**PA03**

# Helium Beam Acceleration in The KEK Proton Synchrotron

I.Sakai, A.Takagi, Y.Mori*, S.Machida, M.Yoshii, T.Toyama, M.Shirakata, Y.Shoji and H.Sato

National Laboratory for High Energy Physics, Oho 1-1, Tsukuba Ibaraki 305 Japan

A helium beam has been successfully accelerated in the KEK 12 GeV Proton Synchrotron up to 23 GeV of the limiting energy of the main ring. Although a charge exchange injection of negative hydrogen ions has been used in the booster synchrotron, it cannot be applied to the injection of positive ions, such as helium ions and other heavy ions. A new type of septum magnet for a beam injection system which can realize both negative and positive ion injections, has been developed. The septum magnet has three conductor plates which combine the bump magnet and the septum magnet in a body. A newly developed injection system realized alternative use of both negative and positive ion injection schemes.

## I. INTRODUCTION

The charge exchange injection system has been widely used for the injection system of proton synchrotrons, because of its excellent efficiency of multi-turn injection of proton beams. This system is also used to inject proton and deuteron beams into the KEK booster synchrotron [1]. This system, however, cannot be applied to the injection of positive ions, such as helium ions and other heavy ions. Therefore, a conventional multi-turn injection scheme must take the place of the charge exchange scheme. There is no space for another injection system because of the booster designed well-compact. To replace the injection devices every operation cycle is not practical.

To avoid this, a certain technical break-through is indispensable. A new injection system has been developed to realize both negative and positive ion injection. With this system, in April, 1994, a helium beam was successfully accelerated, and a physics experiment has been carried out [2]. Also, a high intensity proton beam has been accelerated by using this system .

Until now negative ion charge-exchange injection system and positive ion multi-turn injection system regarded to be a distinct system. But this new injection system has opened the multi-purpose uses of the proton synchrotron, i.e. from high intensity proton beam acceleration to high energy heavy ion beam acceleration . The principle of the newly developed positive/negative ion injection  system and the first helium acceleration is summarized in this paper.

## II. NEW INJECTION SYSTEM

### A. Charge -Exchange Injection

A schematic layout of the combined injection system which is presently being used for proton and helium-ion acceleration is shown in Figure 1. Four bump magnets having single-turn conductor plates are arranged asymmetrically so as to enlarge the angle between the injection orbit and the circulating orbit under a limited magnetic field. Bump 2 is a newly developed magnet, which is combined with the septum magnet for positive ion injection.

During a charge-exchange injection, only the bump magnets are excited. This situation is quite equivalent to that in the conventional charge-exchange injection system. These bump magnets are connected in series, and are excited up to 0.39 T in order to change the closed orbit so that the beam impinges on a carbon stripping foil. In Figure 1 the dotted line indicates charge-exchange injection. Negative hydrogen ions are fully stripped at the foil, and start to circulate in the ring. In order to prevent an emittance blow-up due to multiple scattering at the foil, the bump magnets must be turned off just after the completion of injection.

### B. Multi-Turn Injection by a Septum Magnet

The solid line indicates positive-ion multi-turn injection which overlaps the charge-exchange by bump 2. A cross-sectional view of bump 2 is shown in Figure 2. This has been newly developed and plays the role to combine the bump magnet and the septum magnet. This combined magnet bump 2 has three single-turn conductor plates in the pole faces [3]. The electrical currents flowing through these conductors produce two dipole magnetic fields having opposite signs, which are separated by a middle thin conductor plate (1 mm thick), which forms a septum.

During positive-beam injection, the closed orbit must be shifted by 60 mm toward the septum magnet in parallel which is achieved by exciting two additional bump magnets (not shown in Figure 1). Their positions are one quarter of the betertron wavelength upstream and downstream from the injection point. Beams are gradually injected from the center of the phase space to the outside by changing the field excitation of the additional bump magnets.
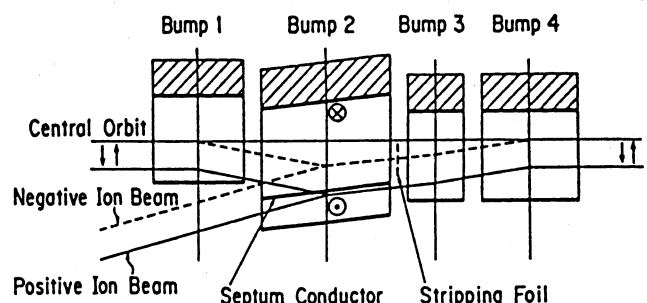


Fig. 1. New injection system for the KEK-PS booster

---

* Present address: Institute for Nuclear Study, University of Tokyo, 3-2-1, Midori-cho, Tanashi, Tokyo 188 Japan

Central Orbit
Negative Ion Injection Point
Positive Ion Injection Point

(-B)
Magnetic
Field

0

Septum Conductor
(1mm thick)

Bump Magnetic
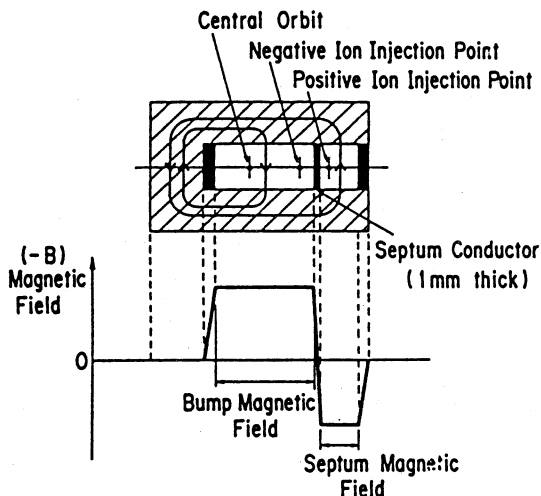Field

Septum Magnetic
Field

Fig. 2. Cross sectional view of Bump 2 and the exited field pattern for positive beam injection.

## III. POWER SUPPLY SYSTEM

A block diagram of the power supply for the bump and septum magnets is presented schematically in Figure 3. The wave form of the bump field (excitation current of the bump magnet) for charge-exchange injection is shown in Figure 4 (a). The bump magnets must be turned off just after completion of injection, in order to prevent any emittance blow-up due to multiple scattering at the stripping foil. This can be realized by using a PFN-type pulsed power supply. As for the septum magnet, the pulse width, since it depends on the number of possible turns at beam injection, would be enough for 30 μsec. Although it may be possible to use DC current, in order to eliminate any cooling problems, pulsed-mode operation is necessary. The wave form of the septum field (excitation current of the septum magnet) is shown in Figure 4 (b). This can also be realized with a PFN-type pulsed power supply insulated from ground, whose electric power is provided by an insulating transformer. The PFN and its power supply, floated on a high-voltage insulation, are controlled through optical fibers [4].

As shown in Figure 4(c), in the middle thin conductor which forms a septum, a current that is twice as large flows instantaneously during positive ion-beam injection by overlapping the bump current and the septum current. However, since the pulse width of the current is less than 40% of the bump current, it is not necessary to add another cooling system to the ordinary magnet system.
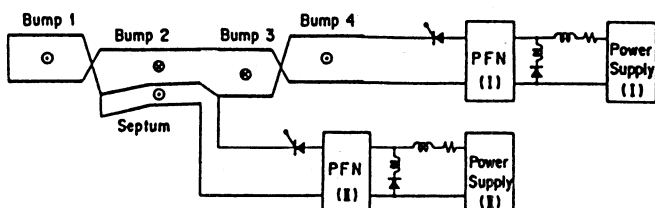
Bump 1
Bump 2
Bump 3
Bump 4

PFN
(I)

Power
Supply
(I)

Septum

PFN
(II)

Power
Supply
(II)

Fig. 3. Block diagram of the power supply.

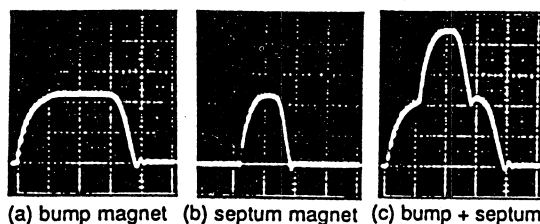(a) bump magnet   (b) septum magnet   (c) bump + septum

Fig.4. Excitation current on the central septum conductor.

## IV. ACCELERATION OF HELIUM IONS

Most of the problems in RF acceleration of light ions of Q/A = 0.5 at the KEK-PS had been cleared at the time when deuteron acceleration succeeded in 1992. However, in the acceleration of helium ions, there remains difficulties with respect to multi-turn injection of the positive ions.

### A. Booster Injection

The 750kV $He^{2+}$ ion beam is injected into the linac. The helium beam is accelerated under the $4\pi$mode operation scheme[3]. Its velocity is half that in the case of proton acceleration. As a result, at the end of the linac it has 3% less momentum than that of proton beam. The beam transport parameters and booster injection parameters must be optimized according to the beam momentum.

During multi-turn injection the beam is painted on the horizontal phase space. As shown in Figure 5, trace (c), by changing the decay current of additional bump magnets, the circulating beam orbit during an injection period was moderately shifted for efficiently stacking the linac beam. This is also a new attempt in accelerator technology. Four turns of the linac beam were accumulated with this technique.
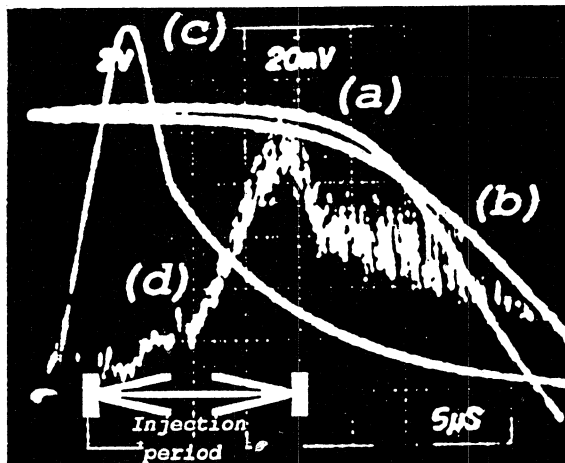
Figure 5. Current wave forms of the injection magnets and beam current monitor at the booster injection: (a) septum, (b) main bump, (c) additional bump with two time-decay constants and (d) beam current.

We observed a very fast beam loss; only half of the accumulated beam was extracted from the booster. This beam loss was caused at the time that the main bump magnet field fell sharply to zero. Field measurements of the main bump magnets showed that the eddy currents induced in the magnets caused a total error field, so as to cause closed orbit distortions, the maximum value of which was about 4 mm. The total error field due to the septum magnet eddy current, as well as the main bump magnet, was also measured. However, both of the error fields induced by eddy currents are of opposite sign and can cancel each other by adjusting falling time of both magnets.

After the schedule of helium beam experiments, the problem of beam loss at the fall period of main bump magnet field has been solved by this cancellation, which is confirmed by machine study using positive proton beams. The acceleration of higher intensity helium ion beams is expected in the next experiment.

## B. Acceleration in the Booster and Main Ring Synchrotrons

For heavy ion accelerations in both the booster and main ring synchrotrons, the radio-frequencies of the accelerating systems are lower during injection, and sweep more widely than in proton acceleration. The tuning systems in both synchrotrons have been modified. The injection frequencies can be changed by attaching additional capacitors in both systems. Especially, in the main ring synchrotron, the bias current power supplies for the ferrite loaded tuning cavities were upgraded.

The intensity of a helium beam was expected to be at most on the order of $10^{10}$ particles per bunch. To stable accelerate such a low intensity beam the pre-amplifiers of both the position and beam phase monitors for the RF feedback systems have been improved.

During a commissioning run lasting one month, the helium beam was very stable, it was also expected at various energies of 8 GeV (2 GeV/u) to 20 GeV (5 GeV/u), based on the requirements of the physics experiments.
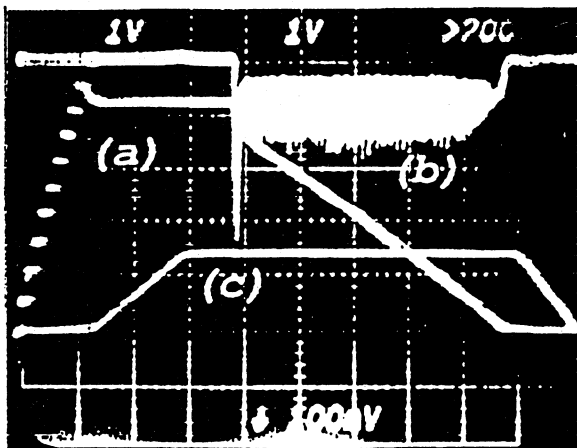


Figure 6. Helium acceleration in the main ring: (a) a helium beam intensity during a cycle, (b) a slowly extracted intensity and (c) a main magnet field pattern.

## V. SUMMARY

A new injection system which combines the bump magnet for charge-exchange injection and the septum magnet for positive-ion multi-turn injection has been developed to realize both negative and positive-ion injection in the KEK PS. Although the "combined" system is a rather novel one, it is not a fragile system as a last resort. The combined injection septum magnet can form a sharp, steep septum field, as shown in Figure 2, rather than that of the conventional septum magnet used to separate the circulating beam and injection beam. Using this combined injection system in April, 1994, operation to accelerate helium-ion beams ($He^{++}$) for physics experiments had been performed for one month. After that, proton-beam acceleration by charge-exchange injection has continued until now (May 1995) without any trouble. The combined injection system has the performance equal to a conventional charge-exchange injection system.

This new injection system has opened up new uses of the KEK PS, i.e. from high-intensity proton beam to high-energy heavy-ion beams.

## VI. ACKNOWLEDGMENT

## VII. REFERENCES

[1] Y. Mori, et. al., Acceleration of Deuteron Beam in the KEK Proton Synchrotron, IEEE Particle Accelerator Conference, 1993, p.3754.
[2] I. Sakai, et. al. Helium Beam Acceleration in The KEK Proton Synchrotron with A Newly Developed Injection System for Positive/Negative Ions IEEE Particle Accelerator Conference, 1995, to be published.
[3] I.Sakai, Magnet System for both Negative-Ion Charge-Exchange Ingection and Positive-Ion Multi-Turn Injection, 14-th International Conference on Magnet Technology
[4] I. Sakai, et. al. A New System to Trigger Fast Rise Thyristers, IEEE Particle Accelerator Conference, 1989, p.2005.