Status of the 12-GeV KEK-PS Upgrade Project for the Long-BaseLine Neutrino Oscillation Experiment

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Abstract

Commissioning of the long-baseline neutrino oscillation experiments started from January, 1999, at the KEK-PS. In order to prepare the experiment, intensity upgrade studies and the hard ware improvements have been performed for a few years. The neutrino oscillation experiment requests the fast extraction. It needs to construct the fast kicker magnet system, and to re-construct the septum magnets and some other equipment. The switching of the fast extraction and the slow extraction can be done without the evacuation of the equipment in order to serve the beam for the multi-users as effective as possible. The results of the upgrade projects and the commissioning will be presented.

1 Introduction

The KEK-PS complex comprises two 750 keV Cockcroft-Walton pre-injectors, 40 MeV injector linac, 500 MeV booster synchrotron and 12 GeV main ring as shown in Figure 1. It has been operated successfully to serve a proton beam for more than past two decades [1]. Beams have been serving by the half integer slow extraction to East and North counter halls. Beam bunches accelerated in the booster except to the main ring are utilized as NML (Neutron and Meson Laboratory). To meet the need of new physics research, there are several objectives for the PS upgrade. Especially, an intensity upgrade is coming to the urgent problem for the long-baseline neutrino oscillation experiment[2]. This experiment demands the fast extracted high-intensity beam (10^{20} protons at the production target for a few years) creates the high current neutrino beam, which will be injected to Super-Kamiokande, about 250 km west of KEK. The main ring upgrade projects, intensity upgrade study, construction of the fast extraction system have been performed [3, 4, 5, 6]. The neutrino beam line and the production target were constructed for same days by the beam channel group in the Institute of Particle and Nuclear Studies [7]. Commissioning has been done from January to the end of June, 1999, and the first event was detected on June 19 at the Super-Kamiokande [8].

2 Fast Extraction and Neutrino Production Systems

Fast extraction of full circulating beam is requested for the neutrino oscillation experiment. The EP1 extraction system was modified so that both of slow and fast extraction are possible. The careful orbit analysis allows using existing slow extraction devices, such as bump and septum magnets system, the changeable system of the extraction kicker and electro-static septum (ESS) in the same vacuum chamber.

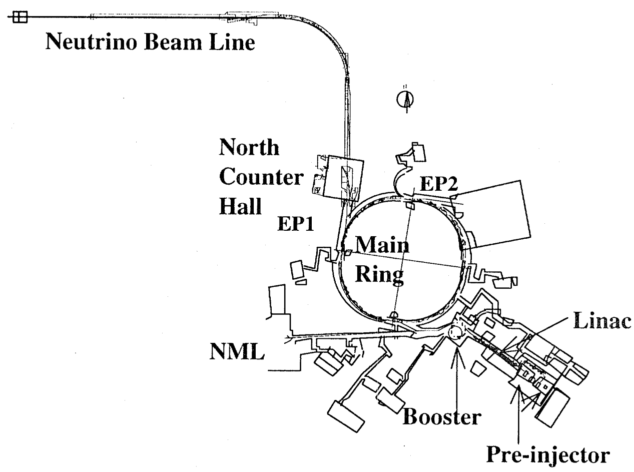

Figure 1 : Layout of the 12-GeV KEK-PS.

The kicker magnet consists of the 12.5 ohm kicker magnets and Blumlein power supplies to save the transmission time [9]. The field strength is requested higher than 0.11T and this should be realized within the space of 3m in one long straight section. The parameters of the kicker magnet are shown in Table 1 and the issues of the modification are as follows,
· ESS-kicker chamber construction, · kicker magnets construction, · ESS replacement, · septum A, B magnets improvements, · septum C magnet power supply construction, · septum E magnet replacement,
· beam ducts replacement, · control system upgrade.

Table 1. Parameters of the kicker magnet

Extraction Energy	12GeV
Magnetic Field	0.11T
Kick Angle	5.0mrad
Gap (Vertical)	55mm
Gap (Horizontal)	110mm
PFN Voltage	70kV
Rise Time (include transmission)	155ns
Flatness	1.1μs

A neutrino beam line extended from EP1-A primary beam line of the north counter hall towards the direction of the Super-Kamiokande. This comprises the straight section, the arc section, the target station, the decay volume and the μ-monitor pit[7]. A fast-extracted proton beam will be transported about 400 m and focused onto a production target. Two magnetic horns in the target station will focus produced pions to the forward direction, so as to maximize the neutrino flux which will be produced by decay-in-flight of pions in the 200 m decay volume. A primary proton beam will be stopped in the beam dump. A high-energy part of muons will be monitored at the μ-monitor pit. The neutrino flux is enhanced by a factor of 14 when two magnetic horns are operated. A positioning of the Super-Kamiokande from the KEK site was made by the global positioning system (GPS) [10].

3 Upgrade Studies before 1998

Every effort to realize the upgrade of KEK-PS have been devoted. Booster synchrotron accelerates more than 2 x 10^{12} ppp for NML, however, the main ring cannot accept the beam of this intensity. Machine studies for the intensity upgrade have continued to make clear the cause and cure of the difficulty. First of all, several tools for the machine study were developed and/or upgraded, such as an injection error monitor[11], a fast beam loss-monitor, a tune measurement system with an RF kicker, a fast wire scanner[12] and NMR field monitor[13] for the main ring bending magnet.

The concentrated studies in the spring of 1995 was focused on the beam injection to the main ring [3]. It seemed that the forth-order resonance was one candidate and in order to reduce the quadruple imperfection, several correction quadruples were necessary. However there were no installation space in the ring to install them, then the vertical tune was changed from 7.22 to 5.22 to reduce the effect of the fourth-order resonance. In order to increase the vertical aperture, the re-alignment of the main ring magnet in the vertical plane was done during summer shut down, 1996. The injection efficiency has increased up to 95-97%. During the magnet realignment was done, the fast floor movement, which seemed to depend on the weather condition, was observed . In order to confirm this phenomena, the measurement of the relative quadrupole magnet level and the floor tilt in the ring were going on [14].

The eddy current-induced sextupole field in the vacuum pipe in the main bending magnets forces the horizontal chromaticity into shifting from negative to positive values at the beginning of acceleration. Then the instability occurs just after acceleration starts. Octu-pole magnets were installed in the main ring to suppress the head-tail instability by the Landau damping, and the studies to confirm the suppression of instability and to measure the dynamic aperture are now processing [15].

Since KEK-PS's impedance budget has been not concerned, a lot of high impedance materials were periodically located along the ring. The two-third of resonant impedance devices, vacuum ducts between the bending magnet and the quadrupole magnet and the beam position monitor, were replaced by low impedance ones in 1996[5]. Further, in order to cross the transition energy in stable condition, γ-jump magnet power supplies were upgraded to make the voltage twice. The issues of the intensity upgrade are as follows,
· realignment of the quadrupole magnets in the main ring,
· replacement of bend-quad beam pipe, · upgrade of beam position monitors, · installation of beam instrumentation, · upgrade of the power supply for the γ-jump magnets, · installation of octu-pole magnets, · reliability of the accelerating RF.

4 Intensity Upgrade Studies at the Commissioning

Main ring beam tuning started on January 27 ,1999, by the slow extraction mode and the neutrino beam line tuning started on January 31 using slow-extracted beam. On the morning of February 3, the extraction system was changed from the slow extraction mode to the fast extraction mode after tuning the neutrino beam line except the horn system. System change was done in only three hours and main ring beam tuning started again. The kicker magnets were excited and the fast extracted beam was observed on the monitor screen at the exit of the septum magnet E. After short beam-off for the check of some instrumentation, the fast extraction tuning started again and the beam was confirmed on the production target. Fast extraction started again on March 3 after the completion of the horn system, and the task force tried to realize the beam intensity upgrade in the main ring[16].

Fast (< msec), medium (< a few msec), and slow loss (<50 msec) at the injection porch strongly depend on a set of betatron tunes in both directions beyond a beam intensity of 6.0x10^{11}/bunch. Fast loss is caused from betatron mismatching and rapid emittance blowup due to space-charge

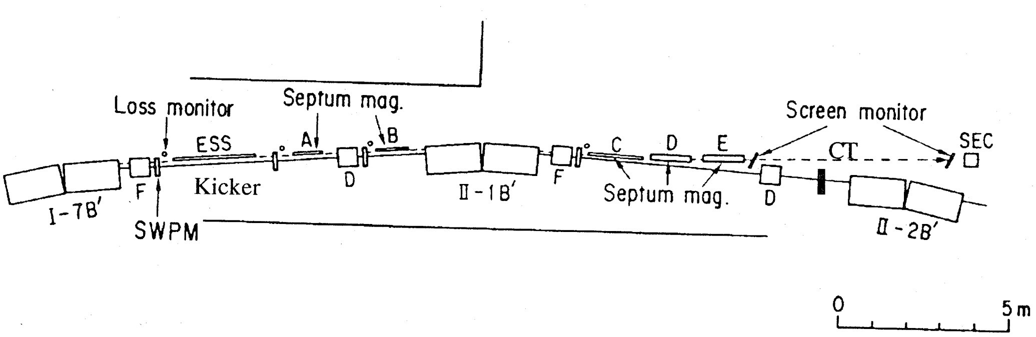

Figure 2 : Layout of the EP1 extraction system. ESS and kicker magnets are installed in the same vacuum chamber. Fast extracted beam bunches are measured by CT at the exit of septum magnet E.

forces coupled with the dynamic aperture depend on octupole fields. At this moment, the octupole magnets excited by the DC power supply. In order to optimize the octupole at the both of dynamic aperture at the injection and the correction of chromaticity after the acceleration start, the power supply should be replaced to ac ones.

Most of collective instabilities depend on the local beam density. Bunch shaping by an artificial beam blowup in the longitudinal direction is quite effective to cure the instabilities. A modulation method of the RF voltage by band-limited white signals[17] has been adopted. A particle resonates at one band of the modulation frequency and changes its amplitude where the resonate frequency shifts due to a phase nonlinearity of the RF voltage, the particle then starts to resonate at another frequency in the same band. This resonant dynamics continues until the particle arrives at the outer boundary that is covered with the band width. Although the control of longitudinal beam emittance was not perfect, a substantial reduction in the line density before transition has been practically achieved and the acceleration efficiency was clearly improved. This method was also adopted in the booster and very effective to reduce the beam loss during main ring injection. As a result, an average of 6.5×10^{12} ppp protons were accelerated. Figure 3 shows a history of the intensity upgrade.

5 Result

Fast extraction was completed by the 12.5 ohm kicker magnet with the Blumlein system. Fast and slow extraction are easily changed in a few hours. Intensity upgrade studies contribute to realize the average of 6.5×10^{12} ppp protons (maximum 6.8×10^{12} ppp) by the careful tuning of betatron tune, COD, the chromaticity control after accelerate by the sextupole magnets, Landau damping by the octu-pole magnet and the RF voltage modulations in the both of booster and main ring by the bunch shaping using a band-limited white signal. The first neutrino event was detected on June 19 at the Super-Kamiokande. For more intensity upgrade, there are many tasks should be requested such as re-alignment of both of bending and quadrupole magnets, octupole power supplies should be replaced ac ones, fixed system of the band-limited white signal RF modulation, upgrade of the orbit correction steering dipole magnet system and reliability of the accelerating RF etc.

Acknowledgment

The authors would like to express their sincere thanks to M. Kihara, director general of accelerator laboratory and I. Yamane, director of PS division, for their encouragement. They are much indebted to many colleagues of PS and beam channel staff for their discussions and collaborations.

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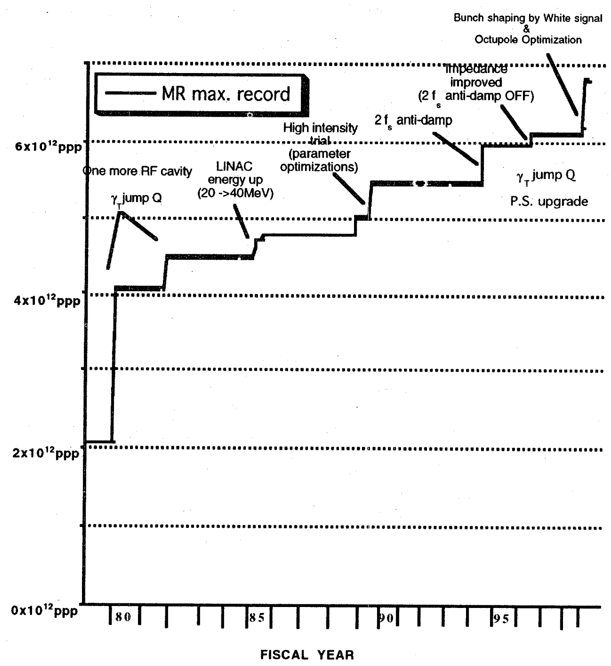

Figure 3 : History of the accelerating beam intensity in the main ring.