*The 6th Symp. on Accelerator Science and Technology, 1987, Tokyo, Japan (© Ionics, Tokyo, 1987)*

# PRESENT STATUS OF THE 12 GeV PROTON SYNCHROTRON

KEK PS Group (Presented by I. Yamane)
National Laboratory for High Energy Physics
Oho-machi, Tsukuba-gun, Ibaraki-ken, 305, Japan

## ABSTRACT

The injection scheme of the booster synchrotron of the KEK PS has been converted to the $H^-$ charge-exchange injection and the injection energy has been also upgraded to 40 MeV in 1985. The cooperative use of the polarized proton beam has been started in 1987. The present status after the improvements is reported.

## INTRODUCTION

There has been appreciable change in the status of the KEK-PS[1] after the last meeting of this symposium. Three up-grading plans, which were prepared before the long forced shutdown in 1984 to 1985 due to the construction of the TRISTAN, have been put into practice as follows:

1) The scheme of beam injection into the booster synchrotron was converted from the proton multi-turn injection to the $H^-$ charge-exchange injection at the reopening of operation after the long forced shutdown.
2) A new linac tank with an energy gain of 20 MeV was installed in the tunnel in summer 1985. The injection energy of the booster synchrotron was extended from 20 MeV to 40 MeV.[2]
3) Supply of the polarized proton beam to the users of the main ring beam was started in May 1987.

The beam intensity of the booster synchrotron has increased through the improvements 1) and 2). The highest intensity achieved in the booster changed from $6.7 \times 10^{11}$ ppp for the proton multi-turn injection to $1.55 \times 10^{11}$ ppp for the $H^-$ charge-exchange injection.

It was a notable progress that the medical use was started in the BSF (Booster Synchrotron Utilization Facility) at the reopening of operation after the long forced shutdown.

## $H^-$ INJECTION AND $H^-$ CHARGE-EXCHANGE INJECTION

### $H^-$ ion source and preaccelerator

The unpolarized $H^-$ ion source[3] is a multicusp $H^-$ ion source, which consists of a cylindrical plasma chamber, a cesiated molybdenum converter and a couple of $LaB_6$ filaments.

Relatively low operating temperature (∿ 1450°C) of the $LaB_6$ filaments brings about a long lifetime (∿ 2500 hr) of the filament and a low Cs consumption rate. The long lifetime of the filament as well as the long interval between charges of cesium has been effective to the stable operation of the source.

The current of the $H^-$ beam is 15 ∿ 20 mA in the normal operation and the beam is very stable. The normalized 90 % emittance measured at the entrance of the linac is ∿ 2 mm•mrad.

The preaccelerator is the old Cockcroft-Walton accelerator of 750 keV energy. The length of the beam pulse, that is required to be accelerated, is tailored by an electrostatic chopper installed in the beam transport line between the preaccelerator and the linac.

### Linac and debuncher

The linac is an Alverez-type linear accelerator which consists of two tanks with an energy gain of 20 MeV each.[4] It accelerates the $H^-$ ion from 750 keV to 40 MeV.

The design features of the second tank, which was newly fabricated, are as follows:

1) It is based on the post-stabilized structure.[5]
2) Drift-tube quadrupoles are made of Alnico-9 permanent magnets.[6]
3) The tank is provided with fourteen tuners. Two of them are used to tune the resonant frequency of the tank to that of the first tank automatically.
4) The servo-loop technique is applied to stabilize the relative phase between two tanks.

The r.f. power for the 40 MeV linac is fed by an r.f. system modified from that of the original 20 MeV linac. For the original 20 MeV linac the power of proton beams amounted to 2.4 ∿ 3 MW, and the r.f. power were fed by two TH516 amplifier systems to the cavity. In the 40 MeV linac scheme accelerating negative hydrogens, the beam power is reduced by a large factor and one amplifier is sufficient for one accelerating tank. Therefore, r.f. power from each amplifier is devided by a Tee power splitter and fed to the cavity of one tank.

The typical beam current of the linac is 20 mA at the entrance and 10 mA at the exit of the first tank. The transmission in the second tank is excellent.

It has been recognized that the emittance depends upon the r.f. level, the phase difference between tanks and the strength of drift-tube quadrupoles as well as the position and angle of the injected beam. Measured values scatters from 2 to 7 mm•mrad, but it would be said that the normalized emittance of well tuned beam is ∿ 3 mm•mrad.

The momentum spread of the output beam is 0.4 % (FWHM) with a debuncher and 0.7 % (FWHM) without the debuncher. The debuncher is a re-entrant type of single gap cavity which is installed 9.8 m behind the linac.

### $H^-$ charge-exchange injection[7]

The equipments for the $H^-$ charge-exchange injection are installed in the straight section No.1 of the booster. The $H^-$ ions are changed to protons in the stripping foil which is placed on the injection bump orbit.

Since the injection energy of 40 MeV is rather low, a very thin stripping foil is needed. A new type of stripping carbon foil[8] was developed for this purpose. Carbon foils of about 30 μg/cm$^2$ in thickness have been used in the routine operation at 40 MeV. It has turned out that the lifetime of the foil is sufficiently long. One of the foils lasted for about a year

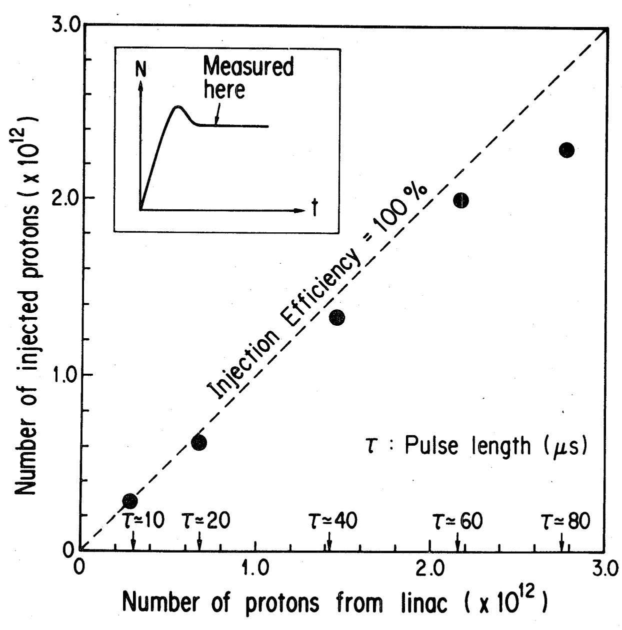


Fig. 1 Efficiency of the charge exchange injection.

and was used for injection of about 10,000 μA•hr $H^-$ ions.

The efficiency of the charge-exchange injection depends on the pulse length of the injected beam, as shown in Fig. 1. The typical pulse length in routine operation is about 30 μs and an efficiency over 90 % is attainable. In practice, it takes somewhat lower value depending on the degree of tuning of the linac and the injection system.

## Beam acceleration in the booster and the main ring

It is notable that the intensity of the booster beam has increased to twice after the change but the intensity of the main ring beam remains at the same level before the change. As shown in Fig. 5 the maximum average intensity of the booster beam has reached to $1.04 \times 10^{12}$ ppp, while that of the last cycle before the change was $5.3 \times 10^{11}$ ppp. On the other hand, the average intensity of the main ring beam remains at the level of $3.3 \times 10^{12}$ ppp that is the average intensity before the change.

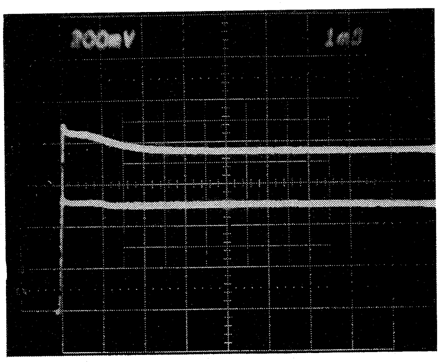

Fig. 2 Variation of particle numbers in the booster.
Upper: $7.7 \times 10^{11}$ ppp (for the BSF)
Lower: $5.0 \times 10^{11}$ ppp (for the MR)

As is shown in Fig. 2, two kind of beams with different intensity are accelerated in the booster. Beams with the higher intensity is assigned to the BSF and those with the lower intensity to the main ring. In order to accelerate such a high intensity beam as assigned to the BSF, the needed r.f. voltage becomes rather higher. This makes the longitudinal emittance of the beam so large that the beam can not be fully captured in the r.f. bucket of the main ring. Therefore the intensity of the beam assigned to the main ring is suppressed at an appropriate level by shortening the pulse length of the $H^-$ beam. Beams with different intensity are accelerated in time sharing mode by two r.f. voltage programs.

The variation of the particle number during acceleration in the booster shows two distinctive drops just after the injection process and around 1 ms after injection. The first drop is considered to be related to the injection process. The second drop corresponds to the adiabatic capture process. The loss during the r.f. capture depends on the beam intensity and is also a complicated function of actual operating parameters of the booster as well as the parameters of the injected beam. Ten to fifteen percent of the beam is lost at the normal operating intensity, $8 \times 10^{11}$ ppp.

In the past few years efforts have been made to improve the feed-back system of the r.f. accelerating cavities. The counter-phase operation of two cavities enables us to reduce the effective r.f. voltage at injection below 100 Vp-p. As a result, the efficiency of the adiabatic capture has been improved.

No operating parameter of the main ring was change by the change of the injection scheme of the booster.

The (100 %) emittance of the injected beam is 45 mm•mrad and 25 mm•mrad in the horizontal and the vertical planes, respectively. The momentum spread is measured to be ± 0.36 %.

The variation of the particle number in the main ring from the start of the injection to the end of the spill is shown in Fig. 3. As can be seen in the picture, the beam loss occurs at the parabola and at the passage of the transition energy. The loss generally depends on the beam intensity and on actual tuning of operating conditions. The loss in this example is ∿ 20 %.

According to the construction of the new counter hall, a new slow-extraction system is now under construction.

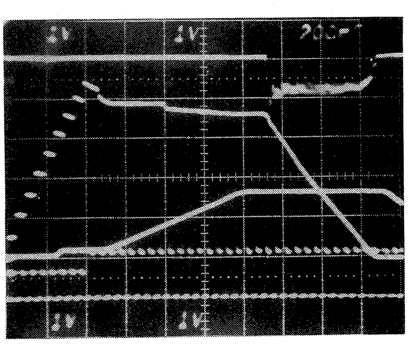

Fig. 3 Variation of the particle number in the main ring. (From top to bottom the spill; the particle number, the magnetic field of the main ring and the pulse train of the booster beam).

# POLARIZED BEAM

## Polarized $H^-$ ion source[9]

The polarized ion source is based on a charge exchange reaction between fast hydrogen ions extracted from an ECR ion source and electron-spin polarized sodium atoms produced by optical pumping with a dye laser.

The dye laser is a pulsed one using two Xe lamps which pumps R6G dissolved in ethanol flowing through a pyrex tube. The peak power is from 300 to 500 W in the pulse width of 60 μs.

## Polarized beam acceleration[10]

The acceleration test of polarized beams started in 1983. During the forced shutdown in 1984 to 1985,

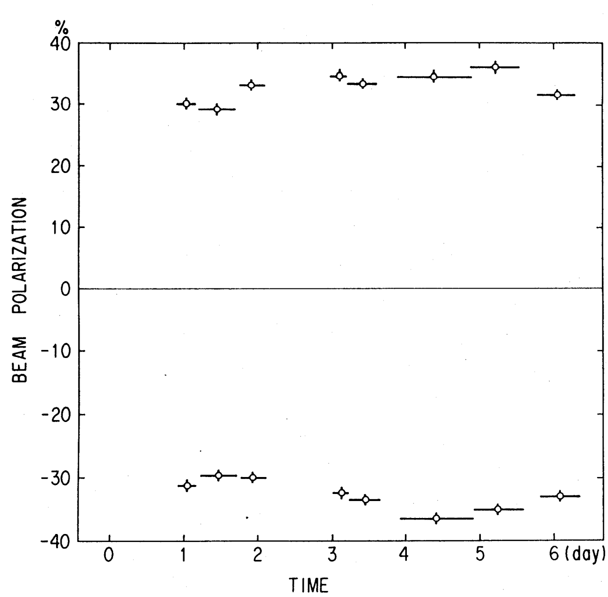


Fig. 4 Variation of the polarization during a cycle.

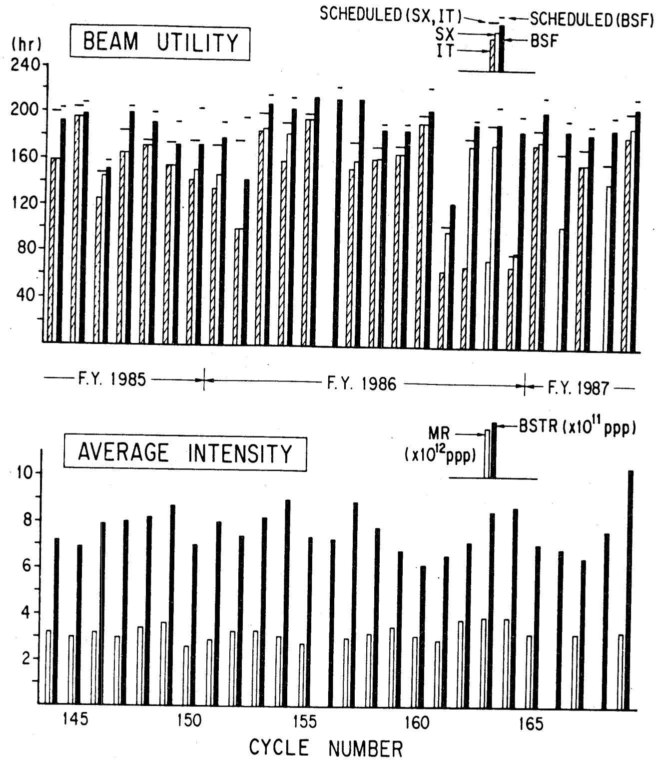


Fig. 5 Variations of the average intensities and the beam utility times.

following improvements have been made:

1) The pulsed dye laser system was developed.
2) Feedback electronics of the r.f. accelerating system and the beam monitoring system have been improved to deal with the low-intensity polarized beam.
3) The internal polarimeter was installed in the main ring to measure the polarization during acceleration.

In the booster there are two strong depolarizing resonances: an imperfection resonance ($\gamma G = 2$) at 108 MeV and an intrinsic resonance ($\gamma G = \nu_z$) at 260 MeV. The method of adiabatic spinflip is used to cross these resonances. In addition a weak resonance ($\gamma G = \nu_z$) is expected at 180 MeV. Calculation suggests some depolarization at this resonance. Actually seventy-five percent of the polarization has been preserved in the booster. The polarization attains 45 % at the beam intensity of $1 \times 10^9$ ppp at present.

In the main ring, the polarization of 43 % was achieved at 3.5 GeV for the first time in December 1986. Tests are now continued to accelerate polarized beams to higher energy. The present aim is 7 GeV.

The cooperative use of polarized proton beams of 3.5 GeV kinetic energy was started in May 1987. Two cycles were dedicated to the physics experiment using polarized proton beams. Fig. 4 shows the run by run variation of the polarization during the second cycle.

## ACCELERATOR OPERATION CONDITION

The 12 GeV PS is usually operated in a "two weeks mode", in which operation is started in Wednesday and stopped in Saturday of the next week. Ten days of operation period is called a "cycle". Except for 1984 and 1985, the machine has been operated in thirteen or fourteen cycles a year.

Since 1980, accelerated beams have been supplied to the BSF at 500 MeV kinetic energy, and also to the IT (Internal Target) and to the SX (Slow Extraction line) at 12 GeV kinetic energy. The booster synchrotron accelerates twenty beam pulses in a second. Nine pulses in every 2.5 seconds are fed to the main ring and supplied to the IT and the SX after acceleration to 12 GeV. The rest of the booster beam pulses are supplied to the BSF. In the present condition of operation beam pulses assigned to the main ring and those to the BSF are accelerated with different intensity in the time sharing mode.

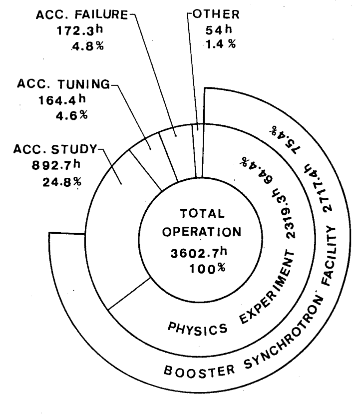


Fig. 6 Machine time distribution in F.Y. 1986.

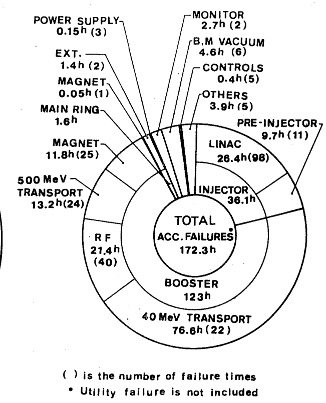


Fig. 7 Failure statistics in F.Y. 1986.

### Beam condition and beam utility

Fig. 5 shows cycle by cycle variations of the average intensities and the beam utility times after the up-grading of the linac energy. Cycles, in which column of the average intensity of the main ring disappears, were dedicated to the machine times using polarized proton beams.

Bars over the columns of the beam utility indicate scheduled utility times. Differences between scheduled and actual utility times are not so large as the cycle by cycle variation of the columns.

Fig. 6 shows the machine time distribution in F.Y. 1986. The fraction of the accelerator study was appreciably high. One of the main themes was the development of the polarized proton beam. Many of other thermes were related to the new situation of the acceleration with the $H^-$ charge-exchange injection.

Fig. 7 shows the failure statistics in F.Y. 1986. A larger part of the failure of the 40 MeV transport were failures of the power supply of the $H^-$ injection magnet. Almost all failures of the linac occured in the modified r.f. system.

## REFERENCES

1) M. Kihara et al., Proc. Int. Workshop on Hadron Facility Technology, Santa Fe, Inn at Lorette, USA (1987), or KEK Preprint 86-107.
2) S. Fukumoto, Particle Accelerator, Vol. 20, No.1 (1986), p.71.
3) Y. Mori et al., Proc. 4th Int. Symp. on the Production and Neutralization of Negative Hydrogen and Beams, BNL (1986).
4) J. Tanaka et al., Proc. 1976 Proton Linear Accelerator Conf., Chalk River, September 1976, p.333. S. Fukumoto et al., Proc. 13th Int. Conf. High Energy Accelerators, Novosibirsk (1986).
5) T. Kato and S. Machida, Proc. 1986 Linear Accelerator Conference, SLAC (1986).
6) E. Takasaki et al., Proc. 5th Symp. Accelerator Science and Technology, KEK September 1984, p.206.
7) T. Kawakubo et al., Proc. 13th Int. Conf. on High Energy Accelerators, Novosibirsk, USSR (1986).
8) I. Yamane and H. Yamaguchi, Nucl. Instr. Meth. in Phys. Res. A254 (1987) 225-228.
9) Y. Mori et al., Proc. 4th Int. Symp. on the Production and Neutralization of Negative Hydrogen and Beams, BNL (1986).
10) S. Hiramatsu et al., Proc. 6th Int. Symp. on High Energy Spin Physics, Marseille, 1984, p.529. S. Hiramatsu et al., Proc. 7th Int. Symp. on High Energy Spin Physics, Protvino, USSR, 1986, p.119.