# APPLICATIONS OF MCP PHASE MONITOR TO OPERATION OF RIKEN HEAVY ION ACCELERATORS

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A new type of beam monitor with an MCP (micro-channel plate) have been developed for accelerators in the RIKEN Accelerator Research Facility (RARF). This device is used for measurement of the time structure of beams after cyclotrons with only slight beam interception. It works as a beam phase monitor to know a small drift (several ppm) of the magnetic field in cyclotrons for a wide range of beam intensity. When the device is used along with a periodically-chopped beam, it is further applied for several measurements such as judgment of the single turn extraction and the turn number inside a cyclotron.

## 1. Introduction

The K540 RIKEN Ring Cyclotron (RRC) is coupled with two types of injectors, a K70 AVF cyclotron (AVF) and a heavy-ion linac (RILAC) as shown in Fig.1. Since 1986, it has been supplying a variety of beams for various kinds of experiments.[1] To meet user's requirements, we should often prepare a beam with high-quality and good stability. In order to get such a beam from the RRC, it is essential to realize the single turn extraction in every cyclotron and keep it throughout a beam time of the experiment.

Requirements for a new device are as follows: It can be used continuously, that is, a non-beam-destructive type monitor and its dynamic range for beam intensity should be large. For this purpose, a beam phase probe with use of a micro-channel plate (MCP) has been developed.[2] It has good sensitivity with respect to energies, ion masses and intensities for various kinds of beams.

## 2. Apparatus

The structure of the new phase probe is shown in Fig. 2. It consists of an electrode assembly, a target (tungsten wire of 0.3 mm in diameter), a micro-channel plate (MCP) , and a linear motion actuator. Electrons and/or photons produced by beam irradiation on the target are accelerated to the MCP entrance surface. During the measurement, the target can be scanned remotely in perpendicular to the beam axis, keeping a constant distance between the wire and the MCP. The beam interception is estimated to be less than 1%. Three sets of devices are installed inside a beam-diagnostic chamber located in the extracted beam line of the AVF cyclotron and the RRC as shown in Fig. 1.

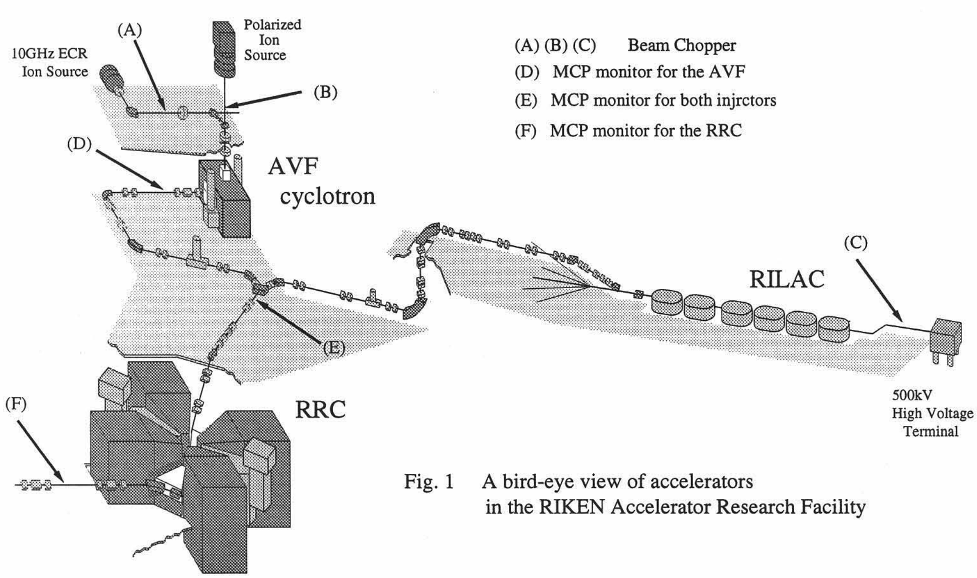


Fig. 1 A bird-eye view of accelerators in the RIKEN Accelerator Research Facility

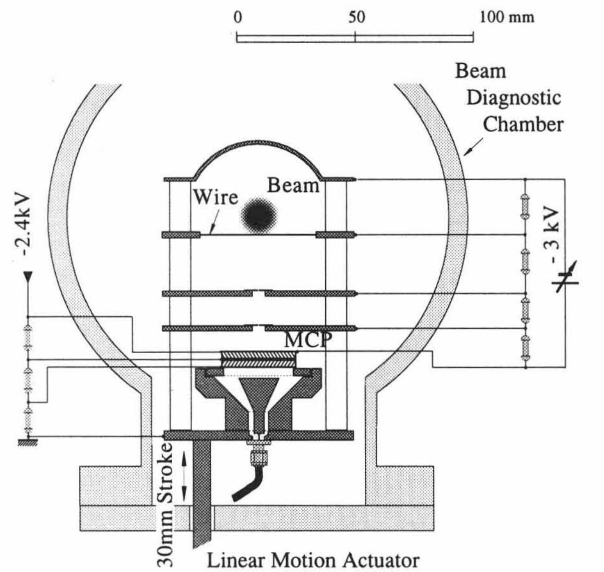


Fig. 2 Cross sectional view of the MCP monitor, which is seen along the beam axis. The MCP is of two-layered type with an available diameter of 14 mm. Double slits in front of the MCP surface prevent the stray electron and/or photons from entering into the MCP.

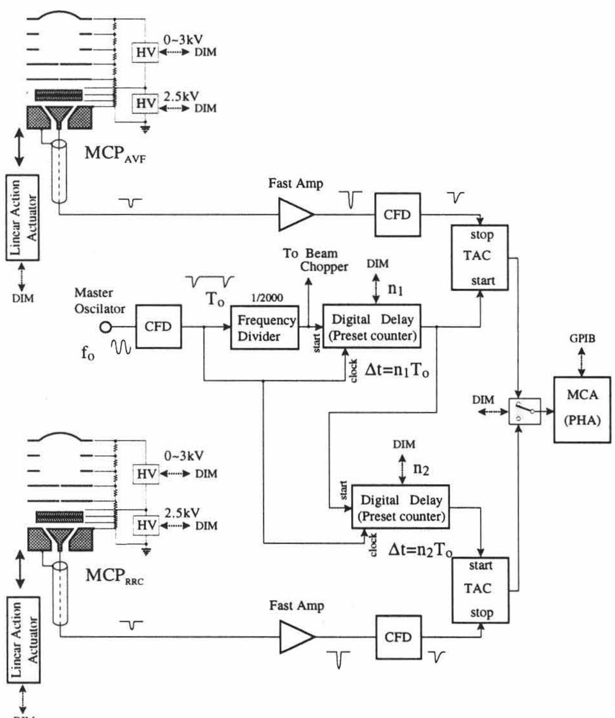


Fig. 3 Block diagram of electronics for the MCP phase monitor. DIM is a remote connection to a host control computer. $n_1$ and $n_2$ are the preset values for two digital delay circuits. In the RILAC - RRC operation, $n_1$ is set one. $T_o$ is the rf period of the injector.

A block diagram of electronics is shown in Fig. 3. As a delay generator up to 100 µs, a preset counter is used, since it has very stable performance compared to analog ones.

Three beam choppers are installed in 500 kV pre-injector line of the RILAC, and in the injection lines to the AVF cyclotron from the ECR ion source and from the polarized ion source. A pulse duration is determined according to the harmonic number of acceleration: 200 ns ~ 1.2 µs. The beam loss due to the chopping is kept less than 1 %.

## 3. Single-Turn Extraction Monitor

### 3.1 *General Case*

Figure 4 shows time spectra of the extracted beam from the RRC, when a beam is chopped with a duration of 1.2 µs. A value of $n_2$ in Fig. 3 was adjusted so as to find the corresponding hollow in

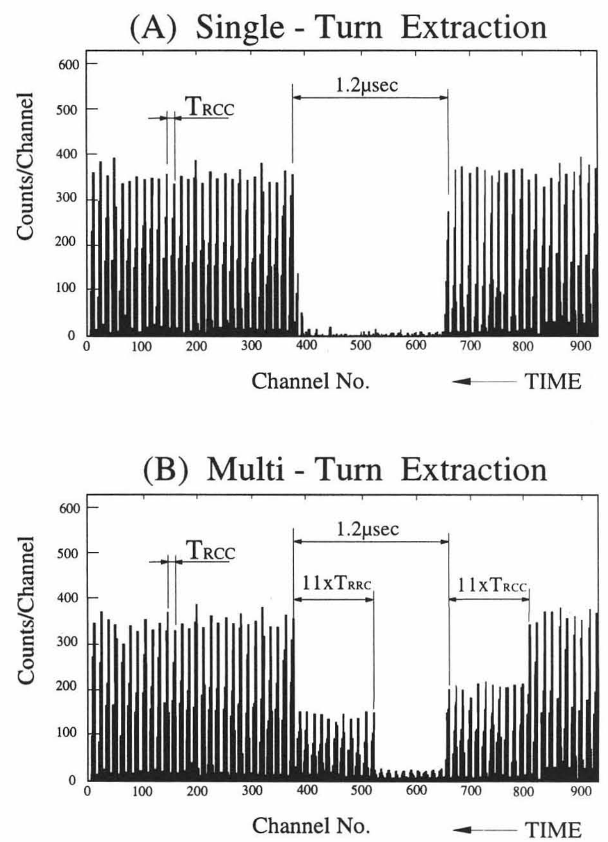


Fig. 4 Time spectrum of the extracted beam form the RRC. The beam is $^{40}Ar$ 7 MeV/u. $T_{RRC}$ is the period of an rf acceleration voltage in the RRC: 56 ns in this case.

the spectrum. When the single-turn extraction is achieved, the shape of the hollow portion is the same as that of the injected beam into the RRC, as shown in Fig. 4 (A).

In the case of double-turn extraction, a beam bunch is divided into two parts with the septum of deflector. Normally these two parts are paired in one bunch. But, when a beam is switched-on and switched-off, the two kinds of parts involved in one turn of the RRC appear individually as small bunches, as shown in Fig. 4 (B). The number of these parts which appear in the time spectrum is equal to the harmonic number of the RRC. The fraction of eleven small peaks gives us a quantitative information on multi-turn extraction. In principle, this method can be applied to a general cyclotron, as long as such a beam-chopping is available.

*3.2 In case of the AVF-RRC operation*

When the RRC is coupled with the AVF cyclotron, more convenient method to monitor the single turn extraction can be applied to the RRC. The method becomes available only when the following two conditions are satisfied at the same time. One is that a post-cyclotron is operated at double the frequency of its injector. From a standpoint of the rf phase in the post-cyclotron, a beam bunch comes from the injector every two periods. The second is that the harmonic number of the post-cyclotron is an odd number. In the case of the AVF-RRC operation, these conditions are always satisfied.

In the double-turn extraction, a partial beam, which was separated at a deflector, is not mixed up with main bunches and appears independently in the half way between them, as shown in Fig. 7 (B). In this figure, the results of 100 MeV/n $^{18}O$ beam are shown and the small peaks due to the double(or more)-turn extraction are observed at the middle points of two main peaks. One can always know to what extent the single-turn extraction is achieved in the RRC without any beam chopping.

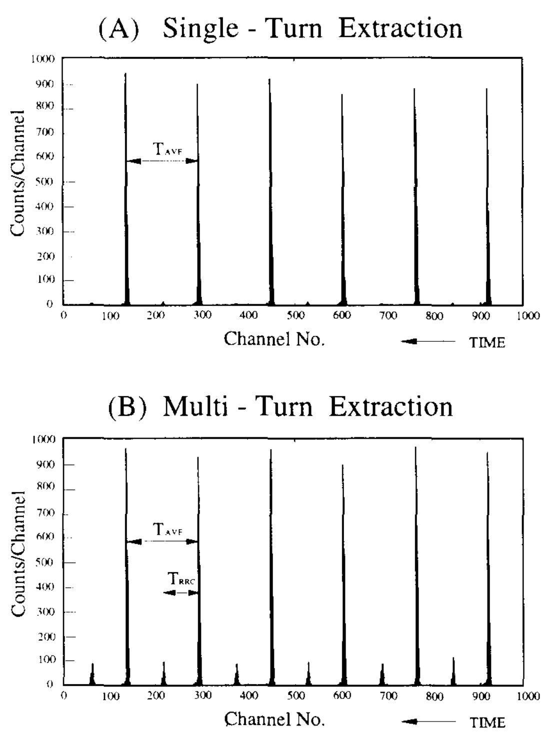


Fig. 5 Time spectra of the extracted beam from the RRC. The beam is 100 MeV/u $^{18}O$ and is not chopped. (A) is the case when single turn extraction is realized in more than 99%, and, on the other hand, (B) is when 12% of beam is extracted from the next turn. $T_{AVF}$ and $T_{RRC}$ are 68 ns and 34 ns, respectively.

## 4 The Turn Number in Cyclotron

The number of $n_1$ and $n_2$, which are input to the digital delay circuits in Fig. 3, are very important. The value of delay time, $\Delta t_{1,2}=n_{1,2} \times T_0$, when the chopped beam can be observed on a Multi-Channel Analyzer (MCA) screen as a spectrum in Fig. 5, has information about the flight time of beam from the beam-chopper to the MCP monitor, if the signal delay in cables and other electronics are taken into account. In this process, it is necessary to reduce the repetition rate of beam chopping so that the correspondence between chopped beam and monitored one will be easily found.

Moreover, when the drift time of beam in transport lines outside cyclotron are considered, a time spent for acceleration in cyclotron are obtained. Then the turn number inside cyclotrons are easily estimated by use of a harmonic number.

## 5 Beam Phase Monitor

The position of peak in Fig. 4 and Fig. 5 is always relating to a beam phase with respect to an rf phase. It means that this system works as a phase probe. The shift of the peak is linearly related to a drift of magnetic field in the cyclotron. Its sensitivity is so high that a fields drift of

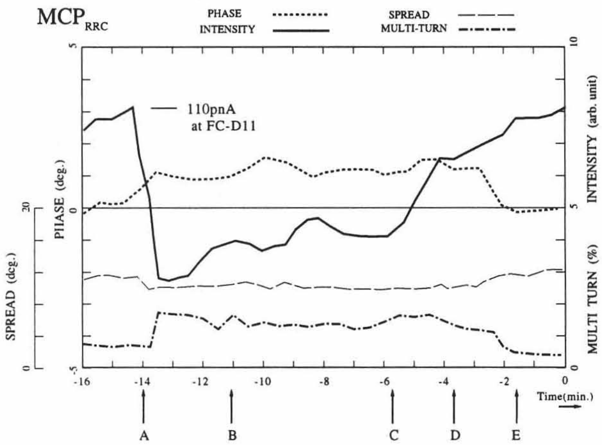


Fig. 6 Example of continuos measurement with the MCP phase probe. Beam intensity (the area of peak in time spectrum), beam phase (peak position), ratio of the multi-turn extraction (shown by a relative fraction of small peaks in Fig. 4 and 5 to the main peaks), and beam bunch spread (peak width in fwhm) are displayed in a duration of 16 min.

several ppm can be known. As the probe works for a very low intensity beam down to 10 ppA in case of 100 Mev/u $^{18}O$, it is more useful than a conventional capacitive pick-up probe. An operator can stabilize the magnetic field by adjusting a magnet current so as to keep this peak at the same position.

Figure 6 shows an example of a time chart of continuous measurement for the RRC. It takes from 30s to 10 min. to accumulate data in the MCA, depending on beam intensity. After the data are taken by a control computer, the relative beam phase, and the beam intensity , and the bunch spread, and the ratio of the multi-turn extraction are calculated. These processes are repeated every several minutes and the time changes of these data are displayed on a monitor. At a point A in the figure, some de-tuning occurred. The beam intensity decreased and the beam phase shifted in positive side, which tells that the magnetic field strength in the cyclotron decreased a little bit. The current for main magnet was increased four times at points B, C, D, and E by a step of 30 ppm, which corresponds to 5 ppm of $\Delta B/B$. The status of beam extraction also degraded in this period. After increasing the magnetic field totally by 20 ppm, the beam intensity was recovered and the beam phase is shifted to the original point of 0 deg.

This measurement can be run continuously even when the beam is used for the experiment, because the beam loss due to this measurement is slight (around 1%).

## 6 Summary

We have developed a new type of the MCP monitor that allows us to measure the time structure of a beam from a cyclotron. The monitor can be applied to judge easily the single-turn extraction from the AVF cyclotron and the RRC.

Once the single-turn extraction is assured, the following two techniques can be used with very compact devices in a low energy injection beam line into the AVF. One is a control of spin direction of polarized beam with a compact $E \times B$ spin rotator just after the entrance of the polarized ion source.[3] The other is a single bunch selection in low energy beam line.[4] The spin direction and the single bunched beam are preserved down to a target as long as the single turn extraction are realized in both the cyclotrons.

The MCP monitor can be also applied to measure very easily the turn number inside cyclotrons and the drift of the magnetic field.

In order to keep the accelerator's parameter constant for a long duration of beam time (as long as a week), this system is useful, because it has a good sensitivity and causes only slight beam destruction.

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