INTENSITY UPGRADE STUDIES AT THE KEK-PS

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Abstract

Intensity upgrade studies have been performed at the KEK-PS for recent years in order to meet the need of new physics researches, especially the long base line neutrino oscillation experiment. Studies are concentrated on the reduction of the beam losses during injection, at the acceleration start and at the passing the transition energy. Obtained results up to date are 6.8 x 10^{12} particles at the acceleration start and 6.1 x 10^{12} particles after acceleration, however an average beam intensity of 3-5 x 10^{12} ppp are currently supplied for the experiments due to the beam loss during the slow extraction. We report the present results of these studies.

1 CURRENT STATUS OF THE KEK-PS OPERATION

The KEK-PS consists of four accelerator complex, two 750KeV Cockcroft Walton pre-injectors, 40MeV injector linac, 500MeV booster synchrotron and 12GeV main ring. One pre-injector is utilized for ordinary H^- operation and another one was used for D^- and/or alpha ion operation. Figure 1 shows a layout of the KEK-PS complex. After the counter experiment started on 1976 using the secondary beam from an internal target and the fast extraction for bubble chamber experiment, the KEK-PS has been operated successfully to serve an intense proton beam for the past two decades.[1] Proton, deuteron and alpha beam have been serving by the half integer slow extraction to East and North counter halls. In those days, beam intensity at the booster extraction and in the main ring were 6x10^{11}ppp and 2x10^{12}ppp, respectively. Beam bunches accelerated in the booster except to the main ring are utilized as NML (Neutron and Meson Laboratory).

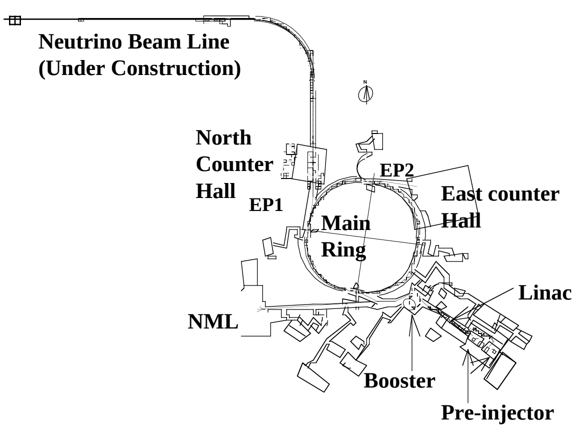

Figure 1. Layout of the KEK-PS Complex.

As the results of much effort, the beam intensity was increased to 5.4x10^{12}ppp in the main ring on 1989 and 2.4x10^{12}ppp for NML on 1990. Although the highest beam intensity in the main ring was upgraded to 5.95x10^{12} ppp on 1994, an average intensity for utilities is still 3-5 x 10^{12} ppp due to protection of radio activation. In order to increase the beam intensity for the need of new physics researches, especially the long base line neutrino oscillation experiment, studies are concentrated on the reduction of the beam losses during injection, at the acceleration start and at the passing the transition energy.

2 MACHINE STUDY FOR THE INTENSITY UPGRADE

Every effort to realize the upgrade of KEK-PS have been devoted. Booster synchrotron accelerates more than 2 x 10^{12} ppp for NML. If the main ring can accept and accelerates the beam of this intensity with no beam loss, 10^{13} ppp beams could be expected for main ring utility. However, the circulating beam intensity is limited to about 6 x 10^{12} ppp for some reasons. The machine study has continued to make clear the cause and curing of the difficulty in order to realize the beam intensity upgrade. First of all, several tools for the machine study were developed, such as an upgraded injection error monitor, a fast beam loss monitor which can observe it turn by turn using computer workstations and so forth.

Table 1. Aperture of the Main Ring. (πmm mrad.)

	Mechanical	Measured
Horizontal	135.0	81.0
Vertical	31.0	15.0

Transverse Aperture Survey

The aim of the first study was to concentrate the main ring beam injection problem on 1995. The local aperture measurements of the main ring were performed to make clear the real orbit center in the vacuum chamber. The twenty eight steering dipoles were excited independently to make a local bump orbit at each section in the main ring. The vertical aperture seems to be determined by the diameter of the vacuum chamber in the bending magnet. The orbit was set to the center of the vacuum chamber as decided above, then the beam survival were measured to make clear and maximize the acceptance with dependence on the injection error. As the result of this study, the closed orbit, especially vertical, seems essential for the beam loss at the injection. Table 1 shows the main ring aperture of the calculated value from

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real mechanical dimension and the measured value, respectively. It is still unknown that the reason of difference between the mechanical and measured aperture.

Higher Order Resonance Correction

The usual operating point of PS main ring was at ν_x=7.12 and ν_y=7.25. In order to avoid beam loss due to the space charge detuning for a high intensity beam, it should be select rather higher operating point. However, a third order resonance, $\nu_x + 2\nu_y = 22$, and fourth order resonances, particularly $4\nu_y$=29 and $2\nu_x + 2\nu_y = 29$ seem to be obstacles. The correction of these resonances were established by the sextupole magnets and the octupole magnets using rather low intensity beam, about 4 x 10^{11}ppp. After fixed the correction parameter, the high intensity beam, 1.3 x 10^{12}ppp, were injected from booster and measured the tune mapping of beam survival as shown in Figures 2a and 2b. A fast beam loss is brought near integer operating point, on the other hand a slowly beam loss is brought at around larger than .25.

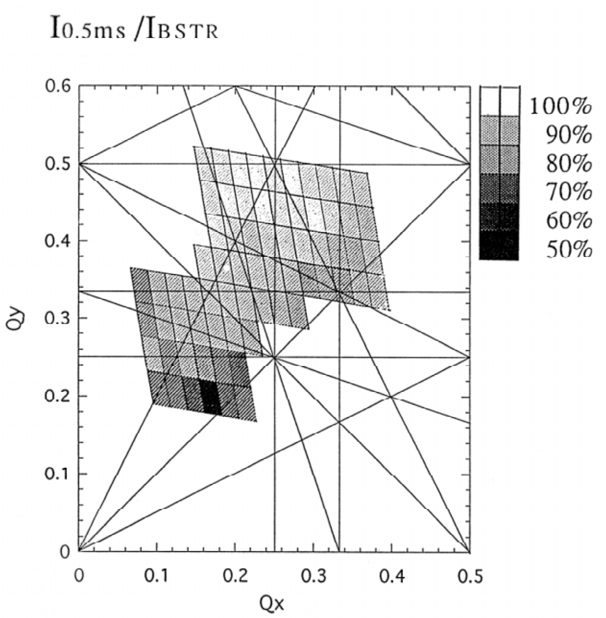

Figure 2a. Beam survival tune mapping of high intensity beam after resonance correction. Ratio between the intensity of booster extraction and 0.5ms after injection.

These show that there are no region where more than 70% of the beam survives. It seems that these forth order resonances are caused by the space charge induced quadrupole imperfection.[2] In order to reduce the quadrupole imperfection, several correction quadrupoles are necessary, however there are no installation space in the ring. Then, the panofsky type hybrid quadrupole magnet, which will be use for both of quadrupols for the imperfection correction and dipoles for the COD correction, are considering. At this present, the vertical tune was changed to 5.25 to curing the effect of the forth order resonance. However, the intensity is still same as the old operating point.

From the view point described above, the re-alignment of the main ring magnet in the vertical plane was done on the summer shut down, 1996. The injection efficiency has increased up to 95-97%, although it was less than 93% before re-alignment.

Another studies on the longitudinal acceptance measurement and the broad band reactive impedance measurement so forth were performed on 1995.[3]

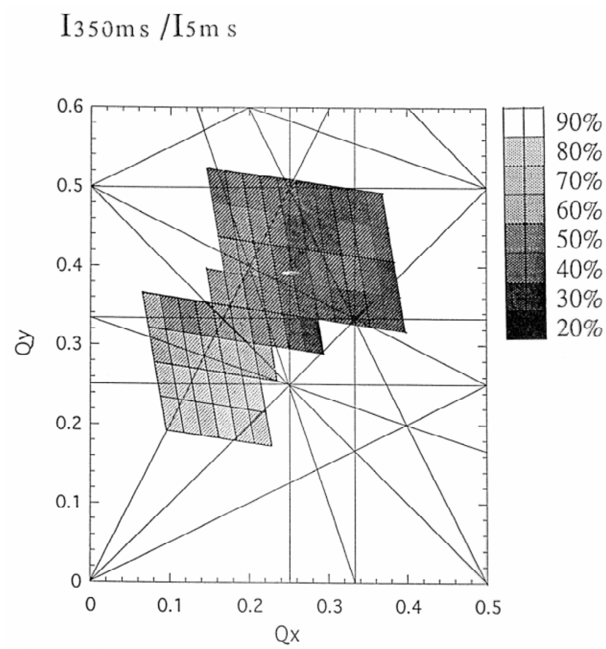

Figure 2b. Beam survival tune mapping of high intensity beam after resonance correction. Ratio between the intensity of 5ms and 350ms after injection, respectively.

Beam Loss During Acceleration

Major beam loss during acceleration is at the acceleration start and at the transition crossing. As the recent studies, following facts come to our knowledge. Some head-tail instability occurs several tens milliseconds after acceleration start [4] and the microwave instability occurs after crossing the transition energy.[5]

First one of these phenomena depends on of course the chromaticity, and this occurred after changing the vertical operating point. The total chromaticity, caused by the eddy current in the vacuum duct inside the bending magnet and the remnant of the sextupole magnet etc., becomes positive 80ms after acceleration. Mode one phenomena disappears by the correction of chromaticity. Various mode of the head tail instabilities occur depend on the chromaticity so the study is under going to clear more detail.

Depend on the knowledge of a proton-klystron model [6] for the microwave instability, a part of the vacuum ducts between the bending magnet and the quadrupole magnet and the beam position monitor (BPM) except high radioactive position were replaced on the summer shut down, 1996. The emmitance brow-up after this replacement clearly decreased.[5]

Figure 3 shows an acceleration efficiencies, intensity ratio between acceleration start and end, and it's improvement effect. Closed circles are the data during rather high intensity operation several years ago. Open circles are the data after last summer shut down.

5.5-6.1 x 10^{12} ppp at the acceleration end for about 20 minutes have been achieved at the high intensity trial operation on October, 1996. The acceleration efficiency of this trial are also shown in Figure 3.

Reduced the harmonic number seems advantage method in order to beam trapping at the acceleration start. Harmonic six operation has been considering instead of usual nine harmonics, but this is not better since one bunch should be taken out due to the rise time of kicker described later.

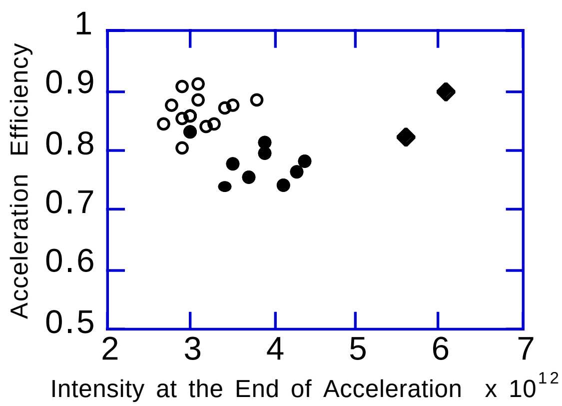

Figure 3. Acceleration efficiency, intensity ratio between acceleration start and end, at the former high intensity operation in 1989 and after improvement of duct impedance. Closed circles are the 1989 data. Open circles are the data after BPM and B-Q duct replacement. Closed diamond are the typical results at the high intensity trial after that.

3 DESIGN OF THE FAST EXTRACTION SYSTEM

Fast extraction of full circulating beam should be requested for the neutrino oscillation experiment.[7] At this present, KEK-PS equipped two slow extraction lines and one internal target beam line. A switching the fast extraction and the slow extraction is considering for multi user requests.

According to the careful orbit analysis for the feasibility using existing slow extraction devices, such as bump and septum magnets system, the changeable system of the extraction kicker and electro-static septum in the same vacuum chamber has decided in stead of former design, which is the small kicker distribution system.[8] A large orbit excursion is the problem since the extracted beam passes through non linear magnetic field region of both bending and quadrupole magnets. Table 1 shows a typical calculation results.

In order to extract the beam during one turn, the kicker magnetic field should have a rise time less than 30ns and more than 1.1μs flat top since the harmonic number is nine and bunch length is about 125ns. The time space between the beam bunches of 30ns is so short for the rise time of fast kicker magnet that one bunch is taken out to obtain the time space for rise time. This means 155ns available for the kicker rise time. The field strength is requested higher than 0.11T and this should be realized within the space of 3m in one long straight section. In order to double of the kicker magnetic field and save the transmission time, the distributed small kickers with the Blumelein system was decided to construct. Prototype one has just constructed and is under exciting test.[9] However, eight bunches acceleration means the beam intensity is reduced to eight ninth. If we adopt the harmonic number six operation, the space between bunches increase to 60ns, but one bunch should be still taken out, then this is not advantage method. First rise kicker magnets are strongly desired.

4 SUMMARY

Acceleration of about 6x10^{12} ppp intense beam has achieved, however, an average intensity during normal operation has been still 3-5 x10^{12} ppp. Since much studies have been concentrated to make clear the beam loss problem the reason of the beam loss is getting to understand little by little.

Twenty years has passed since the KEK-PS constructed, then several equipments and parts become decrepit. The failure time has increased for recent a few years. It was about 3% before 1992, but more than 5% recently. Taking into consideration for this problem is also important subject for the reliability of machine operation.

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