Non-Destructive Velocity Monitor for the HIMAC Injector

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Abstract

A non-destructive monitor for measuring the velocities and intensities of beams from the HIMAC injector was developed. The beam velocity is estimated from the phase difference between the signals from the two electric pickups.

1 Introduction

HIMAC (Heavy Ion Medical Accelerator in Chiba) began its operation in 1993, and is supplying beams not only for clinical trials, but also for basic research during the night time and on the weekends [1]. In the basic research, ion species from He to Ar are being used, while the clinical trials employ C beams.

The injector supplies beams of 6MeV/u to three courses (two synchrotron rings and a direct use of injector beams) "simultaneously", changing the beam direction. Furthermore, an upgrade of the time-sharing acceleration (TSA) is in progress. In the TSA mode, the injector supplies different ion species to three courses, changing ion sources on a pulse-to-pulse basis. After the upgrading, therefore, it is necessary to condition the injector system for a given beam without interfering with other beams. In the present system, the beams must be stopped during beam tuning, because the energy is estimated using a bending magnet, and the intensity is measured by a Faraday cup. For using in the TSA mode, a non-destructive monitor was developed and tested. The new monitor must be capable of measuring the beam velocity with an accuracy of 1/1000 to carry out tuning for synchrotron injection. It must also cope with a short duration of the beam pulses because of a duty factor of 1/1000 of the injector.

2 System composition

A schematic diagram of the system is shown in Fig.1. [2]. Signals induced in two electric pickups by the periodic beam bunches are picked up by RF probes, and supplied to amplifiers, band-pass filters (BPF), and frequency converters. The Phase difference ϕ between the two signals is related to the beam velocity β as follows :

$$\beta \lambda = 360 \, L / \phi , \qquad (1)$$

where λ and L denote the wavelength of the acceleration frequency and the distance between the two pickups, respectively.

In the HIMAC injector, the RF frequency is 100MHz and the beam velocity is around 6MeV/u ($\beta=0.11295$). Since an accuracy of 1 deg is obtainable for a phase-difference measurement, the distance between two pickups was chosen to be 1017 mm, giving a phase difference of 6 π rad. Electric pickups, made of SUS304 and having a
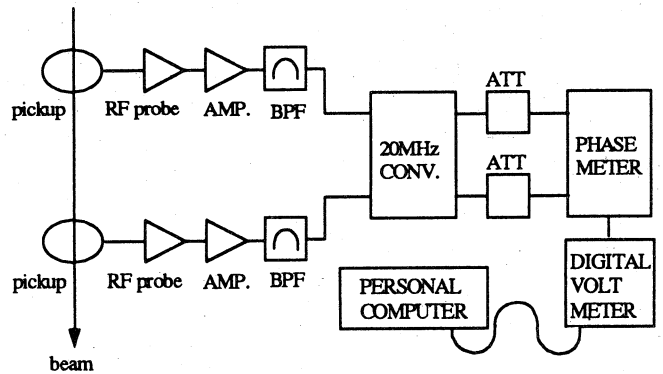

Fig. 1. Schematic diagram of the non-destructive monitor system. (BPF: band pass filter, ATT: attenuator)

diameter of 44 mm and a length of 60 mm, were installed in the beam line about 11.5 m downstream of the injector linac. The RF probes, having a band width of DC to 2 GHz, were attached to the pickups as near as possible (40 mm). Amplifiers with a gain of 10 were placed inside of shield boxes next to the probes to maximize an S/N ratio, while other modules were set up in a different room, 10 m apart. Read-out data of the phase meter are sent to a personal computer in the control room through the GPIB.

3 Results of beam tests

3.1 Beam intensities and output signal levels

Figure 2 shows typical output signals of amplifiers, induced by C^{6+} beams with an intensity of 240 μA.
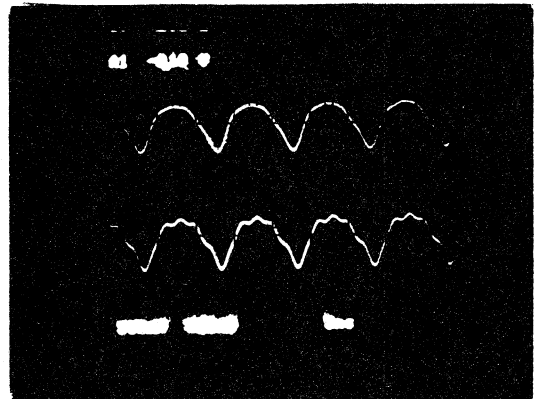

Fig. 2. Signals from the amplifiers. (5ns/div. and 500mV/div.)

The peak-to-peak voltage is around 700 mV, while the noise amplitude without the beam is around 10 mV. The structure of the signals may reflect the particle distribution inside the bunches.

The relation between the beam intensities and the output voltage showed good linearlity, as displayed in Fig.3. An intensity of 240 µA is enough to be used by the synchrotron being operated at full intensity.
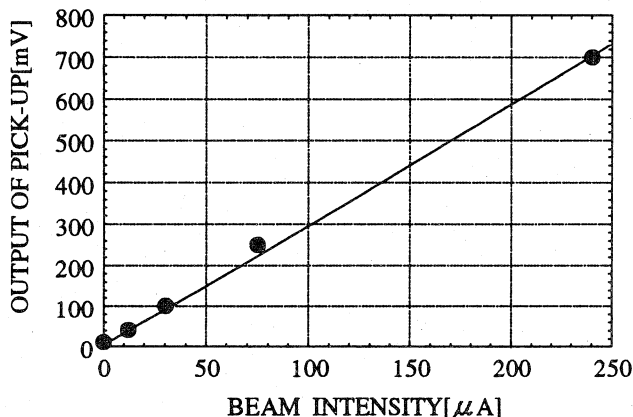

Fig. 3. Relation between the beam intensities and output voltages.

3.2 Phase meter output

The phase difference between the two pickups was observed using carbon beams with a pulse duration of 450 µs. Ordinarily, the input of the phase meter is supposed to be signals with DC or long duration. The stability of the phase-meter output, therefore, is of concern, because the beam duration from the HIMAC injector is 700 µs in a typical case. Figure 4 shows the relation between the pickup output corresponding to the beam pulse, and a gate pulse given to the phase meter. A gate pulse, during which the signal was fed to the phase meter, was delayed for 150 µs to avoid any large oscillation at the beginning of the signal. The sample-hold signal, and therefore the read-out timing, of the phase meter output was varied 50 µs to 400 µs from the beginning of the gate pulse. The phase-meter outputs were found to be stable within 0.2 deg, including the intensity fluctuation from pulse to pulse.
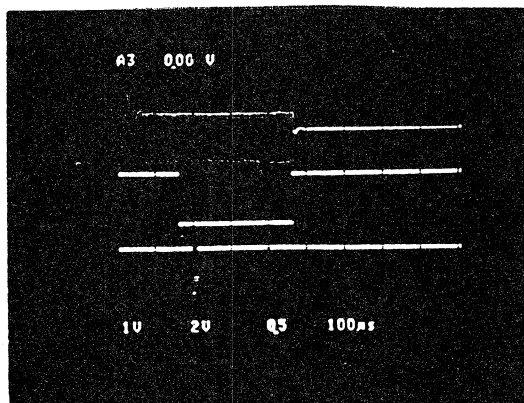

Fig. 4. Relation between the amplifier outputs (top) and a gate pulse (middle). The bottom signal is a timing pulse of a sample hold, when the output of the phase meter was read out (100 µs/div.).

The intensity dependence of the phase-meter output was also examined. The beam intensities were varied by an attenuator, which comprised metal sheets with slits of variable sizes and was installed between the ion sources and the injector, so that the beam sizes and duration were not altered. A slight dependence was observed: averaged outputs with an intensity of 70 µA were different by 1.3 deg (26mV) from those of 200 µA. When the beam intensity was less than 20 µA, the phase-meter outputs fluctuated significantly, and did not give definite results. The output of the amplifier was too small to be fed to the phase meter.

3.3 Velocity measurements

The phase difference was measured by changing the beam velocities. The beam velocity was varied by shifting the acceleration RF phase of the No.3 DTL tank. The beam energies were monitored by a couple of magnets: a 70 deg bending magnet and a 20 deg pulse-operated switching magnet, installed about 14.5 m downstream the injector linac. Two slits with a width of 1 mm, upstream and downstream of the magnets, define the beam orbit. Using a field strength measured by a NMR, one can estimate the beam momentum with an accuracy of 1/1000.

Figure 5 shows the relation between the NMR output of the bending magnet and the output of the phase meter. The fluctuation of the individual data was within the error bars. Two outputs are consistent, and an accuracy of 1/1000 seems obtainable.
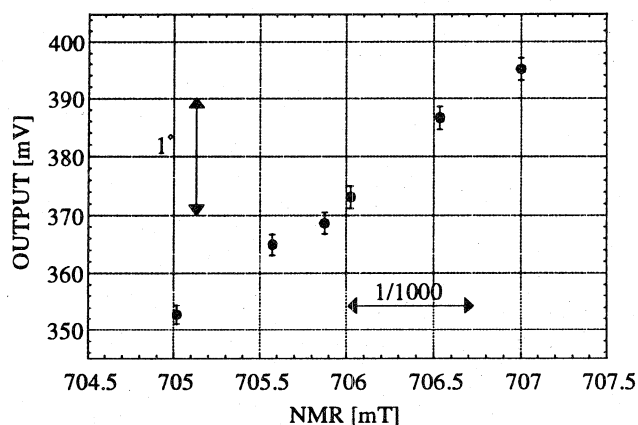

Fig. 5. Relation between the magnetic-field strength of the bending magnet and outputs of the phase meter.

The beam velocities were calculated based on the phase difference. The phase difference caused by cables and circuits was estimated by supplying the same test pulses into the two RF probes. The results were compared with the beam energies calculated from the magneic-field strength and the bending radius. The two results agree reasonably with each other, as shown in Fig. 6 by the solid triangles. Since our purpose is to monitor the variation of the beam energies, not to calculate the absolute energies, the result is quite satisfactory.
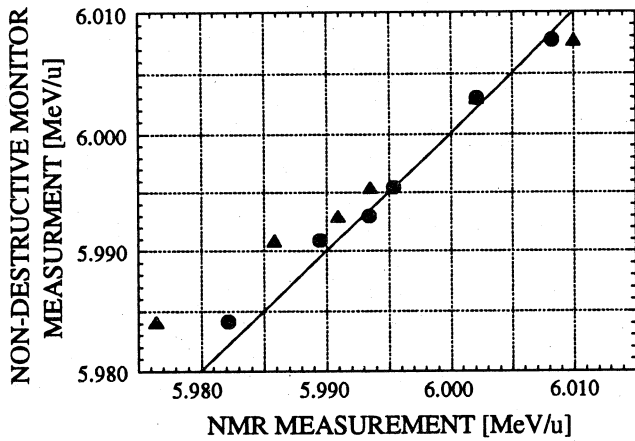
Fig. 6. Comparison between the beam energies measured by the velocity monitor and those evaluated by the bending magnet field. The solid triangles are the calculated results by two methods, while the solid circles include a correction for an effect of the switching magnet.

As noted before, the 20 deg pulse-operated switching magnet was involved in the energy measurements. Since it is not practical to carry out fine-tuning of the pulse-operated magnet, the field of the switching magnet was kept constant during the energy measurements. The data corrected for the effect of the switching magnet were plotted with solid circles in Fig. 6, giving a slightly better agreement.

4 Conclusion

The non-destructive monitor tested showed satisfactory results. A modification of the control system in order to install the monitor is in progress. The monitor should be improved so as to reduce the intensity dependence of the phase difference, and to be capable of measuring the phase difference at very low intensities.

References

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