VIII. 4  An Apparatus for Measuring the Beam Emittance of the Tohoku AVF Cyclotron

1. Introduction

On the basis of the emittance monitor\textsuperscript{1)}, which has been used at K.E.K. for 750-keV pre-injector of the 12-GeV proton synchrotron, we designed an emittance-measuring system for an AVF cyclotron, which has been proved to be very useful to know the beam quality and to obtain easily the best beam transportation.

From the specification of our cyclotron, the system is required to be applicable to the following conditions:

(i) beam-energy range of 3–40 MeV/amu,
(ii) beam intensity from 40 nA to 50 µA,
(iii) emittance value from 0.09 to 1088 mm-mrad,
(iv) measuring and processing time of about one minute for one run.

The system consists of sensors, driving and control devices and a data-processing device. Elliptical-phase-space contours and current-density distributions in the phase space are displayed on a video screen and are easily understandable.

2. Sensors and the operation

Several methods\textsuperscript{1–4)} have been used for the measurement of beam emittance. Among them, the one slit-multidetector method\textsuperscript{1)} is here adopted, and its principle is shown in Fig. 1, where the sensor consists of a slit and a multi-current detector. The current-density distribution, together with the divergence, is measured with a multi-current detector of 63 terminals. By moving simultaneously the slit and the multi-current detector with motors, the current-density distribution in the phase space is obtained.

A beam emittance of an AVF cyclotron is generally small, for instance, about 30 mm-mrad for 40-MeV protons from our cyclotron. Moreover, a proton beam of several tens of MeV has a range of a few mm in copper. Hence, the distance between the slit and the multi-current detector, namely the drift space, should be about 800 mm for a slit width of 0.2 mm. The multi-current detector is made of plates of 20-mm width of, alternatively, copper and Mylar as is shown in Fig. 1. The copper plates of 0.2-mm thickness are used as electric terminals and all the copper plates are electrically isolated with 0.05-mm thick Mylar foils. The electrical interference between the terminals has been prevented by grounding the 0.05-mm-thick copper plates. With such an arrangement as this, we can measure an emittance with an accuracy of 0.2 mm × 0.44 mrad.

The current distribution in a beam passed through the slit is observed by signals from the terminals. The current is integrated during the period of 20, 40 or 60 msec and is stored in a sample holder. The current signals are led to a 12-bit A/D converter before the sensor moves to the next measuring position. The timing chart is shown in Fig. 2. During a cycle, the integrated-beam current
is processed, the sensor is displaced, and the data are accumulated. The current-density distribution in the phase space can be displayed for monitoring at any time.

Two sensors of the same type were used; each of them is for measurements in the horizontal and the vertical directions. The slit and the current detector move with steps of 0.2 mm and the total displacement can be 20 mm or 40 mm. The sensor is driven with pulse motors, which is regulated by timing pulses from the data processor. The slits for the sensors are installed at positions of 4.0 m and 3.9 m from the beam exit of the cyclotron, respectively, for the horizontal and vertical axes. Specifications of the sensor are shown in Table 1.

3. Hardware of the data process

The hardware of the data-processing system is schematically shown in Fig. 3, where functions of the domains enclosed by the dashed lines are represented.

Radiofrequency noises coming from the cyclotron are mixed with the signal in the analogue circuit and give rise to errors. The radiofrequency noises in the transmission cable were found to be 200 mV_p-p at maximum, whereas the resolution of the A/D converter is about 1 mV for input signals. This difficulty was removed by the use of a radio-frequency filter which suppresses the noise level by 47 dB.

4. Data process

The stored data were analysed with 8080 A CPU into the current-density distribution in the phase space (a). From this distribution were obtained the elliptical-phase-space contours (b) and the emittance of the beam current (c). This information — (a), (b) and (c) — is printed out and can also be displayed on a CRT as a three-dimensional-mapping transformation of the data points. Representations of (a) and (b) on a CRT are shown in Fig. 4. The current-density distribution is here displayed as a bird's eye view. Elliptical-phase-space contours are obtained by plotting the data points of the same current intensity and by identifying them with pattern recognition by an observer.

5. Survey of properties of the extracted beam

In order to obtain a good beam transportation, it is needed to assure that the beam emittance is small enough in comparison with the acceptance of the beam-transport device and also that the center of the beam should coincide well with that of the beam-transport system. These characteristics of the beam depend on the acceleration condition of the cyclotron and vary with the cyclotron parameters. As an example, extracted-beam profiles of 20-MeV protons are surveyed as a function of the septum curvature of the deflector and are shown in Fig. 5, where it is seen that the center of elliptical-phase-space contours changes with the septum curvature. It was sometimes found that the center of the extracted beam does not coincide with that of the beam-transport line and it is difficult to adjust it using a steering magnet which is installed just after the exit of
the cyclotron. In such a case, this emittance-measuring system was found to be quite useful and effective to obtain a good beam transportation.

6. Summary

An emittance-measuring system of one slit-multidetector type was designed, manufactured and tested. It was found that this system makes it very easy to measure the beam characteristics and to make an adjustment of the cyclotron parameters to obtain a good beam transportation. In our laboratory, it is now customary to measure the beam emittance before doing a beam transportation. Photographs of the system are shown in Fig. 6.

Acknowledgments

The authors are indebted and grateful to Mr. Ohmura, Mr. Hoshika, Mr. Ono and Mr. Kan for operation of the cyclotron throughout the experiment and also for the help to the test and adjustment of the system.

References

4) Egelhaaf C., Theses (Berlin, 1976).

<table>
<thead>
<tr>
<th>Table 1. Specification of the sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current to be measured per copper plate and accuracy</td>
</tr>
<tr>
<td>Integration time</td>
</tr>
<tr>
<td>Number of copper plates for current measurement</td>
</tr>
<tr>
<td>Displacement of sensor</td>
</tr>
<tr>
<td>Geometrical precision of sensor setting</td>
</tr>
<tr>
<td>Acceptable maximum number of data</td>
</tr>
</tbody>
</table>
Fig. 1. Principle of the one slit-multidetector method for emittance measurement. The notation $I(x)$ is the current-density distribution in the space and $i(x, \theta)$ is that in the phase space.

Fig. 2. Timing chart of the system.
Fig. 3. Block diagram of the hardware for the data process.

Fig. 4. Display of the emittance of a 40-MeV-proton beam.
(a) the current-density distribution in the phase space,
(b) the elliptical-phase-space contours: the horizontal axis is in units of mrad and the vertical axis is of mm.
Fig. 5. Extracted-beam profiles of 20-MeV-protons. The septum curvature of the deflector is denoted by $C_v$, and $e_{(10\%)}$ means the emittance which is determined from the data points corresponding to $10\%$ of the maximum beam current.

Fig. 6. View of the emittance-measuring system.