Development of a Beam Phase Monitor with a Micro-Channel Plate for the RIKEN Ring Cyclotron

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Abstract

A beam monitor with a micro-channel plate (MCP) has been developed for measurement of time structure of various kinds of beams at the RIKEN Ring Cyclotron (RRC). It works not only as a phase monitor used for stabilizing magnetic fields inside cyclotrons, but also as a monitor giving information about single turn extraction and turn number inside cyclotrons. It has a good sensitivity with a large dynamic range of beam intensities, compared with the old-type phase monitor with capacitive pick-up probes.

I. INTRODUCTION

The RIKEN Ring Cyclotron (RRC)[1] is a post-stage accelerator, coupled with an AVF cyclotron (AVF) or a heavy-ion linac (RILAC). To get a high-quality beam stably for a long duration, it is important to keep the beam phase constant on each accelerator. For this purpose, a beam phase measurement system with capacitive pick-up probes has been installed, and beam phases are continuously monitored in the cyclotrons and in the beam lines. For low-intensity beams, which is required frequently by experimenters, however, the signal becomes so small that the system does not work fully. Thus a phase probe with a wide dynamic range of beam intensity is necessary for this case. The new device is also required to allow us a continuous measurement for the whole beam time. Accordingly it must be of a non-beam-destructive type.

Recently, we developed a very sensitive monitor by use of a micro channel plate (MCP), which is widely used in a field of experimental nuclear physics[2].

II. DEVICE

The structure of the new phase probe is shown in Fig. 1. A micro-channel plate (MCP, F4655, Hamamatsu photonics Ltd.) with a sensitive region of 14 mm$^{\Phi}$, is set parallel to the beam axis. It has a small target of 0.3 mm$^{\Phi}$ tungsten wire strung in parallel with the MCP surface. The target intersects only a small fraction of beam (a few percents at maximum). Electrons and/or photons produced on the target by beams are introduced to the MCP through double slits. There are four sets of electrodes for producing an electric field for the electron acceleration. The wire is biased up to -3 kV against the entrance surface of the MCP, which is biased independently at -2.4 kV to its anode at the ground potential. The whole electrodes including the target and the MCP can be moved remotely in perpendicular to the beam axis, keeping a constant distance (50 mm) between the wire and the MCP. In this way the position of wire with respect to the beam is selectable in order to adjust a signal rate (0.1 ~ 10kcps) from the MCP. Fast and large signals with a rise time less than 1 ns and with a gain larger than 10^7 are obtained from the tapered coaxial-shaped anode of the MCP.

Timings of these signals with respect to the time origin determined by an RF master oscillator are measured with a time-to-analog converter (TAC) and analyzed by a multi-channel analyzer.

The device is installed inside a beam-diagnostic chamber located in the extracted beam line of the RRC and preliminary tests with various kinds of beams were done.

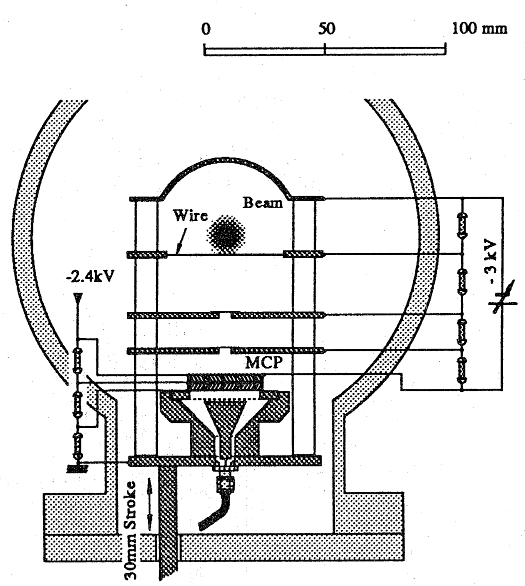

Fig. 1. A structure of a new type of beam phase monitor with an MCP. All electrodes are made of stainless steel and supported by ceramic insulator rods. Each electrode is biased so that a uniform field is produced from the wire to the MCP.

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III. RESULTS

A typical example of time spectrum obtained for 100MeV/n ^{18}O beam is shown in Fig. 2. In this case, the RRC is operated with the AVF. Beam bunches appear with time intervals of an rf period of the AVF, T_{inj}, which is equal to 2 x T_{RRC}, an rf period of RRC. The time spread of beam bunch was measured to be 940ps in FWHM, corresponding to an rf phase spread of 10 degrees.

Here, signals from the MCP are due to photons (considered to be mainly x-rays). Yields of photons and electrons depend on kinds of beams. For heavier ions with low energy, for example 7MeV/n ^{40}Ar, main signals are due to electrons emitted from the target. For protons and deuterons with energies greater than 100 MeV, the rate of signal originating from the wire is very low, and in these cases, a thicker target is required. For light ions, such as carbon and oxygen, with energies higher than 100 MeV/n, the yields of photons and electrons are comparable.

A. Stabilizing a magnetic field of the RRC

The position of peak in Fig. 2 is always relating to a beam phase to an rf phase. This allows the device to work as a phase probe. The shift of the peak caused by the change of magnetic field in the RRC is shown in Fig. 3. An operator can stabilize the magnetic field by adjusting a magnet current so as to keep this peak at the same position.

B. Monitoring single-turn extraction of the RRC

In Fig. 2, small peaks are observed at the middle points between large main-beam peaks. These small peaks are due to multi-turn extraction of the RRC. In case of the AVF injection, a harmonic number of the RRC is an odd number of five, and $T_{inj} = 2 \times T_{RRC}$ (the AVF bunches exist every other acceleration phase of the RRC). These conditions result in the extracted bunches as illustrated in Fig. 5 (A), when the multi-turn extraction occurs in the RRC. The small peaks correspond to the fragments of the bunches in the last internal orbit. They are peeled off by the deflector septum before entering the extracted orbit. By observing the time spectrum such as Fig. 2, it is quite easy to know to what degree the single turn extraction is achieved.

In case of the RILAC injection, however, this method is not available, because the fragments overlap the main beam bunches (T_{inj} is equal to T_{RCC}). In order to observe the fragments clearly, we cut the RILAC-injected beam bunches in certain duration by using the electric chopper nstalled in the injection line of the RILAC[3]. Figure 5 shows the spectrum obtained, when a beam is chopped for the duration of 1.2μs, for the case of the RRC harmonic number of 11. The beam loss was in the order of 3% under the following conditions: the voltage was 3kV; the rise time shorter than 50 ns; and the repetition cycle 25kHz. Figure 5 (B) illustrates the principle of this method. After the chopper is turned on, 11 bunches (the number corresponds to the RRC acceleration harmonics) without fragments accompanied are observed, because the fore-going fragments disappear. After turned off, 11 fragments are obsearved first. By use of this method, we can observe to what degree the single-turn extraction is achieved for the RILAC-injected beams.

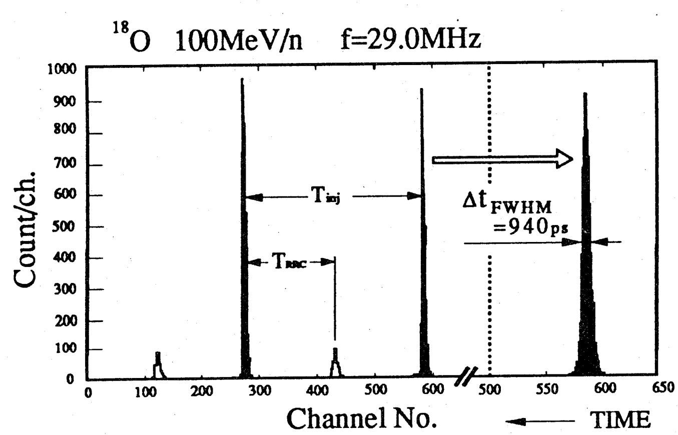

Fig. 2 Example of time spectrum of signals from the MCP for a 100MeV/n ^{18}O beam. These signals are considered to originate from photons produced at the wire by the beam, because no accelration voltage is applied of the electrode during this measurement. A start signal for the TAC is given by the MCP signal and a stop signal is an rf reference. Shadowed peaks are due to a main beam, and unshadowed peaks are due to the effect of multi-turn extraction.

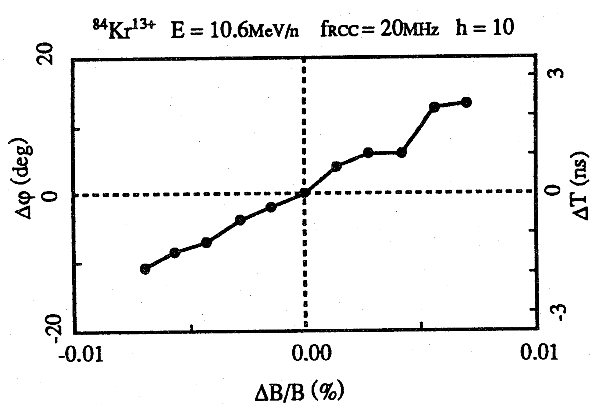

Fig.3 The peak shift (that is, beam phase) vs the change of magnetic field in the RRC.

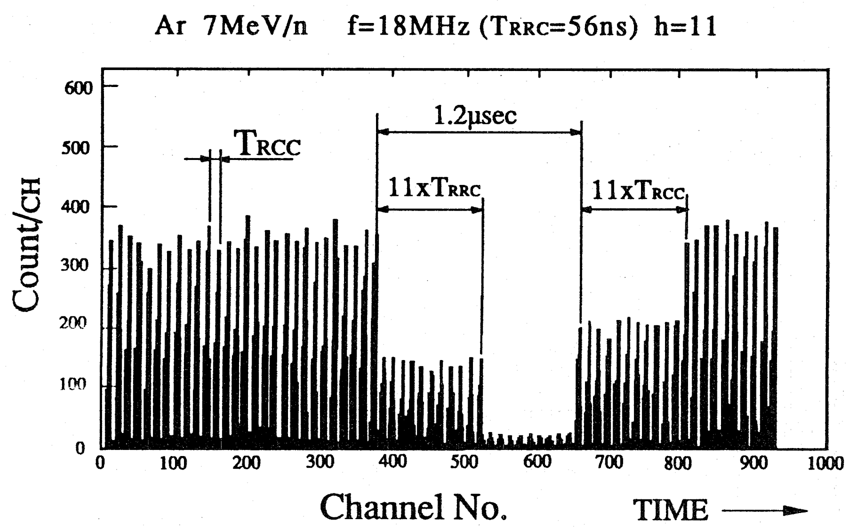

Fig. 4. A time spectrum of beam bunches when the beam is cut partially (1.2μs) by the beam chopper installed in the RILAC injection line. The start of the TAC is done by the trigger signal for the chopper, which is sychronized to the rf phase. The stop for the TAC is the MCP signal.

IV. CONCLUSION

The beam monitor with the MCP is very useful not only for the measurement of beam phase but also for the judgement of single-turn extraction. For other applications, the measurement of turn number inside the cyclotron is available. These measurements can be done with a slight beam loss (almost non beam destructive).

Now we are preparing to install these devices in the injection line to the RRC as well as in the extraction beam line. These monitors will help us to maintain the beam stably and also to tune the beam quickly.

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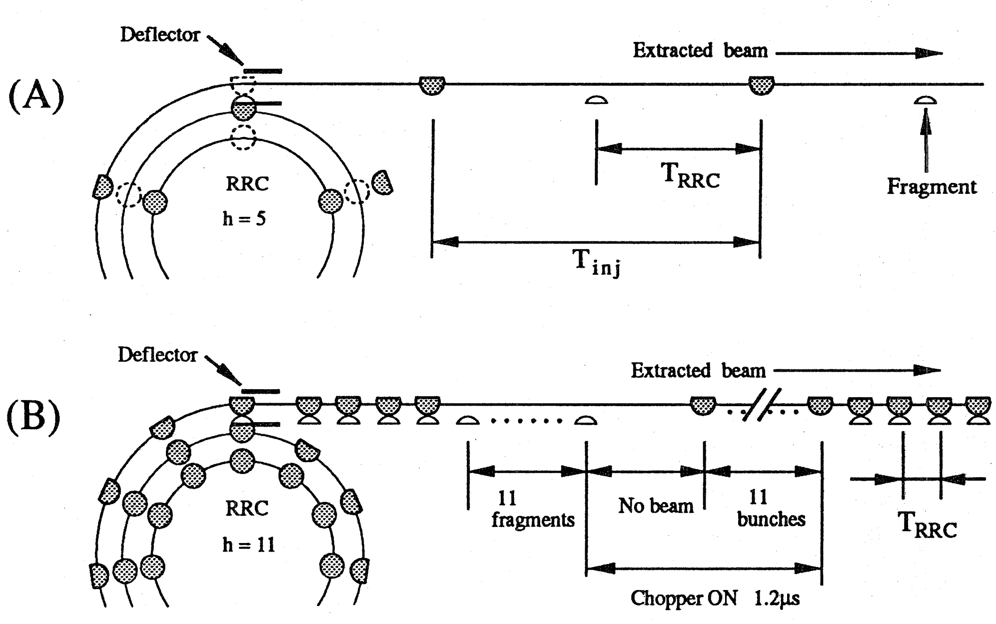

Fig. 5 Conceptional illustration of multi-turn extraction of the RRC. (A) : in case of the AVF injection, harmonic number being 5. (B) : in case of the RILAC injection, harmonic number being 11, by chopping beam bunches partially.