The beam intensity of the KEK PS-Booster synchrotron cleared the level of $2 \times 10^{12}$ ppp. To realize this intensity many efforts have been paid 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 $2 \times 10^{12}$ ppp from $8 \times 10^{11}$ ppp at the start. The aim has been recently achieved and the synchrotron is now operated in routine at an intensity level of $2 \times 10^{12}$ 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 $1.2 \times 10^{12}$ ppp. However, it steadily increased accompanying progress of injector tuning and improvement 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 $2 \times 10^{12}$ protons up to 500 MeV at a repetition rate of 20 Hz and the average current is 6 μA in the routine operation. For the BSF (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 limited to about $4 \times 10^{12}$ by beam losses at the beginning of acceleration and at the transition energy. A present typical time dependence of the Booster beam intensity is shown in Fig. 1 (b) with that at the start of the intensity improvement project (a).

The efficiency of H− injection is now nearly 100 % even when about $2.4 \times 10^{12}$ 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 suppressed up to an intensity level of more than $1.7 \times 10^{12}$ ppp.

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...
and reformation of the bump orbit were necessary to correct the \( \Delta R \). After the correction the \( \Delta R \) 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](image)

**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 occurred 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 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 \( \mu \)sec after to 200 \( \mu \)sec before the bottom of the guiding field.

**Power Level Readjustment of two linac tanks**

Since the addition of the tank II to upgrade the \( \text{H}^+ \) 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 that:

![Fig. 6 Tank I RF power dependence of the output beam energy](image)
Energy was calculated with some conditions:
- : with a large emittance
- : with a small emittance

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 1 ms 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. 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.

Acknowledgement

It is definitely acknowledged that all achievements described here were due to the patient efforts of all PS group members and the authors were speakers at the second meeting to discuss intensity upgrade of the Booster which became the base of this report.

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