PERFORMANCE IMPROVEMENT OF THE KEK PS-BOOSTER SYNCHROTRON

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The beam intensity of the KEK PS-Booster synchrotron cleared the level of 2×10^{12} ppp. To realize this intensity many efforts have been payed not only to recover missed Booster ring acceptance and to make the Booster RF power supply tolerable against a heavy beam loading, but also to tune synthetically all the system from the ion source to the 12 GeV synchrotron.
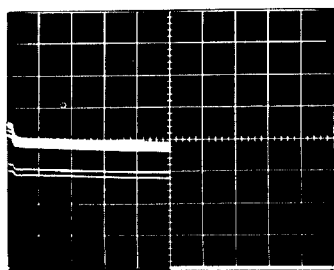
Introduction

At the KEK proton accelerator [1], a project has been undertaken for the last two years to increase beam intensity of the booster synchrotron to 2×10^{12} ppp from 8×10^{11} ppp at the start. The aim has been recently achieved and the synchrotron is now operated in routine at an intensity level of 2×10^{12} ppp. In the first year, many efforts were payed to understand and solve two problems, namely a low injection efficiency below 90 % and a large beam loss about 1 msec after injection. These problems were settled in a year. At the beginning of 1988, the injection efficiency became nearly 100 % and the beam loss disappeared. Then the beam intensity was about 1.2×10^{12} ppp. However, it steadily increased acompanying progress of injector tuning and inprovement of the RF power supply to tolerate higher beam intensity.
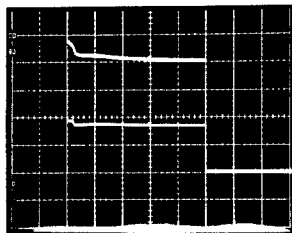
Present Status of the Booster Synchrotron

At present, the KEK PS-Booster synchrotron accelerates about 2×10^{12} protons upto 500 MeV at a repetition rate of 20 Hz and the average current is 6 μA in the routine operation. For the BSF

(a) before improvement

2×10^{11} ppp/div
5 msec/div

(b) after improvement

5×10^{11} ppp/div
5 msec/div

Fig. 1 Improvement of the Booster beam intensity during acceleration

(Booster Synchrotron Utilization Facility) this full beam is usually supplied, but a reduced amount of proton is supplied for the 12 GeV main ring, because the beam intensity which can be safely accelerated to 12 GeV is limitted to about 4×10^{12} by beam losses at the beginning of acceleration and at the transition energy. A present typical time dependence of the Booster beam intesity is shown in Fig. 1 (b) with that at the start of the intesity improvement project (a).

The efficiency of H^- injection is now nearly 100 % even when about 2.4×10^{12} H^- ions are injected. The beam loss at about 1 msec after injection which had been a serious question for a long time is now supressed upto an intensity level of more than 1.7×10^{12} ppp.
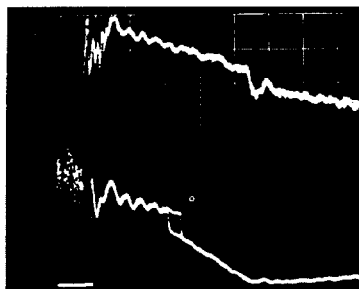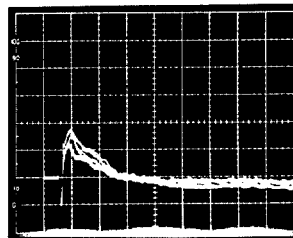

(a) before improvement

upper : phase error signal
lower : ΔR (10 mm/div, 0.2 msec/div)

(b) ΔR after improvement

(5 mm/div, 0.2 msec/div)

Fig. 2 Oscilloscope displays showing reduction of the ΔR just after injection

Readjustments

Recovery of missed acceptance

In some machine studies for the project to upgrade the Booster beam intensity, it was found that the orbit radius was considerably large at the injection time. The ΔR (error of the orbit radius) was about 20 mm or more as is shown in Fig. 2 (a) lower. The ΔR was coupled with the size of the injection bump orbit [2] as Fig 3 shows. Therefore both increase of the minimum guiding field

INJECTION BUMP MAGNETS
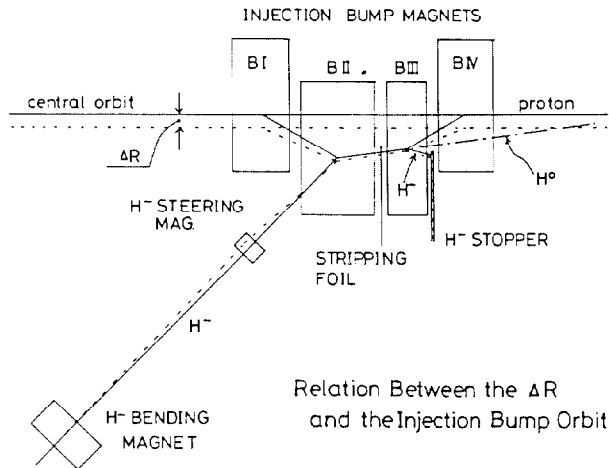
Relation Between the ΔR
and the Injection Bump Orbit

Fig. 3 Schematic view of the beam orbits around the Booster
injection point

and reformation of the bump orbit were necessary to correct the ΔR.

After the correction the ΔR became fairly small as Fig. 2 (b) shows
and the horizontal acceptance seemed to recover a considerable
amount.

In the vertical plane, a correction of the closed orbit was
made with a pair of steering magnets which were newly installed in
two straight sections. Although these steering magnets are d.c.
magnets, they are effective to correct the closed orbit at the injection
time. Figure 4 shows Booster beam intensity contours on the plane
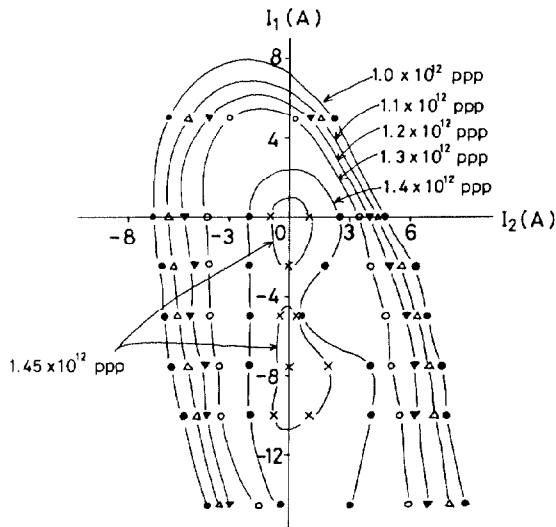of steering magnet currents. At present they are operated with $I_1 = -4.8$ A and $I_2 = 0.0$ A.

Fig. 4 Booster beam intensity contours on the plane of steering
magnet currents

Improvements of RF Power Supply

The bias power supply in the Booster RF power supply II
was improved so that its frequency response sufficiently covered the
frequency range(< 6 kHz) of the synchrotron oscillation at the
injection time. Figure 5 shows the frequency response before (a)
and after (b) improvements. It effectively suppressed the fluctuation
of the RF bucket caused by the large fluctuation of the autotune
signal which had occured accompanying the beam injection.

Also improvements in connection between ground levels of
the power amplifier and the cavity made equality of those levels
much surer and greatly suppressed the misoperation of the autotune
phase detector. This considerably raised tolerability of the RF power
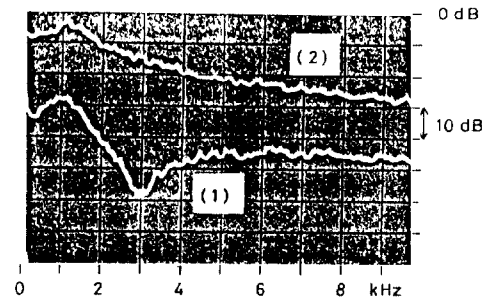
(a) before improvement (May , 1987)
(1) output current amplitude
(2) input for the driver circuit when
the bias current is 500A
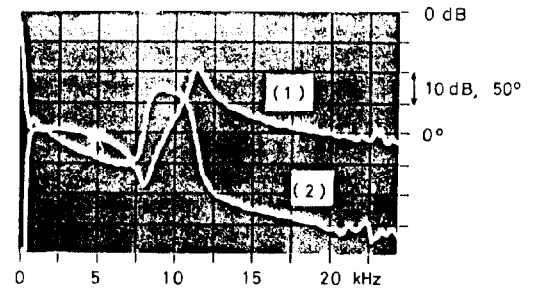
(b) after improvement (Jan , 1988)
(1) output current amplitude
(2) output current phase

Fig. 5 Frequency response improvement of the Booster RF II ferrite
bias power supply

supply to higher beam intensity.

In addition to these improvements, it seems very effective
for improvement of adiabatic beam capture to have changed the
beam injection time from 240 μsec after to 200 μsec before the
bottom of the guiding field.

Power Level Readjustment of two linac tanks

Since the addition of the tank II to upgrade the H⁻ beam
energy to 40 MeV [3], tank power levels had been set at about 1.4
MW for the tank I and at about 1.05 MW for the tank II, following
former experiences with the 20 MeV linac and early tuning results of
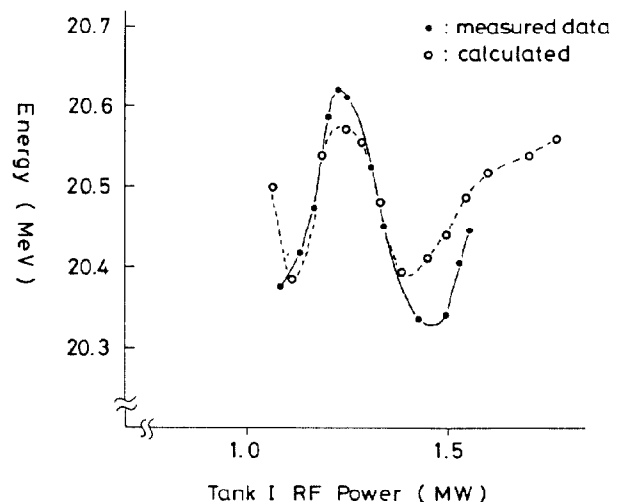the new 40 MeV linac. However, it turned out at around July, 1987

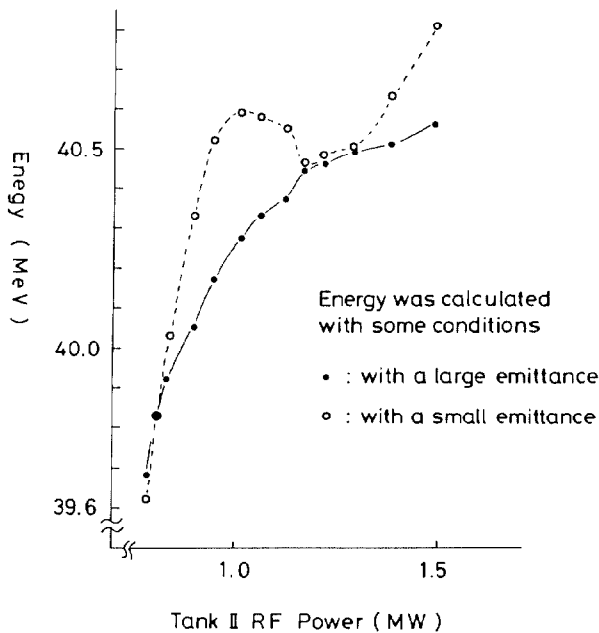Fig. 6 Tank I RF power dependence of the output beam energy

Fig. 7 Tank II RF power dependence of the output beam energy

that, when the power level of the tank I got down to 1.2 MW, the booster injection efficiency became considerably high and the beam loss at 1msec after injection decreased despite of rather high beam intensity. The value 1.2 MW meant that the energy of output beam from the tank I was 20.6 MeV, as is shown in Fig. 6. And 20. 6 MeV was the design value of the injecting energy for the tank II.

The power level of the tank II was gradually raised from the autumn of 1987 and also settled at around 1.1 MW. Following the design calculation, the fact that the power level of the tank II was about 1.1 MW meant that the energy of output beam from the tank II was nearly 40.4 MeV as is shown in Fig. 7. This energy was slightly higher than 39.5 MeV to which the B_{min} (minimum of the guiding field) had been adjusted in the early tuning after the linac upgrade. It explained naturally why the B_{min} had to be raised to reduce the ΔR just after injection.
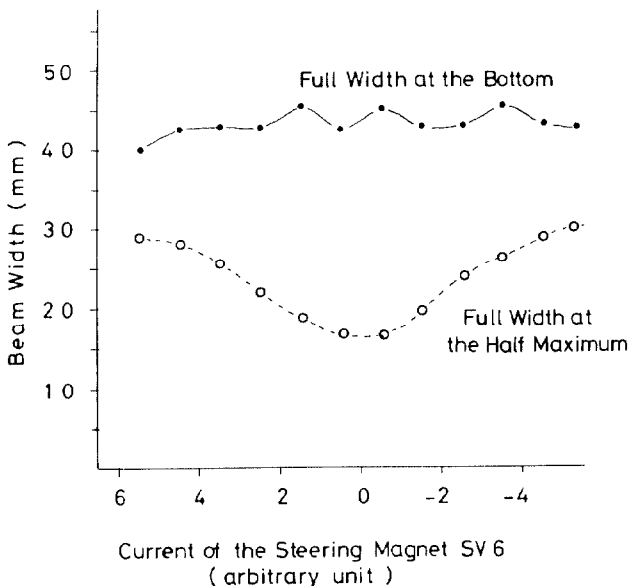

Fig. 8 Dependence of the vertical beam width at a profile monitor Pr-5 in the Booster extraction line upon current of a steering magnet SV-6 in the Booster injection line
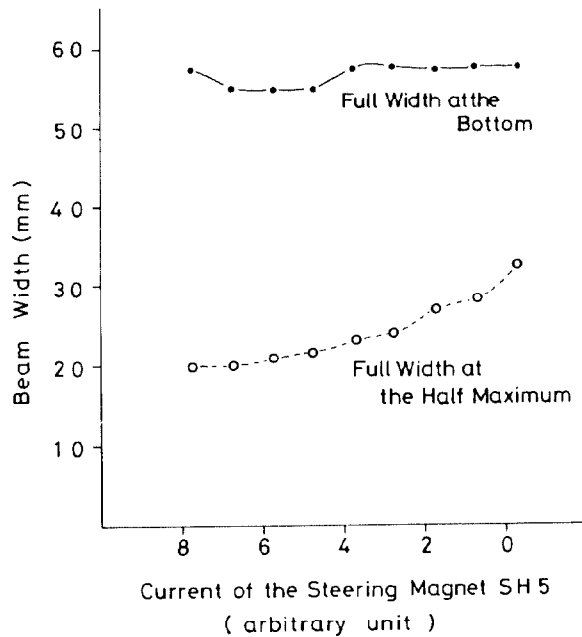

Fig. 9 Dependence of the horizontal beam width at a profile monitor Pr-6 in the Booster extraction line upon current of a steering magnet SH-5 in the Booster injection line

Overall Tuning from the Ion Source to the Main Ring

In the first year of the project, it was found that some profile monitors in the beam transport line from the booster to the main ring provided convenient and effective monitors to observe injection error of the booster synchrotron. Figures 8 and 9 show examples of beam size variation depending upon the current of steering magnet in the Booster injection line. By this method of monitoring, injection error of the Booster became to be considerably suppressed.

In the next year, more comprehensive tuning from the H⁻ ion source to the Main ring was undertaken. Accompanying progress of the tuning, conditions of the Booster injection and acceleration were obviously improved. Especially tuning of the linac injection line was very effective. In this situation the Booster beam intensity was steadily increased as the beam intensity tolerance of the RF power supply became higher.

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