HIGH INTENSITY PERFORMANCE OF THE KEK 12GEV-PS FOR THE K2K EXPERIMENT

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Abstract

The long–baseline neutrino oscillation experiment has been successfully running since April 1999. In order to realize this experiment, improvement of the KEK-PS such as intensity upgrade studies and the hardware improvements had been performed. A factor of 50% increase of the beam intensity was achieved. It depends on the every effort to overcome the beam loss mechanism such as the micro-wave instability, the space charge effects at the various periods from injection through extraction period. 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 is possible without the evacuation of the equipment and the multi-users experiments are available in short time. The performance of the improvements of the KEK-PS and the high intensity operation status 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 (BR) and 12 GeV main ring (MR). It has been operated successfully to serve a proton beam for 25 years[1]. Beams have been served 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). An intensity upgrade was coming to the urgent problem for the long-baseline neutrino oscillation experiment, K2K (KEK to Kamioka)[2]. This meant the fast extracted high-intensity beam creates the high current neutrino beam to Super-Kamiokande about 250 km west of KEK. The hardware upgrade, intensity upgrade study [3, 4, 5] and construction of the fast extraction system had been performed [6]. The beam channel group in the Institute of Particle and Nuclear Studies constructed the neutrino beam line and the production target for same days [7]. Commissioning was started in January 1999 and the K2K experiment is continuing since April 1999.

Papers on accelerator development devoted to K2K experiment by the end of 1999 were collected into one volume [8]

2 FAST EXTRACTION

Fast extraction of full circulating beam is requested for the K2K experiment. The EP1 extraction system was modified so that both of slow and fast extractions are possible. The careful orbit analysis suggested the feasibility using existing slow extraction devices, such as bumps and septum magnets system. The septum magnets C,D,E are excited in series by one power supply for the slow extraction. However, the septum C should be excited in independently for the fast extraction according to the orbit analysis. Then, the septum C magnet power supply and the switching devices to change the extraction mode were constructed. The automatic changing system of the extraction kicker and electro-static septum in the same vacuum chamber was also constructed. Fast extracted beam does not need septum A,B field so the moving region of these magnets were expanded. The beam ducts near these septum magnets were also replaced.

In order to double of the kicker magnetic field and save the transmission time, the Blumlein system was decided to construct. The field strength is requested higher than 0.11T and this should be realized within the space of 3m in one long straight section. C-typed distributed magnets with half width of the normal type are connected face to face each other [6]. A neutrino beam line extended from EP1-A primary beam line of the north counter hall towards the direction of the Super-Kamiokande [7]. A fast-extracted proton beam is transported about 400 m and focused onto a production target.

Main ring beam tuning and the neutrino beam line tuning started on January 27, 1999. This was performed by the slow extraction since the beam monitoring in the extraction beam line was easier than fast extraction. 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. 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.

3 INTENSITY UPGRADE

Every effort has been devoted to realize the intensity upgrade of KEK-PS. The BR accelerates more than 2 x 10^{12} ppp (proton per pulse) for NML. However, the MR cannot accept the beam of this intensity. Machine studies for the intensity upgrade have continued to make clear the reason and cure of the difficulty. Several tools for the machine study were developed and/or upgraded, such as an injection error monitor [9], a fast beam loss-monitor [10], a tune measurement system with an RF kicker [11], a fast wire scanner [12] and NMR field monitor for the main ring bending magnet [13].

According to the concentrated studies results in the spring of 1995 [3], some parameter changing and hardware improvements were done. The vertical tune was changed from 7.21 to 5.21 to avoid the effect of the space charge induced fourth-order resonance since there were no installation space in the ring to install the correction magnets. At this present, vertical tune is set to 5.24 to avoid the effect of space charge tune shift at the high intensity beam operation. In order to increase the vertical aperture, 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% from former 90-92%.

During the magnet re-alignment work, the fast floor movement was observed and it seemed depend on the rainfall. In order to confirm this phenomenon, the measurement of the floor tilt in the ring and the moisture in the soil above the tunnel have been going on [14].

The loss observed just after the beginning of acceleration resulted from the horizontal head-tail instability, which due to a large change in the chromaticity produced by the sextupole field induced in the beam-pipe of the dipole magnet [4]. In order to suppress this phenomenon, octupole magnets were installed in the main ring.

According to an understanding of a lot of high impedance materials in 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]. To cross the transition energy in stable condition, γ-jump magnet power supplies were upgraded to make the voltage twice [15].

These improvements expected to the intensity upgrade, but a high intensity operation should be waited until fast extraction start on March 3 after the completion of the horn system.

Serious and final problems are the beam loss during injection porch and the transition crossing. Measurement of the beam profiles using flying wires and a multiparticle tracking simulation made clear the space charge effects, nonlinear effects of the sextupole and octupole magnets and closed orbit distortion during injection porch [16].

A unique technique to increase the bunching factor and to reduce the space charge effect is the bunch shaping by modulating acceleration RF voltage with a band-limited white signal [17]. This is not necessary to remake the high voltage hardware but the band-limited white signal across the twice of the synchrotron frequency is fed into the voltage control loop in the low-level system [18]. Center of the frequency of the band should track the synchrotron frequency. This was realized by frequency modulating the clock of the arbitrary waveform generator. This method was applied to the BR, which contribute to reduce the space charge effect during the injection porch of the MR, and also to the MR before transition energy. These applications contributed to achieve more than 6 x 10^{12} ppp.

Remaining problems were to reduce the beam loss at the fast extraction and the closed orbit distortion. In spite of the detailed extraction fine-tuning, the extraction efficiency did not overcome to 93-95%. Results of the extraction study and some other research, we understand that the beam loss was caused as follows. 1. Effect of the titanium foil window and the air between the septum C,D,E magnets : 1.7% (calculation). 2. Cancellation of the secondary particle into the beam current transducer : about 1% (calculation). 3. Minimized loss near the septum C magnet : about 2% (study). 4. Totally, 4.7 + x % beam loss is existing. x% is still unknown factor, but it depends on the difficulty of the bump orbit optimization due to the restriction of the extraction hardware system layout. There is conclusive circumstantial evidence about the air effect, that is, about 40m extraction beam line became to 1 atmosphere pressure due to the failure of the vacuum pump system [19] and the extraction efficiency decreased to 92-93%.

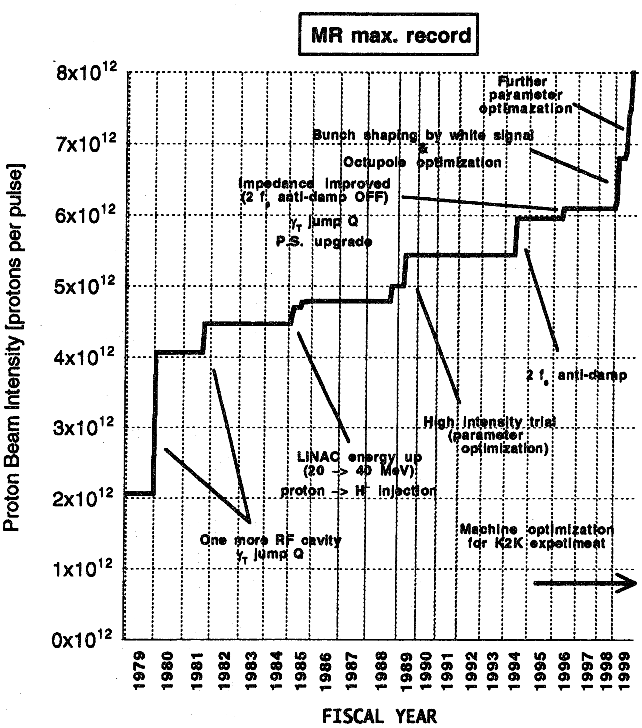

Figure 1: History of the intensity upgrade of the accelerated beam in the MR.

4 OPERATION STATUS

Following the first stage commissioning during January and February 1999, commissioning started again on March 3 after the completion of the horn system. Extraction beam intensity of more than 6 x 10^{12} ppp was achieved on May, 1999 and then 8 x 10^{12} ppp was accelerated owing careful and fine-tuning following the band-limited white signal manipulation. Figure 1 shows the history of the intensity upgrade of the accelerated beam in the MR. Until now, stable operation has been kept with the intensity of 6.2 – 6.5 x 10^{12} ppp for the K2K experiment as shown in Fig.2. At this present, more intensity than this value is restricted by the radiation safety limit in the extraction beam line.

5 CONCLUSION AND CURRENT SUBJECTS

From April 1999 to July 2001, 5.41 x 10^{19} pot (protons on target) are accumulated and 4.79 x 10^{19} pot are used for experimental analysis [20]. K2K team presented that a total of 44 neutrinos from KEK have been identified in the Super-Kamiokande detector. The number of events expected in the absence of neutrino oscillations would be 64. This result is statistically inconsistent with the no-oscillations hypothesis at about the 97% confidence level [21].

Re-alignment of the main ring magnet in the vertical plane was done for several times, but the horizontal re-alignment has been never done. Measurement of the horizontal alignment, which was done in 2000 summer shut down, indicates the significant distortion [22]. Present steering magnets system has not enough power to correct the closed orbit up to 12GeV. In order to realize more stable operation and further intensity upgrade, the main ring magnet re-alignment of both direction and/or upgrade of the steering magnets system should be desired.

Although, a life of 12GeV-PS will be nearly over until 50GeV-PS (JAERI-KEK joint project) completion, every effort for further upgrade is under consideration in the grappling with the deterioration of almost equipment. A second harmonic RF cavity, loaded by magnetic alloy, is under studying in the MR [23]. A plan of the intensity doubler, which is a combination of beam stacking in 500MeV accumulation ring and acceleration of a super-bunch in the main ring, has been proposed and under consideration [24].

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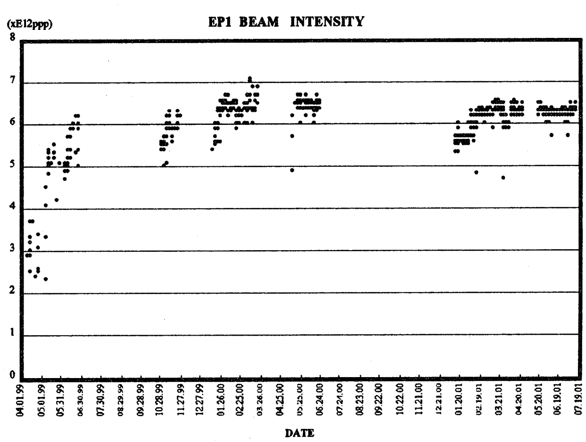

Figure 2: Fast extracted beam intensity for the K2K experiment from April 1999 to July 2001.