# The KEK Proton Synchrotron

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*Abstract*

The KEK Proton Synchrotron has been operated successfully to serve intense proton beams for the particle and nuclear physics experiments for the past two decades. In recent years, the large efforts for improving the extracted beam quality and the beam transfer efficiency between each cascaded accelerator have been done. Deuteron beam has been successfully accelerated in 1992. Moreover, ion beam acceleration has been initiated recently. As a next step, helium beam acceleration is scheduled in April 1994.

## I. INTRODUCTION

The KEK Proton Synchrotron is an accelerator complex consisting four accelerators: 750 keV Cockcroft Walton, 40 MeV Linac, 500MeV Booster Synchrotron and 12 GeV Main Ring. Since the Proton Synchrotron made a start on its 12 GeV operation in Dec. 1976, the accelerator has been repeatedly upgrading in order to increase its proton beam intensity. However, our recent efforts have rather directed for improving the extracted beam quality and the beam transfer efficiency between each cascaded accelerator. For this purpose, a new computer control system with the distributed VME computers have been introduced to the KEK-PS, which aimed to have effective and systematic controls and data handling of each component of the machine [1]. Lots of signals related to the accelerator operation also send to the computers, and their on-line analysis become to be efficiently available.

The Main Ring Synchrotron has been utilized mainly to produce secondary beams, such as anti-proton, kaon, pion, and so on, for the past two decades. However, coming into the 1990's, the experimental programs using primary beams have been proposed. And the KEK Proton Synchrotron has been required for the machine available for accelerating and extracting not only proton beams but various beams, such as deuteron, He and so on, with various energies. For the sake of realizing such requirements, modifications of the accelerators have been initiated as a task in the Accelerator Division.

In Jan.1992 deuteron beam was successfully accelerated at KEK, and the experimental programs have been successfully carried out in 1992 and 1993. Since 1991, one month of coming every April has been assigned to accelerate deuterons. Helium beam acceleration is scheduled in April 1994 as a next step of atomic beam programs.

## II. RECENT PROTON ACCELERATION

One of the most effective and practical improvements for stable acceleration is that by moving the low level electronics of the booster rf system to the auxiliary room the booster rf systems are less affected from the beam induced noises, which also makes possible to optimize precisely the loop gains for the rf feedbacks.

In the last two years, the annual operation is about 4500 hours, ~67% of total operation time spent for physics programs in which deuteron programs were included and ~17% for accelerator studies.

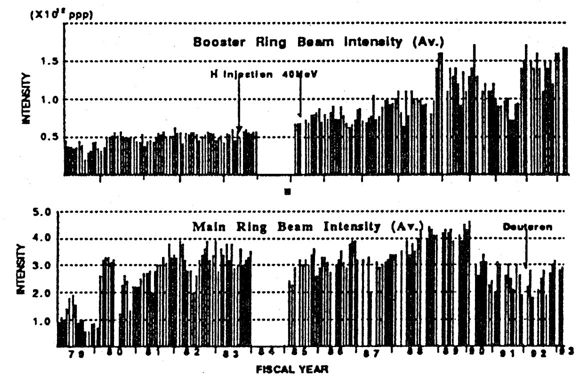
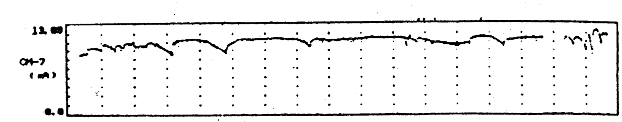


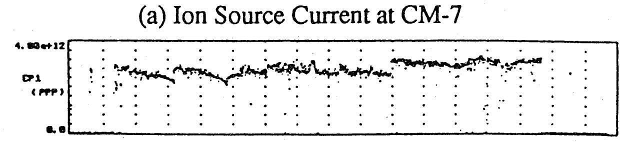

Figure 1. Cycle-to-Cycle Variation of Average Beam Intensity of both The Booster and 12-GeV Proton Synchrotrons.

### A. Preinjector and Injector

As Figure 2 shows, fluctuations in an intensity of extracted beam from the 12 GeV Main Ring is closely related to a change of beam current from the ion source. This change of beam current is due to some conditions inside the ion source, such as a change of cathode current, a change of amount of Cesium ions on the converter surface, etc.



(a) Ion Source Current at CM-7



(b) Extracted Beam Current (EP1)

(unit: 1 day / bin )

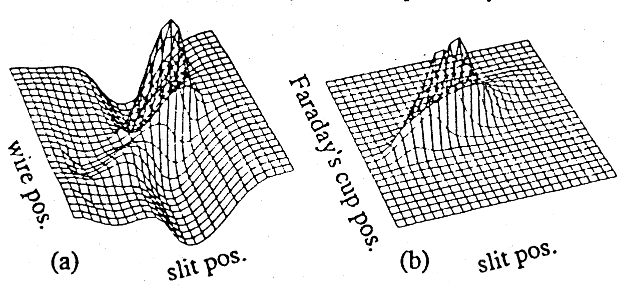
Figure 2. Fluctuations in Both The Extracted and Ion Source Beam Intensities

And also, a discharge inside the accelerating tube of the Cockcroft-Walton preinjector affects the beam intensity.

Numerous electrons from the ion source simultaneously extracted with $H^-$ ions cause to initiate the discharge. Two pieces of permanent magnets were placed inside the ion source as an electron suppresser, which could completely eliminate electrons from the ion source. Numbers of discharge were immensely suppressed by this modification.

### *B. 40 MeV Transport Line*

The emittance monitor at the 40 MeV Line was improved and modified in the late 1992. The previous emittance monitor consisted of a silt and a Tungsten wire electrode. The wire collects beams through the slit as an electric signal. However, the electric signals from the wire electrode were influenced by secondary electrons. The output signal was always perturbed by them. To avoid this problem, a newly designed Faraday's cup has been installed instead of Tungsten wire. With this modification, more reliable emittance measurement became possible. Typical rms values of transverse emittance of 40 MeV proton beam are $\varepsilon_H = 3.3\,\pi$ and $\varepsilon_H = 2.8\,\pi$ mm mrad. Figure 3 shows comparison between the results with old and new systems, respectively.




Fiqure 3. Comparison between the Two Emittance Measurements: Typical vertical signal distributions are shown, (a) measured by the previous slit-wire system (b) the new slit-Faraday's cup system.

The non-destructive profile monitors [2] and the emittance monitor have been utilized for a beam transport tuning and for a booster injection matching. The parameters of the Q-magnets and steering magnets of the transport line can be automatically optimized with the Twiss parameters from the measured beam profiles. Also recently, by means of the tomographic analysis for the beam profiles, it becomes possible to estimate the three dimensional beam distributions in the transverse phase space.

### *C. Time Structure of Slow Extracted Beam*

The slow extracted beam (=spill) is not an ideal DC beam, but has a burst structure. This burst depends on the ripple components of magnet power supplies or on the re-bunching structure of the circulating beam; the former contributes the low frequency components of the time structure less then ~1 kHz and the later the high frequency components related to a revolution period of beam. The amplitude of ripple components is strongly affected to the AC power line fluctuation of 6.6kV. The ripple components are normally 50 and 100 Hz, and the ripple ratio of QF magnets at the 12GeV acceleration pattern is typically the order of $10^{-6}$. But, as the fluctuations in an AC power line raise, the other frequency components (such as 70 or 130 Hz,etc.) become greater, and the ripple ratio increases up to the order of $10^{-4}$. In order to suppress a low frequency burst structure, the feedback roop analysis of the spill controller has been carried out. While, by means of driving the RF system with the re-bunch signal so as to cancel a wake filed of beam, it has successfully suppressed the high frequency burst structure.

### *D. Beam Monitor*

For stable acceleration of low intensity beams in both synchrotrons, a high quality beam monitor signal is essential for the rf beam feedback. For example, in helium beam acceleration, the intensity is expected to be at the most between 1/5 and 1/10 of that in acceleration of D+ or H+ beam. Therefore, the pre-amplifier gain has been increased. Also, in order to measure an absolute current of low intensity beam, a highly sensitive DC current transformer; so-called the parametric current transformer [3], has been installed in the Main Ring recently. A preliminary examination of this monitor shows that the relatively low intensity beam can be detected. But rf and beam induced noises are considerably large, the intensity is limited to ~$10^{10}$/bunch. The suppression of these noises is an urgent problem. In the Booster Synchrotron, the proton beam of $4.5\times10^9$ /bunch has been successfully accelerated with 40 dB higher gain of $\Delta r$ feedback monitor and 20 dB of $\Delta\phi$, and in the Main Ring an intensity of $1.1\times10^{10}$ /bunch x 9 bunches by using 20 dB higher gain of both $\Delta r$ and $\Delta\phi$ feedback monitors. These results cover the estimated helium beam intensity in Table-2.

## III. DEUTERON BEAM ACCELERATION

### *A. Summary of Deuteron Acceleration*

Since the deuteron program started in 1991, including the studies of proton beam simulation, 109 shifts of the machine study time were used for the deuteron acceleration tests, and the slow beam extraction trials with various different energies [4]. The main parameters of deuteron beam are summarized in Table 1.

Table 1.
Typical Beam Parameters in Deuteron Acceleration

| | |
|---|---|
| Ave.Beam Intensity @ Flat top | ~ 2 x $10^{12}$ |
| Acceleration Efficiency : Booster | ~ 85 % |
| : Main Ring | ~ 90 % |
| Extraction Efficiency | ~ 90 % |
| Emittance @ Linac Exit (rms:mm.mrad) | |
| : Vertical | 5.6 |
| : Horizontal | 9.8 |
| Momentum Spread ($\Delta p/p$) at MR injection | 0.33 % |
| Bunch Width at Booster extraction | 150~180nsec |

In order to accelerate deuteron beam, some of modifications in the accelerator have been carried out and the scheme of operation has been changed as necessities.

For making a complete longitudinal bucket matching between the Booster Synchrotron to the Main Ring, the extraction RF voltages of the Booster Synchrotron are limited to ~ 5 kV. Under this condition, the bunch length of the beam injected into the Main Ring is typically 160 nsec. The pulse widths of both the booster extraction and the main ring injection kicker magnets are 130 and 110 nsec in proton acceleration. For deuteron acceleration, therefore, those widths are extended to be 250 and 180 nsec, respectively, so that the kickers cannot kick the edge of beam.

# IV. HELIUM BEAM ACCELERATION

In the case of acceleration of atomic ions heavier than deuterium ion such as $^4$He, $^{12}$C, $^{14}$N..., not negatively but positively charged ions are accelerated in the present Linac, hence the booster injection method entirely differs from that in proton ($H^-$) or deuteron ($D^-$). A multi-turn injection technique is adopted instead of a conventional charge exchange injection method. A new septum magnet [5] has been invented so that both negative and positive beams could be injected into the Booster Synchrotron. This magnet is indeed a key whether ion beam acceleration becomes possible without disturbing acceleration of a high intensity proton beam supplied to the Booster Utility Facility.

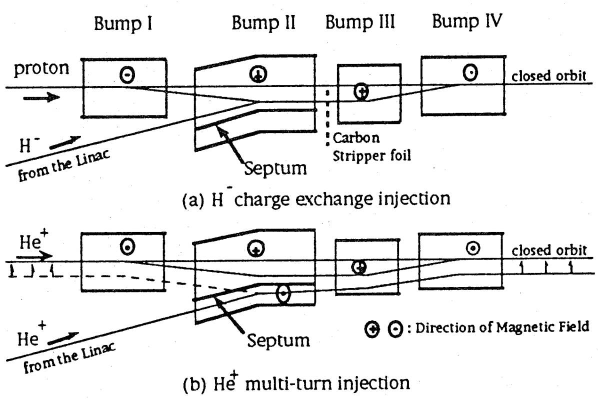



Figure.2 Comparison of Booster Injections for Negative and Positive Ions

## A . *Booster Injection*

The newly designed septum magnet is replaced with one of four bump magnets ( named as Bump II in Figure 2). This septum magnet has the opposite sign magnetic fields in both sides of its vertical septum plane. So, negatively charged beam such as $H^-$ or $D^-$ travels outside of the septum plane, and its electrons are stripped at a carbon foil. On the other hand, in the case of a positively charged beam injection, the closed orbit at the injection point is shifted about 50 mm outside from the central orbit by exciting two fast bump magnets, which are placed at both up- and down- streams of the booster injection point ( not shown in Figure 2), the beam is injected inside of the septum plane and its injection point moves horizontally from the center to the outside of the phase space by moving the bump orbit.

## B. *Helium Acceleration*

Helium ions are extracted as singly charged positive ions from an cusp type of ion source. and accelerated by the Cockcroft Walton preinjector with total accelerating voltages of 750 kV, at an adjacent gas cell ($N_2$ or Ar gas) their electrons are stripped and fully stripped helium ions; $He^{2+}$(e/m = 0.5), are generated. They are injected into the Linac and accelerated up to 10MeV/u. The capture efficiency is expected to be ~30%, that is comparative with that in deuteron acceleration. The beam intensity in the Booster Synchrotron should be less than a tenth of that in deuteron acceleration, because of the 3 to 6 turns of injection are expected. In Table-2, the estimated helium beam intensities at each point of acceleration are summarized.

Table 2
Summary of Expected Helium Beam Intensity

| | | | |
|---|---|---|---|
| Ion Source | | 15 pmA | |
| after gas stripper : $He^{2+}$ | | 5 pmA | |
| Linac | : Entrance | 3 pmA | |
| | : Exit | 0.9 pmA | |
| Booster | | $3 \times 10^{10}$ ppb | * |
| Main Ring | | $2 \times 10^{11}$ ppp | ** |

* : estimation of three turns injection including 30% of beam losses in the ring
** : 9 bunches and 30% of beam losses in the ring

# V. SUMMARY

In the 1990's, the KEK Proton Synchrotron has attained a steadied age. Our efforts have been focused on operating each component of the accelerators stable and systematic. The introduction of distributed VME computer system is also one of the factors met with a good result. On the other hand, the experiment programs using primary beams have been accepted at the Program Advisory Committee. And, both accelerations of various ions, including protons, and their extractions with various energies have been strongly required of the accelerator. Deuteron program was the really first step toward the new future of the KEK Proton Synchrotron. To succeed to accelerate helium acceleration in the next step is to develop the KEK Proton Synchrotron into the world unique accelerator, which may cover both particle and nuclear physics in the region of energy of GeV per nucleon.

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# VI. REFERENCES

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