# TRANSVERSE-ACCEPTANCE MEASUREMENT SYSTEM FOR JAEA AVF CYCLOTRON

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*Abstract*

We are developing an acceptance measurement system to evaluate the matching of the emittance of an injection beam to the acceptance of the AVF cyclotron. The system is composed of a phase-space collimator in the low energy section and beam intensity monitors which are installed just after the phase space collimator and in the high energy section. The phase-space collimator, which consists of two pairs of movable slits, is used to inject beams with very small-emittance into the cyclotron by defining position and divergence angle of the beam from an ion source. The acceptance is measured as the phase space distribution of the ratio of the beam intensity at the high energy section to that at the phase space collimator. In the preliminary test, only a part of distribution for the acceptance was measured because the injection-beam emittance from an ion source did not cover the whole acceptance. A steering magnet has been added to expand measurable area by scanning the injection beam in synchronization with the acceptance measurement. The result of a test experiment showed the emittance of the injection beam was able to be enlarged more than ten times. It was confirmed that this technique was valid as the method of increasing the injection emittance for measuring the whole of the acceptance.

## INTRODUCTION

The JAEA AVF cyclotron in TIARA (Takasaki Ion accelerators for Advanced Radiation Application) produces various kinds of ion beams from 10 MeV $H^+$ to 490 MeV $^{192}Os^{30+}$ for research in biotechnology and materials sciences. The ion species and/or energy of the beam are changed frequently (223 times a year in 2011 [1]). Since the operating parameters of the cyclotron vary according to the kind of beam, the parameters need to be optimized for each beam to be accelerated and be delivered to the target port with minimum beam loss.

Regarding the optimization of the beam injection to the cyclotron, it is required for the beam emittance to be matched to the acceptance of the cyclotron. A part of the injected beam outside the acceptance is lost in the cyclotron. The condition of the injection in longitudinal direction is determined mainly by the voltage and phase of a buncher. The optimization procedure has been established [2]. As for the condition of the injection in the transverse direction, parameters of the magnets in the low energy beam transport line are fine-tuned manually by monitoring the accelerated beam current. However, it is not easy to assess optimum condition because various parameters are mutually related and the acceptance is not precisely known.

We are developing a transverse acceptance measurement system to evaluate the state of the beam injection. The system will help to optimize the injection condition in the transverse direction.

This paper shows the outline of the measurement system and a preliminary measurement test. In addition the enlargement of the effective emittance of the injection beam for expansion of the measurable area that is currently under developing is described.

## SYSTEM FOR TRANSEVERSE-ACCEPTANCE MEASUREMENT

The system for transverse acceptance measurement is shown schematically in Fig. 1. The main components of the system are the phase-space collimator in the low energy beam transport line and the intensity monitors in the high energy section. One of the monitors is selected depending on the position where the acceptance is measured. To measure the acceptance for accelerating and transporting the beam to the deflector entrance in the cyclotron, for example, a current monitor inside the cyclotron is used, while in the case of acceptance to the outside of the cyclotron a Faraday cup in the high energy beam transport line is used.

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 passes through the system.

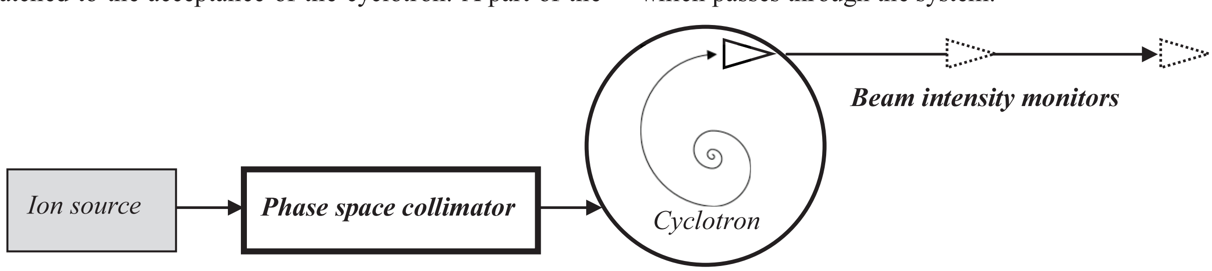


Figure 1: The system for transverse acceptance measurement.

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### *Phase Space Collimator*

The phase space collimator, which limits the incident beam to an arbitrary small area in the horizontal or vertical phase plane, is used to inject a small portion of the beam into the cyclotron. It consists of two pairs of position defining slits and angle defining slits. One pair is used to limit the beam in the horizontal (*x-x'*) plane and another in the vertical (*y-y'*) plane. The slit is formed by a pair of metal blades. The position and width of each slit are variable by stepper motors which control the positions of each blade. Figure 2 shows an example of defined phase-space area with one pair of slit. The main specification of the phase space collimator is shown in the table 1.

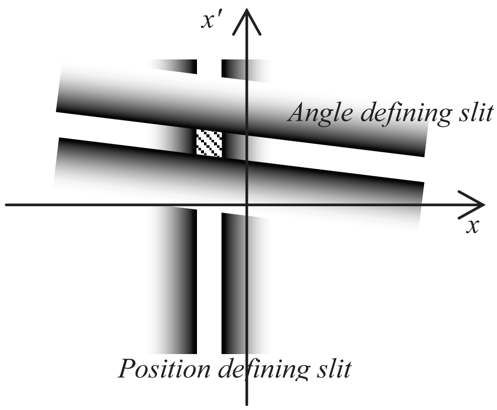


Figure 2: Example of the region defined with the slits of the phase space collimator (shaded region).

Table 1: Main specification of the phase space collimator

| | |
|---|---|
| **Position defining slit** | |
| Position range of the slit center (Measurement range of *x* and *y*) | ±60 mm |
| Slit width | 0.1 mm ～ 4 mm |
| **Divergence defining slit** | |
| Position range of the slit center | ±77 mm |
| (Measurement range of *x'* and *y'* | ±25 mrad) |
| Slit width | 0.1 mm ～ 30 mm |
| (Minimum resolution of *x'* and *y'* | 0.15 mrad) |

### *Beam Intensity Monitor*

Acceptance is evaluated from the beam relative transmission efficiency distribution, which is the ratio distribution in a phase plane between beam distribution at a beam intensity monitor in high energy section and injected beam distribution to the cyclotron from the phase space collimator. Therefore the absolute beam current value is not essential and relative value is adequate. The current value is expected to be the order of nano- or pico-ampares which depends on slit width. To detect the current, Faraday cups which measure absolute current value, simple metal plates for relative current value including emitted current of secondary electron or scintillation counters which measure number of particles are used.

### *Measurement Procedures*

In acceptance measurement, small-emittance beams at various positions in a transverse phase-plane are injected into the cyclotron by scanning the positions of the slits of phase space collimator. As shown in Fig. 3, for example, in the case of a measurement in the rectangle area ($-p \le x \le p$ , $-q \le x' \le q$), the measurement procedures are as follows : 1) the center of the position defining slit and the angle slit is moved to $-p$ and $-q$ respectively, 2) beam intensity is measured continuously as moving the angle defining slit from $-q$ to $q$ keeping the position defining slit at $p$, 3) the position slit and angle slit is moved to position of $p + d$, $q$ by being shifted $d$ in the positive $x$ direction 4) beam intensity is measured continuously as moving the angle defining slit from $q$ to $-q$ keeping the position defining slit at $p+d$, and these procedures are repeated until the slit position reaches $p$. This measurement is performed twice to determine the distribution of the injected beam ($D_i(x,x')$) and the distribution of the beam which reaches a location of the current monitor at high energy section ($D_h(x,x')$). The $D_i(x,x')$ and $D_h(x,x')$ are determined using a current detecting devise just after the phase space collimator and inside or after the cyclotron respectively. The acceptance is obtained by the ratio $D_h(x,x')$/ $D_i(x,x')$

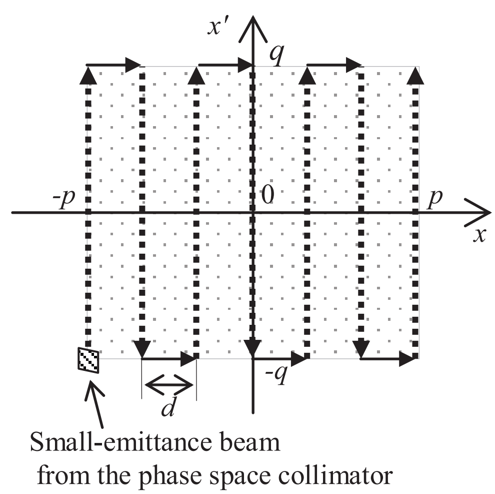


Figure 3: The method of scanning the small emittance beam in a phase plane by the phase space collimator.

## PRELIMINARY MEASUREMENT TEST

A preliminary measurement test was performed using the $^{16}O^{6+}$ beam extracted with the energy of 50.2 keV from a 14.5 GHz ECR ion source. The beam was

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accelerated to 160 MeV and transported to one of the irradiation courses for heavy ion beam (HA course).

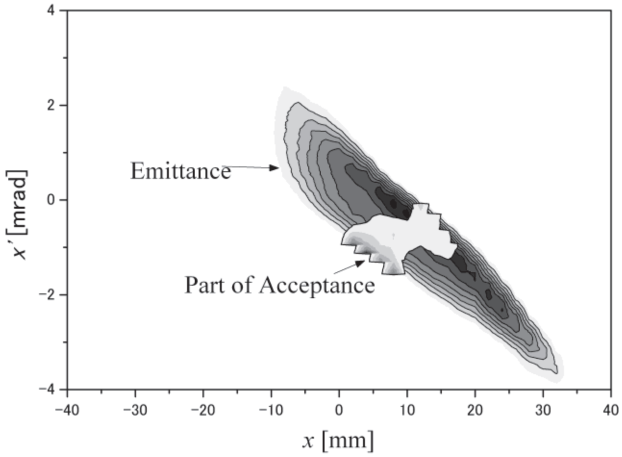


Figure 4: Measured acceptance and emittance.

The beam emittance at the phase space collimator was measured by a metal plate just after the collimator. For the acceptance measurement, a Faraday cup in the HA course was used. Therefore the acceptance for accelerating and transporting the beam from the phase space collimator to the Faraday cup was obtained in the experiment. The measured emittance and acceptance in *x*-*x'* phase planes are shown in Fig. 4. The whole acceptance was not measured because the injection-beam emittance from the ion source did not cover the whole acceptance.

## EXPANSION OF EFFECTIVE EMITTANCE

To measure the whole acceptance, the emittance of the injection beam needs to be so large as to cover the acceptance. A steering magnet just before the phase space collimator has been added to the system to manipulate the injection beam in *x'* and *y'* direction. The expansion of the emittance is made by scanning the injection beam with the steering magnet in synchronization with the acceptance measurement.

Figure 5 shows the beam emittance from the ion source and the result of the effective emittance enlargement. The effective emittance of the scanned beam was more than ten times larger than the original one despite several unsynchronized region that are found as the white quadrangles. It was confirmed that this technique was valid as the method of increasing the injection emittance for measuring the whole acceptance

## SUMMARY

The system for measuring transverse-acceptance has been developed. The acceptance is measured as the phase space distribution of the ratio of the beam intensity at the high energy section to that at the phase space collimator. The steering magnet which scans the injection beam has been added to the system to increase the effective emittance of the injection beam. The validity of the technique for expanding measurable area was confirmed using the newly added steering magnet.

## REFERENCES

[1] S. Okumura et al., "Operation of the AVF Cyclotron", JAEA Takasaki Annual Report (2011), in press
[2] S. Kurashima et al., "Useful technique for analysis and control of the acceleration beam phase in the azimuthally varying field cyclotron Rev. Sci. Instrum. 81, 033306 (2010)

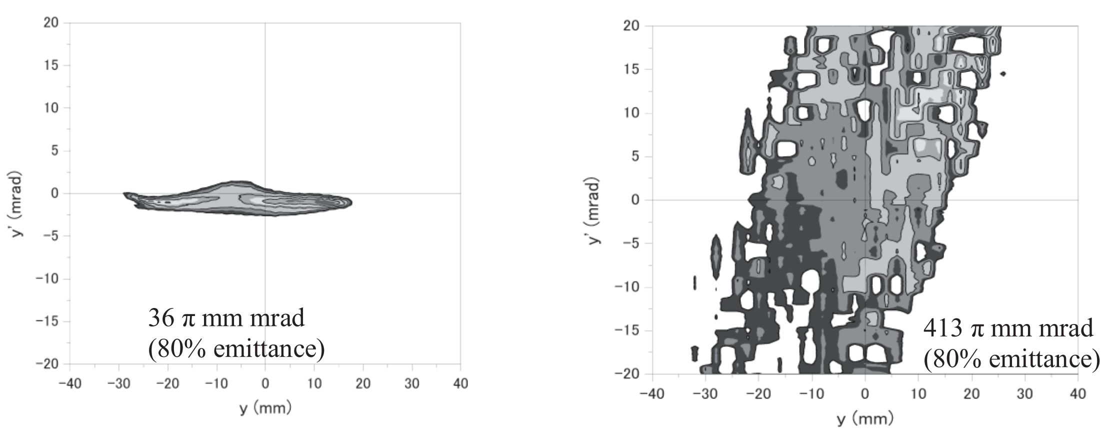


Figure 5: Original beam emittance from the ion source (left) and the enlarged effective emittance by the steering magnet (right).

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