INSTRUMENTATION FOR MEASUREMENT OF BEAM ENERGY SPREAD

Susumu Okumura, Nobumasa Miyawaki, Satoshi Kurashima, Kenichi Yoshida, Mituhiro Fukuda,
Ikuo Ishibori, Takashi Agematsu, Takayuki Nara, Yoshiteru Nakamura, and Kazuo Arakawa,
JAERI, Takasaki, Japan

Abstract

A simple analyzing system has been developed to measure the energy spread of the beam extracted from the JAERI AVF cyclotron with an energy resolution of $\Delta E/E = 0.001\%$. The high analyzing power can be obtained with an existing deflecting magnet system in the transport line by installing three sets of slits with a minimum width of 0.01 mm and a beam intensity monitor with a Faraday cup and semiconductor detectors. These new instruments have been compactly designed to fulfil the geometrical condition of the existing beam diagnostic stations, which are located at the object and image positions. Installation of the new instruments was completed and a preliminary test has been carried out. This system will be used for optimization of the flat-top acceleration to achieve the energy spread of $\Delta E/E = 0.02\%$, required for microbeam production.

INTRODUCTION

A microbeam production using the JAERI AVF cyclotron beam is in progress for research in biotechnology and materials science [1]. A beam focusing system with quadrupole magnets has been adopted for the microbeam production. The energy spread of the beam less than 2×10^{-4} is required for the beam size of 1 μm in diameter, which beam size is especially desired for precise irradiation in biological experiment. A flat-top acceleration system [2] has been installed to the JAERI AVF cyclotron for reduction of the energy spread of the beam. In order to confirm reduction of the energy spread of the extracted beam, we have developed a simple analyzing system using the disperse power of an existing deflecting magnet system in the transport line. The new instruments have been installed to the existing beam diagnostic stations, which are located at the object and image positions of the deflecting magnet system.

PRINCIPLE OF MEASUREMENT

The beam energy spread can be determined by measuring the beam size at the image of the deflecting magnet system. Higher momentum resolution can be obtained by decreasing the slit width since the momentum resolution is determined by the slit width at the object and the image [3].

The momentum resolution can be calculated in the first-order approximation

$Si = M\ So$,

$R = D/Si$,

where So and Si are the slit widths at the object and the image, respectively. M is the magnification, D is the dispersion and R is the momentum resolution $p/\Delta p$.

In order to obtain a momentum resolution $R = 2 \times 10^5$ ($\Delta E/E = 0.001\%$), a slit width of $So = Si = 0.01$ mm is required in the normal condition of the deflecting magnet system: $M = 1$, $D = 2\text{mm}/(1 \times 10^{-3})$.

The intensity distribution of the dispersed beam can be obtained by scanning the position of the slit at the image and detecting the beam passed through the slit. In order to detect low intensity beam, which reduced by the extremely narrow slits, a particle detector has to be used.

MEASUREMENT SYSTEM

Beam transport line

A portion of the beam transport line of the JAERI AVF cyclotron with the deflecting magnet system is shown in Fig. 1. The beam extracted from the cyclotron, which is focused at the beam diagnostic station CS0, is bended with the deflecting magnet to the direction of the switching magnet. The beam, which is not bended, is transported to the experimental room for radioisotope production.

The beam diagnostic stations, TS1 and TS2, are located at the object and the image points of the deflecting magnet system, respectively. Beam instruments, such as a Faraday cup, are mounted on the stations by using the standardized ports (TS1: 152 mm O.D., TS2: 203 mm O.D.). The beam energy can be evaluated from the magnetic field of the deflecting magnet, which is measured with an NMR magnetometer.

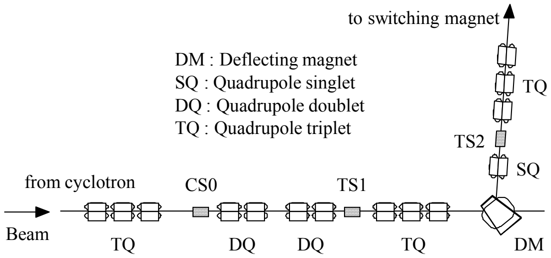

Figure 1 : Beam transport line of the JAERI AVF

Analyzing system for energy spread measurement

Two sets of normal slits, which can limit the beam size for horizontal and vertical directions, were mounted on each station, TS1 and TS2. Each slit has a set of tips, which is made of copper of a thickness of 12 mm with a rectangular shape. The position of the tips can be controlled independently with a motor by counting the driving pulse. It is difficult to achieve a small slit width less than 0.1 mm by the normal slit system.

In order to achieve the desired energy resolution of $\Delta E/E = 0.001\%$, a slit width 0.01 mm is needed. Therefore, we have developed new slits with a precise width control. Although the stations, TS1 and TS2, have to be equipped with new instruments, such as the new slits, there is no space for installation. By reducing the occupied ports from two to one for the viewing monitor at TS1 and by abandoning the use of the normal slits at TS2, one port at TS1 and two ports at TS2 were prepared for new installation.

In the station TS1, the beam, which is previously restricted with the normal slits, passes through the new slit and is restricted the divergence with another new slit for reduction of higher order effect. The beam, which is dispersed in the deflecting magnet system and passes through the new slit, is detected by a beam intensity monitor with a semiconductor detector in the station TS2.

We have designed new instruments under the restricted condition, such as space limitation. In case of the station TS1, two sets of slits have to be mounted on a port. The two slits were designed to be integrated on the same base platform and to be spaced with a distance of 50 mm for achievement of desired divergence limitation. Only the slit tips for divergence restriction can be controlled with a motor. In case of the station TS2, only a slit (the image slit shown in Fig. 2) is mounted on the base platform. Each base platform can be moved with a motor to adjust the slit gap position relative to the beam.

The two slit tips are driven independently to adjust the width and the position of the slit. The slit tip of a tungsten-carbide cylinder with a 4 mm diameter, which is widely used in microprobe systems for ion beams, is applied to all slits in order to obtain extremely low roughness of the tip surface and to reduce scattered particles. The tip is clamped with a aluminum holder and mounted on the one end of a rod. Since the tip position has to be adjusted from the outside of the station, the rod length of 350 mm is needed. Therefore, we chose a rod made of Invar, which has a low thermal expansion coefficient (5×10^{-7} / C°). The rod is supported at two points on the support block and is extended to the atmosphere side through the O-rings for vacuum seal. The micrometer head is connected to the other end of the rod to adjust the position of the slit tip relative to the base platform. In order to produce a repulsion force against the micrometer head, a spring is attached to the rod. For the divergence slit, a micrometer head is mounted on a motor-controlled linear guide to adjust the position of the slit tip relative to another slit remotely.

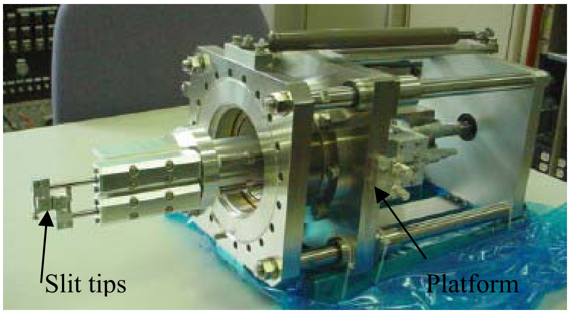

Figure 2: Image slit for the station TS2.

The beam intensity monitor (Fig. 3) for detection of a low intensity beam was installed just behind the image slit in the station TS2. In order to cover a wide range of the intensity, which is required in the development process, two kinds of detectors, a Faraday cup and two semiconductor detectors, were installed. These detectors are mounted on a holder and aligned with the direction of the movement for changing the detector.

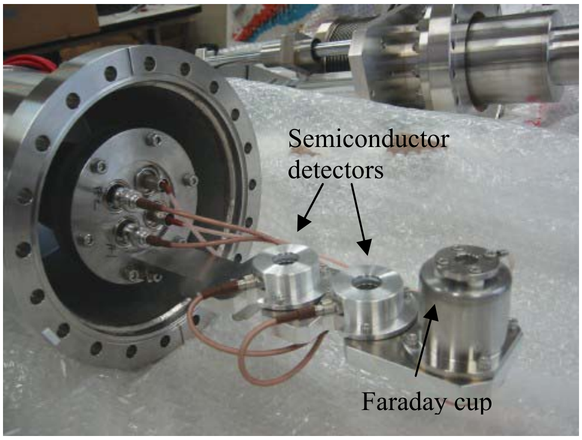

Figure 3: Beam intensity monitor for the station TS2.

SLIT WIDTH MEASUREMENT

Practically, the surface positions might be changed by a thermal expansion induced by a heat load of the beam. In order to investigate the temperature dependence, the slit width was measured in a simulated condition, in vacuum and under heat load.

Measuring method

A laser scan micrometer (LSM-500H, Mitsutoyo) was applied to measure the slit width with a precision of 0.001 mm. A laser scan micrometer can measure the thickness of an object and the opening between objects by scanning the laser and detecting the transmitted laser. In case of this micrometer, the object size under testing is limited within the acceptable space of 34 mm. We prepared a small chamber in order to measure the slit width in vacuum with the micrometer. In order to match the required condition for the micrometer, the chamber has a protruded part, which covers the slit tips with a minimum space and has two windows on the both sides for laser transmission. A feedthrough flange was mounted on the chamber for measuring the slit temperature with platinum resistance thermometers and producing a heat load with heating elements. The thermometers and the heating elements were fixed on the aluminum holders of the slit tips.

Results

We measured the slit width in two heating conditions. One condition is heating only one slit tip, which is located near side to the base platform. In this case, the slit width is reduced when the rod or the aluminum holder extends. Figure 4 shows the temperature dependence of the slit width. The temperature coefficient of the slit width calculated from the slope of the fitted line was - 0.00026 mm / C°. Another condition is heating both slit tips with the same temperature. In case of the slit tip located far side to the base platform, the extension of the rod increases the slit width and the one of the aluminum holder reduces the slit width. The temperature coefficient of the slit width was - 0.00042 mm / C° (Fig. 5). This result indicates that the change of the width is dependent mainly on the aluminum holder, since the coefficients were nearly equal to the thermal expansion coefficient of aluminum (2×10^{-5} / C°). The aluminum coefficient is larger than that of Invar. In order to achieve the slit width of 0.01 mm with a precision of 0.001 mm, it is required to reduce the slit temperature increase less than 1 C°. Therefore, the slits are equipped with thermometers to ensure the slit width.

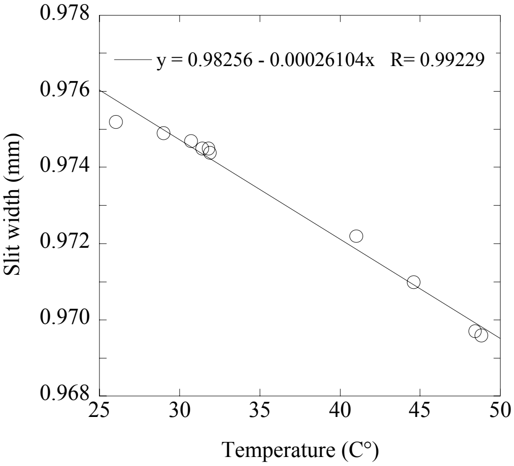

Figure 4: Slit width variation by heating one slit tip.

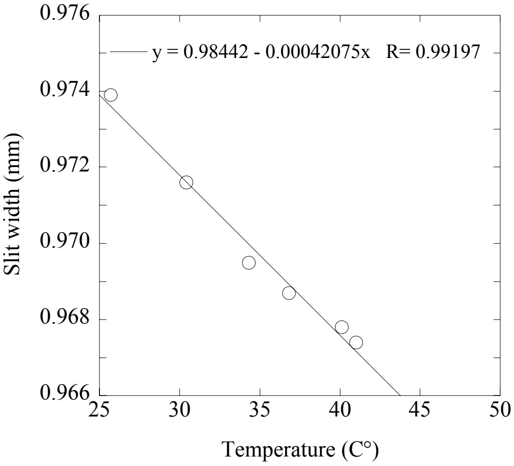

Figure 5: Slit width variation by heating both slit tips.

PRELIMINARY BEAM TEST

The instruments for the measurement of the beam energy spread have been installed in the beam line and a preliminary test was carried out with a 260 MeV ^{20}Ne^{7+} beam. As the first step using the beam, the slit width of 1 mm was applied to the slits at the object and the image positions to confirm the performance of the new instruments. The intensity of the beam, injected to the analyzing system, was reduced to less than 1 nA. The beam intensity, transmitted through the image slit, was measured with the Faraday cup by scanning the position of the image slit. Figure 6 shows the distribution of the beam intensity with a full width at half maximum of 1 mm at the image. This result shows that the energy spread was estimated to be less than 0.1 % in this case.

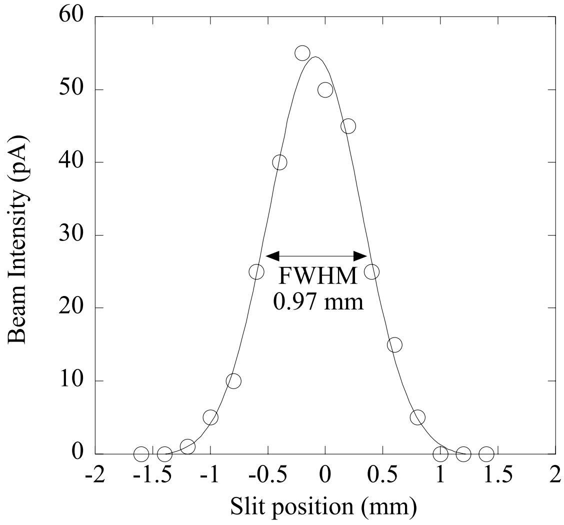

Figure 6: Beam intensity distribution.

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