a160 MeV $^{16}O^{6+}$ beam showed a beam current of the order of from a few picoampere to a hundred picoampere was successfully measured.

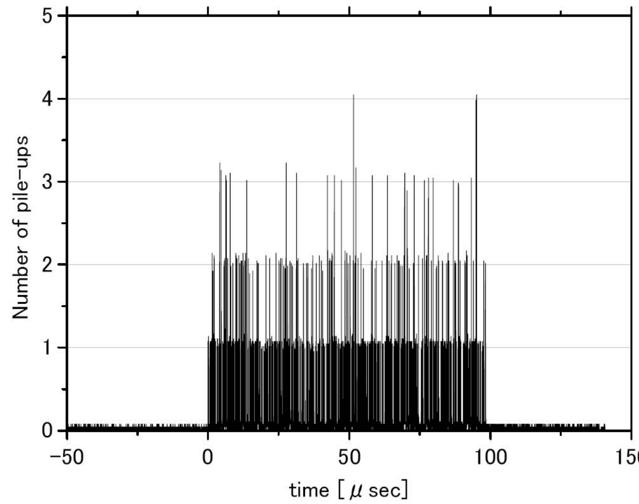

Figure 6: An example of pile-up pulse train.

SUMMARY AND FURTHER WORK

The apparatus have been developed to measure transverse acceptance. The phase space collimator has been installed in the LEBT at the JAEA AVF cyclotron and the beam current monitor using a scintillator has been confirmed to be able to measure beam current with a range from a few picoampere to a hundred picoampere.

The apparatus will be used to measure beam matching combined with an emittance monitor. With beam manipulation in phase space, the better matching will be achieved. This will be applied to transport a higher brightness beam to the end of the microbeam line and to reduce a beam loss in the cyclotron.

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