PULSE-TO-PULSE SWITCHING INJECTION TO THREE RINGS OF DIFFERENT ENERGIES FROM A SINGLE ELECTRON LINAC AT KEK

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Abstract

The electron and positron LINAC at KEK is shared with four storage rings as a unique injector. For the beam injections for each ring, all machine parameters had to be loaded each time to switch the injection mode, where the switching time had been more than 30 seconds. To shorten this time loss ultimately, we have upgraded LINAC, beam transport lines(BTs) and injection sections in order to inject beams into three rings by switching parameters in a pulse-to-pulse mode. In this paper, we describe the fast switching injections in detail.

INTRODUCTION

The injector LINAC at KEK has been operated in four different beam-modes for four different rings. These are called Low Energy Ring (LER) of KEKB (3.5GeV/e^+), High Energy Ring (HER) of KEKB (8.0GeV/e^-), Photon Factory (PF) (2.5GeV/e^-) and Advanced Ring for pulse X-rays (PF-AR) (3.0GeV/e^-). The maximum repetition rate of LINAC is 50 Hz. In KEKB, HER and LER had been alternately injected by switching LINAC parameters. To change a beam mode, it had taken more than 30 seconds to load all parameters of LINAC, as shown in Fig. 1-(a).

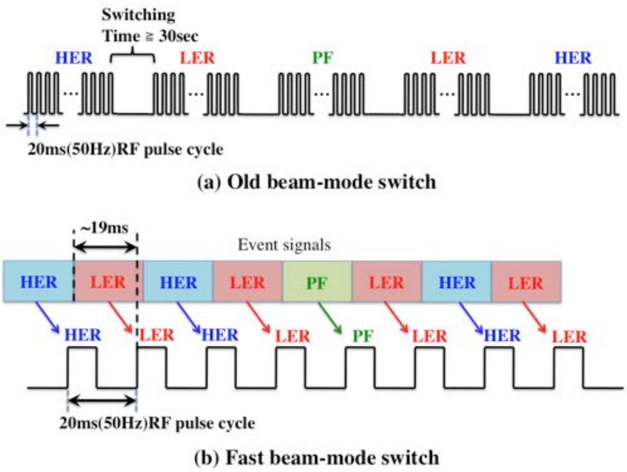

Figure 1: Schematic view of the injection pulses in the two beam-mode switches. The block pulses show beam gate timings. (a) At the slow switch, the beam injection suspended during changing beam-mode. (b) The fast switch tells the next beam-mode 19ms before the beam gate opens.

In KEKB operation, faster switching is required to improve the collision tuning[1]: (1) more stable luminosity tuning at constant beam currents, (2) operation at the shorter lifetimes, (3) speed-up of luminosity tunings(searching for optimum points), (4) prevention of current losses at the head of trains. Furthermore, crab-cavities have been introduced since 2006, demanding more severe tunings.

In addition, LINAC also provides electron beams for two photon factories, PF and PF-AR, a few times a day. The injection time including mode-switch had been about ten minutes for each ring. In PF injection, the switching time from HER was shortened from about one minute to a few seconds in the spring of 2008[2] by changing the beam transport configuration. Since the PF top-up operation starts in the autumn of 2009, the fast switching injections for HER, LER and PF rings will be indispensable.

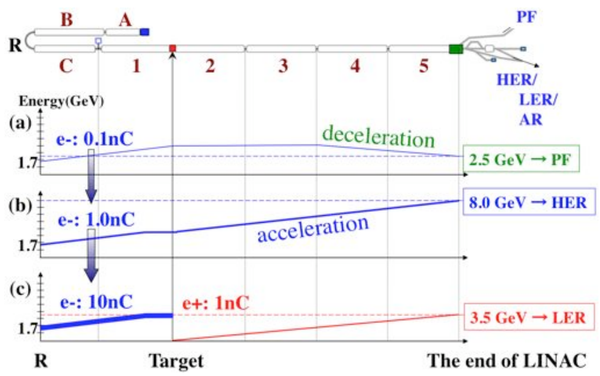

Figure 2: The energy profiles and beam charges for PF, HER and LER from sector R (180-degree arc section) are shown in (a), (b) and (c), respectively. All electron beams are generated from A1-GUN and accelerated to 1.7 GeV at sector R.

Energy profiles and charges of the three rings for the fast switching injection are controlled as shown in Fig. 2. The energies for all beam-modes are the same up to the end of sector 1. After that HER beam is accelerated to 8 GeV by the end of LINAC. The energy of PF beam is kept constant between sectors 2 and 3 by changing the timings of the corresponding low-level RF(LLRF) signals about 57 μs (stand-by mode). In sectors 4 and 5, the beam are decelerated to 2.5 GeV by shifting LLRF phases about 180 degrees. As for LER, the positron beam produced at the target, which is placed between section 1 and 2, is accelerated to 3.5 GeV in the rest of LINAC by shifting the LLRF timings 180 degrees. The primary electron charge for LER before the target is two order higher than that for PF. For HER and LER, two bunches can be accelerated in the same RF

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pulse, which are separated in time by 96ns. The charges are controlled by changing parameters of the electron gun(A1-GUN). There are three grid pulsars, for the 1st bunch of KEKB, the 2nd bunch of KEKB and for PF.

LINAC UPGRADE

The LINAC upgrade project has been proceeded since 2005. The hardware constructions and installations were completed by the end of 2008[2]. Then, commissioning of new components has started and the fast beam-mode switching has been successfully achieved in the spring of 2009 by resolving the following issues.

Event system

Fig. 1-(b) shows a schematic view of the new beam-mode switch. In the scheme, each pulse in the 50Hz RF cycle can be shared with four beam-modes. The control signals for many devices should be sent within 19ms before the next beam gate opens. As a new timing system, an event system[3] is introduced, which consists of an event generator(EVG) and event receivers(EVRs) based on VME64x-bus. EVG at the central station sends the event signals and EVRs receive the information through optical fibers. The timing precision of this system is better than 10ps. The parameters of the following system components are changed by the signals from EVRs within a period of 20ms; (1) A1-GUN: pulse height, bias voltage and delay timing of each grid pulsar, (2) Microwave: phase of sub-harmonic bunchers, phase and timing of LLRF signals and timing of high-power RF signals, (3) Pulsed magnets: a pulsed bending magnet[4][5], pulsed steering magnets[7], a pulsed positron capture coil, (4) Beam diagnostic instrumentation: fast read-out of beam position monitors(BPMs)[6] and beam-mode selection for wire scanners and streak cameras, (5) Injection: selection of septa and injection kickers, (6) KEKB injection: selection of HER or LER (injection phase and bucket selection).

Target with a bypass-hole

Before the summer of 2008, the target for positron production had been frequently inserted into the beam line for the LER injection. The life time of the bellows for target had limited HER and LER injection cycle more than five minutes. Therefore a new tungsten crystalline target with a side hole was newly installed so that HER and PF operations can be done without removing the target; the electron beams pass through the bypass hole due to a bump orbit[7].

Pulsed steering magnets

To make a target bump, four pulsed steering magnets were installed: three pulsed steerings for the horizontal kick and the other for vertical. Their kick angles are 1.0 mrad for 4 GeV beam. The magnet has a 35-mm gap and a 150-mm length. The maximum current of the power supply is 10A and the sine-like pulse with an offset having 19.5 ms width is generated. Ceramic chambers with Mn-Mo coating are used.

Additional six pulsed steering magnets were introduced to correct for the beam orbits on both of the horizontal and the vertical directions at the end of sectors 2, 3 and 4 . The kick strengths can be changed to three values corresponding to the three beam-modes.

Compatible optics

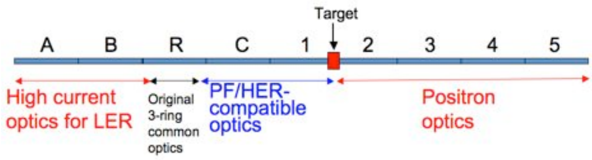

Figure 3: The settings of quadrupole magnets are shown. The horizontal direction shows the axis along LINAC beam line.

The settings of quadrupole magnets in the compatible optics for three beam-modes are schematically shown in Fig.3. In this scheme, the beams with different energies pass without changing the DC magnetic fields. Two independent optics, one dedicated to LER optics and the other to HER/PF optics[8], had been successfully employed so far. Based upon this experience, the better setting of quadrupole magnets in each section was chosen from those two optics so that all beams could be effectively transported. At sectors A and B, high current optics for LER is used. At sector R, the original optics has been adopted as the common one. Between sector C and 1, HER and PF compatible optics with rather weak focusing at the target is used, otherwise the electron beam can not be matched to the positron optics after the target. As a cost of this, the positron yield slightly decreases. After passing the target, positron optics are set for matching the lower energy beam.

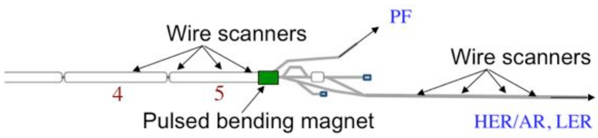

Figure 4: The branching point from the end of LINAC to the BTs for PF, HER/AR and LER. The BT for HER and AR is a common line. Three sets of four wire scanners are installed for optics matching.

To match the optics into the BT downstream to LINAC, we have used wire scanners[9] at the end of LINAC and at the entrance of BT, as shown in Fig.4. After setting the compatible optics mentioned above, the optics at the end of LINAC were matched to LER beam. As shown in Fig.5-(a), the settings of the triplet quadrupole magnets (in red circles), however, were too strong for PF low energy beam, and the beta-functions were too large at the entrance of PF-BT[10]. This is because the next quadrupole magnets are located far from the triplet magnets. For PF beam, we reduced the strength of the triplet quadrupole fields at the end of LINAC by nearly half so that both of the horizontal and vertical beta-functions are suppressed within 60 m as shown in Fig.5-(b). The new optics of PF-BT are designed as shown in Fig.5-(c) in which the beta-functions of Fig.5-(b) are used as the initial values and the beam could pass through the PF-BT. On the other hand, the beams for both of LER and HER could be re-matched to the optics parameters at the entrance of each BT with the wire scanners.

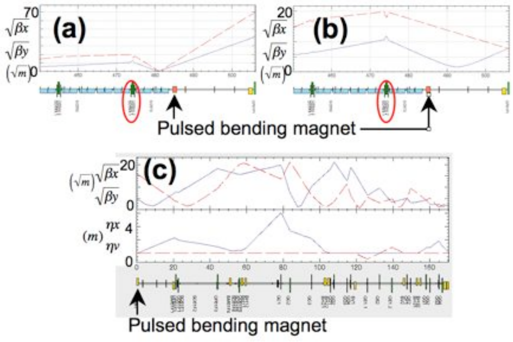

Figure 5: (a), (b) The squared beta-functions for PF beam measured with wire scanners at the end of LINAC. (a) PF optics when the magnet settings matched to LER beam. (b) PF optics after the triplet of quadrupole fields (red circle) are weakened to the nearly half of (a). (c) The squared beta-functions and dispersion-functions of the new PF-BT optics. All blue/red lines indicate the horizontal/vertical functions, respectively.

Orbit Correction

Orbits of the three beam-modes can be measured at the same time by the fast read-out BPMs, which are shown in Fig.6. The orbits of LER beam are corrected for only by DC steering magnets and after that the orbits of HER and PF beams are adjusted by using the pulsed steering magnets for both of the horizontal and vertical directions, as shown in Fig.6.

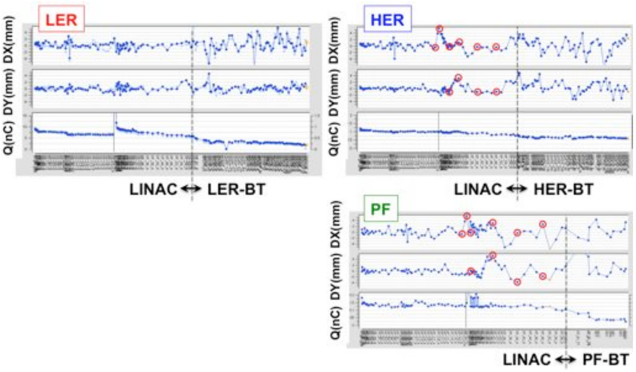

Figure 6: The orbits from LINAC to BT for the three rings measured with the fast read-out BPMs. The horizontal, vertical orbits and charges in each beam-mode are shown. Red circles show places where pulsed steering magnets are installed.

PULSE-TO-PULSE SWITCHING INJECTION

In April of 2009, we have started the pulse-to-pulse switching injections into HER, LER and PF rings as usual operations. Fig.7 shows that the stored currents in the all rings were almost constant as a function of time in the same time. The repetition rates of injections at this time were 12.5/25/0.5Hz for HER/LER/PF, respectively. Even if the beam were aborted in KEKB, the injection into PF were kept. In PF operation, the beam current variation can be set 30μA with a total current of 430mA. The variations of HER/LER are typically suppressed to less than 0.13/0.13% from 1.7/2.5%. Owing to the constant beam currents, the machine condition of KEKB became much stable and the luminosity tunings have been dramatically speeded up[1]. Also in case of beam aborts, the fast switching shortens the restoration time to full beam currents. Another merit is that we could explore the machine parameter spaces widely, which could not be set due to short beam lifetime before. We expect that the higher luminosity could be achieved in this manner.

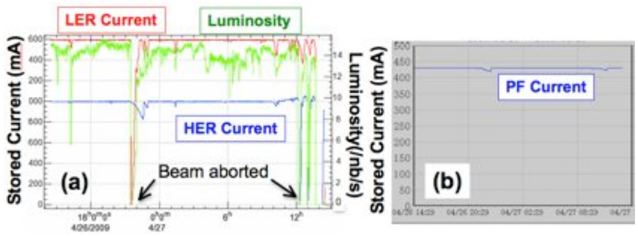

Figure 7: The stored currents in the three rings for one day. (a) Red/Blue lines show stored currents in LER/HER. Green line shows the luminosity. (b) Blue line shows a stored current in PF.

CONCLUSION

We have presented the pulse-to-pulse switching injections to three rings, HER, LER and PF. The KEK injector upgrade aiming at the fast beam-mode switching was successfully developed. The remaining problem is the participation of PF-AR to the fast switching injections, which is now in progress and will be reported in detail elsewhere.

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