DEVELOPMENT OF RAPID EMITTANCE MEASUREMENT SYSTEM

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Abstract

We have developed a new system to measure the beam emittance [1]. With our conventional emittance measurement system, it takes about 30 minutes to get emittances in both the horizontal and vertical plane. For quick measurements, we have developed a new system consisting of a continuously driven slit with a fixed width and a BPM83 (rotating wire beam profile monitor). BPM83 uses a rotating helical wire made of tungsten, the speed is 18 rps. Continuously driven slit consists of a shielding plate with two slits, and is inserted into the beam path at an angle of 45 degrees.
The slit is driven by PLC controlled stepping motor, and it takes 70 seconds to move the full stroke of 290 mm. While moving the slit, the output from BPM83 and the voltage of potentiometer that corresponds to the slit position are recorded simultaneously. We are using CAMAC for data acquisition. Trigger signals are generated by BPM83 and NIM modules. Data analysis takes about 1 second. With this system we can get the horizontal and vertical emittance plots within 75 seconds. This system will definitely make it easier to optimize parameters of ion sources and the beam transport system.

INTRODUCTION

At RCNP, various ion beams are generated in three ECR ion sources and accelerated with AVF Cyclotron (K = 140 MeV) and Ring Cyclotron (K = 400 MeV). The schematic diagram of RCNP cyclotron facility is shown in Fig. 1. Beams are used widely for fundamental and applied physics experiments e.g. precise nuclear physics experiments that combines light ion beam with high energy precision ($\Delta E \sim 0.01\%$) and ultra-high resolution spectrometer Grand-RAIDEN, furthermore experiments using secondary particles (UCN, muon, etc.) by high energy proton beam. At present, the current of 400 MeV proton beam is confined to about 1μA after Ring Cyclotron. However an improvement for beam current intensity and quality is planned for experimental demands e.g. increasing of statistics for precise nuclear physics experiments using high quality beam, supplying halo-free beam for 0° experiments, UCN and muon experiments. For that purpose, an improvement of transport efficiency, furthermore speeding up of beam diagnosis and control are getting to be essential.

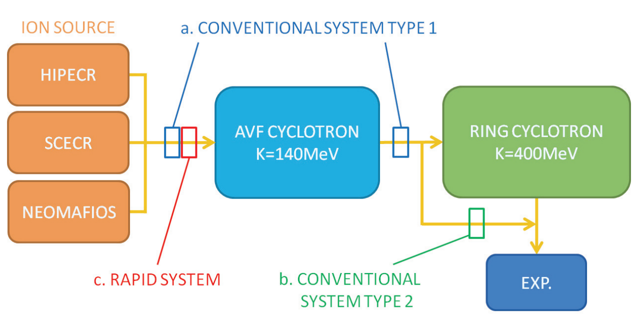

Figure 1: Schematic diagram of RCNP cyclotron facility. One type of conventional emittance measurement systems and the rapid emittance measurement system that will be discussed in this paper are installed in the downstream of three ECR ion sources [2].

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One of the causes to lower the beam transport efficiency is the problem that the beam extracted from ion source is not injected to AVF Cyclotron effectively. To solve the problem, it is important to match the injection beam emittance with the acceptance of AVF Cyclotron. In order to attain that, we have to minimize the ion-source beam emittance and maximize its intensity, namely, to increase brightness. Besides, parameters of ion source and beam transport system should be modulated to match phase space distribution of injection beam with the phase space area of AVF-Cyclotron's acceptance.

To bring up the brightness of the beam extracted from ion source, we need to measure emittance repeatedly, and optimize the parameter for ion source. Though, conventional emittance monitor with beam slits and three-wire profile monitor takes about 20∼30 minutes to acquire data for emittances in both the horizontal and vertical plane, furthermore, we needed to calculate manually for getting emittances and phase space distributions. Therefore it is difficult to measure repeatedly to optimize operation parameter. For this purpose, reduction of data acquisition time and analysis time in emittance measurement is getting to be a crucial issue.

RAPID EMITTANCE MEASUREMENT

There are two types of conventional emittance measurement systems in our facility. Both systems use three-wire profile monitor (TPM), and it takes about 1 minute to acquire a beam profile with TPM. Although it depends on the position resolution we set, the whole data acquisition takes about 20∼30 minutes for that reason. In conventional systems the profile measurement is a rate-limiting step. If the interval of profile measurement is short enough compared to the slit movement, we can reduce measuring time drastically by measuring profiles and moving the slit simultaneously (Fig. 2).

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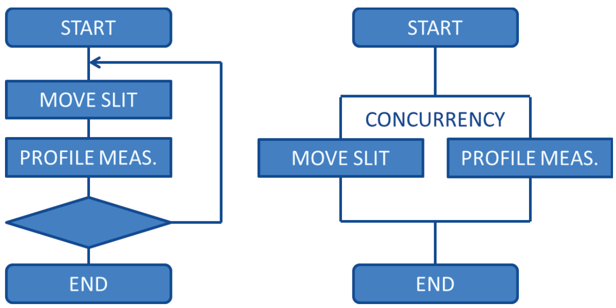


(a) Conv. meas. (b) Rapid meas.

Figure 2: (a) Control sequence of conventional emittance measurement system. (b) Concept of rapid measurement by concurrency control.

Beam Profile Monitor (BPM83)

To develop rapid emittance measurement system, we used rotating wire beam profile monitor BPM83 (Fig. 3b). The BPM83 uses a rotating helical wire made of tungsten, and its rotational frequency is 18 rps, so we can get both horizontal and vertical profile of the beam every 1/18 second. It is commercially available from National Electrostatic Corp.

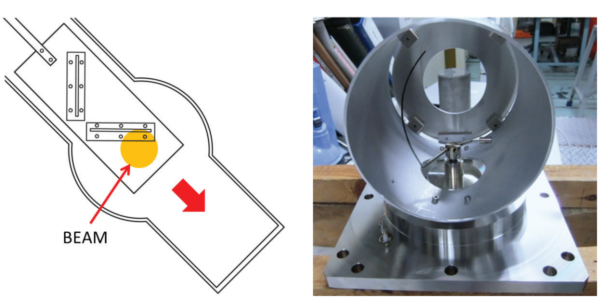
BPM-FP3A is control and reading unit of BPM83. It transmits beam profiles as a voltage signal of several volts and 18 Hz trigger signal for profile measurements. We modified the unit for remote control. A main power and output gain switches are controlled by programmable logic controller (PLC) and electromagnetic relays. It enabled us to control them via TCP communication.

Continuously Driven Slit

Newly designed slit was installed (Fig. 3a). Continuously driven slit consists of a shielding plate with two slits, and is inserted into the beam path at an angle of 45 degrees, that enable us to scan horizontal and vertical planes continuously. The measurable beam diameter is 60 millimeters. The slit width is modifiable, and it is set to 2 millimeters for now. The slit is driven by PLC controlled stepping motor, and we drive it by 14000 pulse/sec. It takes 70 seconds to drive the full stroke of 290 mm. Therefore, the driving speed is about 4.1 mm/s and each slit moves at 0.16 millimeters toward horizontal or vertical direction after one profile measurement. Consequently the effect of slit movement on profile measurement is negligible.

The PLC slit driver is written by ladder program. When the internal relay for starting measurement is turned on via TCP communication, stepping motor revolves to insert the slit toward the beam line. At the other side of a slit chamber the slit stops and returns to position in readiness automatically.

Slit position can be monitored by the number of pulses inputted. However, we used potentiometer mounted on the slit to know the slit position in this system. The output voltage from the potentiometer is introduced to ADC with beam profiles. Thereby, we can record right positions of the slit even if the drive system steps out. Furthermore, the data acquisition is not affected by PLC clock and we could simplify the DAQ and the analysis program.



(a) Continuously Driven Slit (b) BPM83

Figure 3: (a) Schematic diagram of continuously moving slit. (b) Photograph of BPM83 the beam profile monitor.

DAQ system (CAMAC)

DAQ system was implemented by CAMAC. We used CAMAC for using CC/NET to simplify analysis system that will be discussed later. To measure phase space distribution or emittance, we need to get the waveform of the beam profile. Though, one profile from BPM83 is about 55 milliseconds long, so flash ADCs for CAMAC cannot handle data that long. Accordingly, we devised a method to digitize the long waveform with gate circuit and peak hold type ADC (PH-ADC). PH-ADC module stores a maximum voltage of input signal while the gate is opened, so a periodic gate signal enables us to get the long waveform.

We used CC/NET for a crate controller. It is a network crate controller with on-board computer. Debian GNU/Linux is mounted on CC/NET, so it is possible to process data, control PLC by TCP client, transfer files to servers, etc. Therefore, it is powerful to build automated measurement and analysis systems.

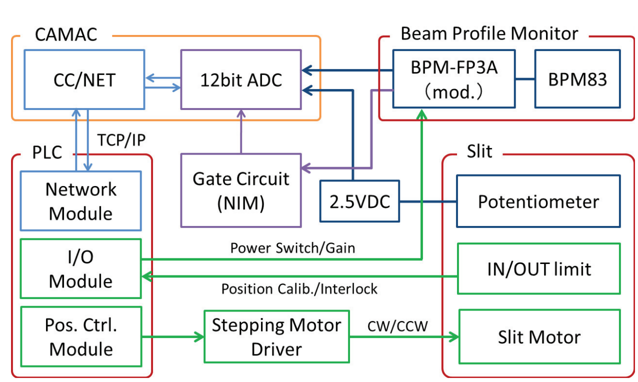


Figure 4: Control and data acquisition system.

DAQ Program

For automatic measurement and analysis, DAQ program is installed on the mainframe. The block diagram of the DAQ program is shown in Fig. 5. When the main program on the mainframe is executed, a measurement program on the CC/NET on-board computer is started via SSH with public key authentication. First the measurement program on the CC/NET request PLC to start slit driving via TCP communication, and then the slit is inserted into the beam line from an evacuation site, the program monitors the slit position. As soon as the slit passes the measurement starting point, about 25 seconds after starting the main program, data acquisition starts. CAMAC ADC stores the beam profile, starting point of one profile, slit position and time stamps in an internal buffer. About 45 seconds later, DAQ finishes, then data in the buffer is saved as the name of the starting time of that DAQ. When the data save is completed, a data file will be transferred to the mainframe via SCP. The mainframe receives an exit status from DAQ program on CC/NET, then analyzes the result data and outputs the result file as EPS. The result file is displayed immediately. It takes one second to analyze and a few seconds to display, so we got to be able to check phase space distributions and emittances in about 75 seconds.

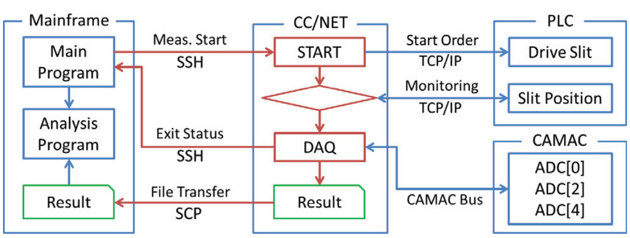


Figure 5: Block diagram of the DAQ program.

ANALYSIS

The result data contains beam profile and the reading voltage that corresponds to a slit position of that time. To calculate a phase space distribution we have to know the angular dependence of the beam intensity distribution. First we calculate the wire position of BPM83 from the time axis of the beam profile. The slit position is obtained from the reading voltage of the potentiometer. The angle to the optical axis is calculated using the slit position and the wire position. We can plot the current at a certain slit position and a certain angle. In this way, the phase space distribution is obtained. When the beam is passing through the slit, there may be some baseline offset on the data. The baseline is monitored on the edge of a profile and subtracted from the profile in the analysis.

90% emittance is calculated from the phase space distribution. For a certain point on the phase space, we calculate the electric charge from the current distribution. We make a fine histogram the electric charge, and integrate them from zero to search for a threshold of 10% of the sum total. The

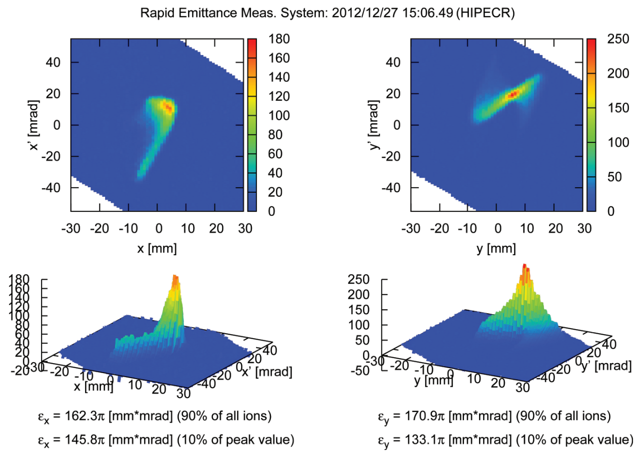


Figure 6: Result of analysis; phase space distributions and emittances in horizontal and vertical planes. 15 keV proton beam from 2.45 GHz ECR-IS. $\varepsilon_x \sim 160\ \pi$ mm mrad, $\varepsilon_y \sim 170\ \pi$ mm mrad

phase space area that is higher than 10% of the maximum current is also displayed on the result. An example of result file is shown in Fig. 6.

SUMMARY

This development enables us to check a phase space distribution and 90% emittance in 75 seconds. A distinctive feature of the emittance measurement discussed here is taking highly reliable method that is using slits and a profile monitor, moreover speeding up the measurement. As mentioned before, we have succeeded shortening greatly in time of measurement and analysis compared with conventional systems.

The final goal of this study is to accelerate high intensity and high quality beam by matching injection beam emittance with the acceptance of latter accelerator. By this study, we got to be able to evaluate beams from ion sources quickly. Therefore the controllability of ion sources is improved.

As stated before, to accelerate beams effectively with plurality components, the emittance acceptance matching between components is significant. Thus we are planning to locate this type of system in several places downstream.

REFERENCES

[1] K. Kamakura, et al., "DEVELOPMENT OF AUTOMATIC EMITTANCE MEASUREMENT", Proceedings of the 9th Annual Meeting of Particle Accelerator Society of Japan (2012)

[2] T. Yorita, et al., "STUDY OF TRANSPORT LINE AND EMITTANCE MONITOR FOR 18GHz SCECR AT RCNP", Proceedings of the 8th Annual Meeting of Particle Accelerator Society of Japan (2011)

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