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INTERACTION POINT ORBIT FEEDBACK SYSTEM AT SuperKEKB

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Abstract

In order to maintain an optimum beam collision condition in a double ring collider such as SuperKEKB it is essential to have an orbit feedback system at the interaction point (IP). We have designed such a system based on experiences at KEKB and PEP-II. For the vertical offset and crossing angle, we will rely on the system based on the beam orbit measurement similar to that used at KEKB. For the horizontal offset, however, we will utilize the dithering system which was successfully used at PEP-II. Some hardware devices have been already fabricated and others are in preparation. The present status of the development is reported.

INTRODUCTION

The design of the system has been done based on the experiences at KEKB [1]. In the following, we summarize differences between KEKB and SuperKEKB from the view point of the IP orbit feedback. Table 1 shows a comparison of the parameters related to the feedback. The symbols for the parameters in the table are those used commonly. A remarkable point with the parameters is that the horizontal beam-beam parameters of SuperKEKB are much smaller than those of KEKB. In SuperKEKB, we will adopt so-called “nano-beam scheme", where the horizontal beam sizes at IP are very small and the crossing angle is rather large to reduce the interaction region of the two beams drastically. In this scheme, we have to use the effective horizontal beam size shown in the table rather than the actual horizontal beam sizes in the calculation of the beam-beam parameters and the luminosity. With those small horizontal beam-beam parameters, we can not rely on the beam-beam deflection method for the orbit feedback at IP in the horizontal direction. Instead, we will adopt the dithering system for the horizontal orbit feedback which was used at PEP-II [2]. Another feature of the SuperKEKB parameters is much smaller vertical emittances (ε_y) than KEKB. Roughly speaking, the vertical orbit drift at the IP will be 3 or 4 times larger in units of the vertical beam sizes than the KEKB case. The vertical beta functions at the IP (β_y^*) are also small. With smaller IP beta functions, the orbit drift in units of the vertical beam sizes will be unchanged, since both beam sizes and the sizes of the drift are proportional to the square root of β_y^* assuming that the beta functions at source points of the orbit drifts are the same. However, the vertical beta functions at the final focus quadrupoles (QC1s) get larger with the smaller IP beta functions. Also considering a higher field gradient of QC1s, the sizes of the orbit vibrations due to the vibrations of QC1s are about the same as those at KEKB. Considering this situation and the smaller vertical emittances, the orbit changes due to the mechanical vibrations of the QC1s will be by more than one order of magnitude larger in units of the vertical beam sizes than those at KEKB. We have been carefully investigating the mechanical vibrations of the final doublets and making efforts to reduce the vibration amplitudes. In the following, we summarize those efforts and their expected effects to the luminosity.

Based on the KEKB data of the vibration magnitude of the final focus quadrupoles, the orbit motion at the IP could be 4 or 5 times larger than the vertical beam sizes in SuperKEKB. To overcome this problem, four countermeasures have been considered, *i.e.* using the coherency of vibrations of quadrupoles for electrons and positrons, modified magnet supports, additional damping for magnet vibrations and finally the orbit feedback. A modal analysis has been performed with the ANSYS code. Vertical oscillation frequencies due to the vibrations of the QC1s on the right side of IP (QC1RP and QC1LP) appear at around 25, 38 , 69 and 100 Hz. If we assume the coherency of the two magnets, the orbit differences of the two beams at the IP at the frequencies will be 18.6, 1.7, 8.3 and 3.1 nm in rms, respectively. The corresponding luminosity degradations are 4.6, 0.2, 0.3, 0.3 %, respectively. The luminosity loss due to the 25Hz oscillation is expected to be recovered by the orbit feedback. The luminosity loss due to the vibrations of QC1s on the left side is similar. In the calculation, the coherency of the two magnets for the electrons and positrons is very important. If there is no coherency, the orbit differences amount to a few times of the vertical beam sizes at the IP.

VERTICAL FEEDBACK

The orbit feedback in the vertical direction will be done with the same method as that for KEKB. Changes of closed orbits give the orbit offset at the IP and the crossing angle. The changes of the orbits are detected by using four BPMs at around the IP. A difference from KEKB is that a much faster feedback will be needed at SuperKEKB. As shown above, we need to suppress the orbit change at around 25Hz. The feedback system is composed of BPMs, a special wideband detector for the BPMs, a digital signal processor unit whose outputs are kicks of corrector magnets, a power supply controller, power supplies of the correctors and the corrector magnets.

Four BPMs for the feedback are installed on the IP side of the final focus quardupoles (QC1RE, QC1RP, QC1LE and

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Table 1: Comparison of Machine Parameters Related to IP Feedback between KEKB and SuperKEKB

	KEKB (operation)		**SuperKEKB** (design)		
	LER	HER	LER	HER	
ε_x	18	24	3.2	5.0	nm
ε_y	151	151	8.6	13.5	pm
$\varepsilon_y/\varepsilon_x$	0.84	0.63	0.27	0.25	%
β_x^*	12000	12000	32	25	mm
β_y^*	5.9	5.9	0.27	0.31	mm
σ_x^*	147	170	10	11	μm
σ_x^*(eff.)[*1]	-	-	249	207	μm
σ_y^*	944	944	48	56	nm
$\sigma_{x'}^*$	122	141	316	447	μrad
$\sigma_{y'}^*$	0.12	0.14	0.18	0.21	mrad
ξ_x	.127	.102	.0028	.0012	
ξ_y	.129	.090	.0881	0.0807	

[*1] σ_x^*(eff.) is an effective horizontal beam size defined as $\sigma_z \sin\phi$, where σ_z and ϕ denote a bunch length and a half crossing angle, respectively.

QC1LP). The distance from the IP to the BPMs is about 51cm. Unlike the case of KEKB, where the BPMs were located on the ARC side of the final focus quadrupoles, the BPM measurements are not affected by the movements of the quadrupoles. The vacuum chamber diameter at the BPMs is 20mm. Each BPM has 4 electrodes and their position is 10.5mm from the center of the chamber. The size of the BPM heads is 1.8mm ϕ [3]. The descriptions of the BPM detector and the signal processor unit can be found in [4–6]. Like the KEKB case, 12 corrector magnets (8 for vertical and 4 for horizontal) will be used for the IP orbit control. They are installed in HER and make orbit bumps of the vertical offset, the vertical angle and the horizontal offset to maintain optimum collision conditions. The magnets are usual but relatively weak steering magnets whose maximum kick is ~50 μrad. "Takasago BWS series" will be used for the power supplies which are commercially available. Reference voltages to the power supplies are sent from a power supply controller which was developed in FY2014. The controller accepts inputs through two different paths. One is from the signal processor unit for the vertical feedback described above. The other is from the dithering system for the horizontal feedback. It should be noted that the orbit dithering will be done by using the corrector magnets installed in LER but the orbit adjustment to maintain collision is done in HER. The former input signals are updated rather fast (typically ~ 32kHz) and the latter are updated relatively slowly (~ 1Hz). The controller combines the two inputs and sends reference voltages to the power supplies. The controller can adjust delays for the individual power supplies to compensate the different phase shifts among the correctors due to the different shape and thickness of the

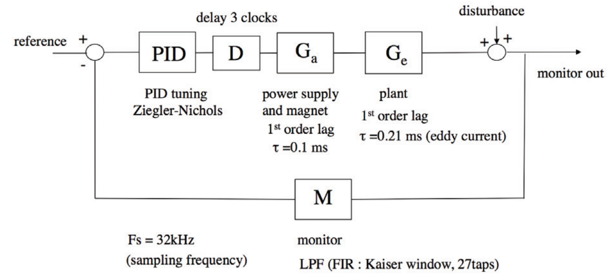

Figure 1: Orbit feedback model.

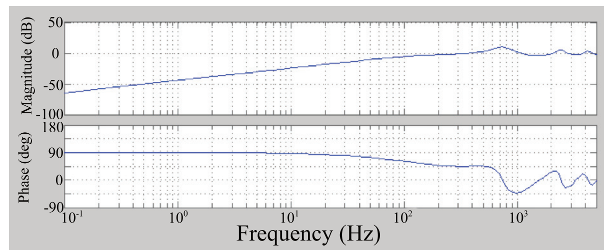

Figure 2: Simulation on disturbance rejection.

vacuum chambers at the correctors. It can also adjust a gain for each power supply. The EPICS IOC is embedded in the system and the inputs from the dithering system are sent via EPICS channel access.

To estimate rejection gains to disturbance, a simulation was done by using MATLAB/Simulink with a model shown in Fig. 1. In the simulation, time lags due to the power supplies, the magnets and the eddy currents of the vacuum chambers are considered and the PID parameters were optimized. The BPM measurement frequency was chosen at 32kHz. The Bode diagram of Fig. 2 shows the rejection gains. At 25Hz, the rejection gain of ~ -17dB is expected and the luminosity degradation due to the vibrations of the final doublets at around this frequency can be suppressed by the orbit feedback. At around 100Hz, however, almost no rejection by the feedback will be expected.

DITHERING SYSTEM

We will start with an analog system, which is a copy of PEP-II system [2], due to a lack of human resources and will upgrade to a digital system afterward, if necessary. The system consists of a fast luminosity monitor, a lock-in amplifier, coils for dithering, dither circuits whose functions are drive amplifiers and gain and phase adjustment for each power supply, actuators (the bump system which is commonly used for the fast vertical feedback), a power supply controller mentioned above, a control system (the actual feedback algorithm will be run in an IOC) and power supplies of the dithering coils. Eight sets of air-core coils for the dithering system were designed and fabricated, and their magnetic properties were measured [7]. The dithering coils will be installed in the SuperKEKB tunnel in June 2015. Each set consists of two pairs of coils, one to provide a horizontal kick and the other to provide a vertical

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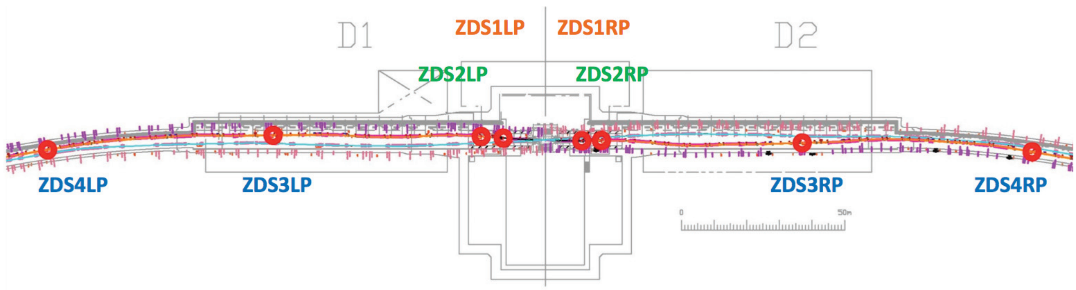

Figure 3: Locations of the dithering coils. Three different coils are indicated by three different colors.

kick to the positron beam. The coils are designed to be mounted on the vacuum pipes directly. The coils will be installed at 8 locations in the LER, 4 on the right side of the IP (ZD1RP, ZD2RP, ZD3RP and ZD4RP) and 4 on the left side (ZD1LP, ZD2LP, ZD3LP and ZD4LP), as is shown in Fig. 3. Three types of coils are needed to be designed as the cross sections of the beam pipes vary by location. Two types (ZD1L/RP, ZD2L/RP) are symmetric in shape while the third type (ZD3L/RP and ZD4L/RP) is asymmetric as this type is mounted on the vacuum pipe ante-chamber. Field harmonics were evaluated by a rotating coil system, shown in Fig. 4. The required field uniformity of 0.1% is achieved over a range of ±10 mm, even with the asymmetric type coil. The LER beam is driven sinusoidally by the dithering system in the horizontal direction at a frequency at around 70 Hz. Coils for vertical kick are prepared in order to correct the x-y coupling caused by the misalignment of the horizontal coils. A lock-in amplifier is used to extract the luminosity components at this frequency as is described in the document [2]. The system will be controlled remotely via EPICS. Details of the system are currently being studied. Some of the basic features of the system are scheduled to be tested during Phase 1 operation without collision. The fast luminosity monitor measures a photon, a recoiling electron or positron from the extremely forward-angle radiative Bhabha scattering, which has very large cross section. We use the two kinds of detector systems based on diamond sensors, and Cherenkov and scintillation counters. Integrated pulse size or pulse count is expected to be proportional to the luminosity of the accelerator in each time span of typically 1ms and is used for the dithering system in real-time operation. System performance has been investigated by using a much extended version of the simulation code developed for the PEP-II system [8]. The input data of the simulator are orbit dependence of the luminosity [9], information on accuracy of the fast luminosity monitor and the vibration data of the final focus quadruples in the horizontal direction. In the simulation, we used a luminosity in the early commissioning phase ($1 \times 10^{34} \mathrm{cm}^{-2}\mathrm{s}^{-1}$). The corresponding counting rate of the luminosity monitor is about 40 MHz. The cycle time of the system was supposed to be 1/3 s. The resultant dither penalty of the luminosity was about 1 %. Figure 5 shows spectra of an orbit (black) and an orbit difference (green) with the feedback. With the feedback, the horizontal orbit difference at the IP can be kept as small as $\leq 10 \mu$m. This value is small enough to keep the maximum luminosity.

Figure 4: Ante-chamber type dithering coil is being measured by a rotating system.

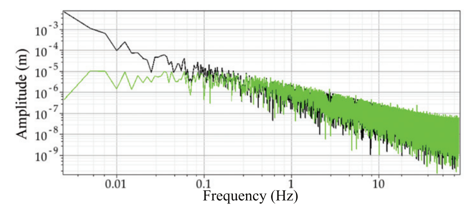

Figure 5: Spectrum of the orbit (black) and the orbit difference (green) with the dither feedback.

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