BEAM COMMISSIONING OF SuperKEKB

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Abstract

In this report, we describe the machine operation in the first 3 months of the Phase 1 commissioning of SuperKEKB. The beam commissioning is smoothly going on. Vacuum scrubbing, the optics corrections and others are described.

INTRODUCTION

The purpose of SuperKEKB is to search a new physics beyond the standard model of the particle physics in the B meson regime. SuperKEKB consists of the injector Linac, a damping ring for the positron beam and two main rings; *i.e.* the low energy ring (LER) for positrons and the high energy ring (HER) for electrons, and the physics detector named Belle-II. The beam energies of LER and HER are 4GeV and 7GeV, respectively. The design beam currents of LER and HER are 3.6 A and 2.6 A, respectively. The design luminosity is $8 \times 10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. More detailed parameters of SuperKEKB is described elsewhere [1].

After 5 years of upgrade work from KEKB, the Phase 1 beam commissioning of SuperKEKB started on Feb. 1st this year and on the way and it will continue until the end of June this year. In Phase 1, Belle-II and the final focus doublet (QCS) are not installed and no beam collision is performed. Missions of the commissioning in Phase 1 are startup of each hardware component, establishment of beam operation software tools, preparation of Belle-II detector, an optics study and tuning without QCS and the detector solenoid magnet and other machine studies. As for preparation for installation of the Belle-II detector, vacuum scrubbing is of essential importance. The Belle-II group require 1 month vacuum scrubbing with the beam current of 0.5 – 1 A, which corresponds to the beam dose of 360 – 720 Ah. In addition, the study on the beam background to the detector is also important by using a test detector named Beast. As for the optics study, Phase 1 provides us with an unique opportunity to conduct a study without the detector solenoid nor QCS. The low emittance tuning is an important item.

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COMMISSIONING STATUS

Brief History

Figure 1 shows the 3 month's history of Phase1 commissioning. The commissioning started on Feb. 1st and the first week was devoted to tuning of the beam transport line. The LER injection tuning started on Feb. 8th and the positron beam was stored in the ring on Feb. 10th. The HER injection tuning started on Feb. 22nd and the electron beam was stored in the ring on Feb. 25th. After those successful beam storage, we gradually increased the beam currents. As of April 30th, the maximum beam currents of LER and HER are 650 mA and 590 mA, respectively. The stored beam currents of KEKB LER and HER after the first 3 months were ~300 mA and ~200 mA, respectively. The speed of beam storage at SuperKEKB is a factor 2 or 3 times faster than KEKB. The reasons for this faster startup are in the following; (1) The bunch-by-bunch feedback system has more effectively suppressed instabilities. (2) Each hardware component has been upgraded with experiences at KEK and has worked fine (RF, Magnet, Vacuum, ...), (3) Operational tools (such as closed orbit correction system) has worked fine based on experiences at KEKB. (4) Less machine troubles than KEKB so far.

Vacuum Scrubbing

In LER, 98% of the beam pipes were replaced with new ones. In the Arc sections, ante-chambers were adopted to suppress the electron cloud effects and to handle the high SR power. On the other hand, in HER almost all beam pipes of KEKB in Arc sections are reused and only 18% of the beam pipes of the ring was replaced with new ones. Therefore, vacuum scrubbing in LER is more important. As is shown in Fig. 1, vacuum scrubbing is being done relatively smoothly [2]. The averaged vacuum pressure of LER and HER are $\sim 3 \times 10^{-6}$Pa at 650 mA and $\sim 3 \times 10^{-7}$Pa at 590 mA, respectively. The beam lifetime at those beam currents of LER and HER are ~60 min. and ~600 min., respectively. The main process to determine the lifetime is the beam-gas Bremsstrahlung and the Touschek effects for both rings. About 1/3 or 1/2 of the particle loss rate comes from the Touschek effect for both rings. As of April 30th, the cumulative beam doses of LER and HER are 240 Ah and

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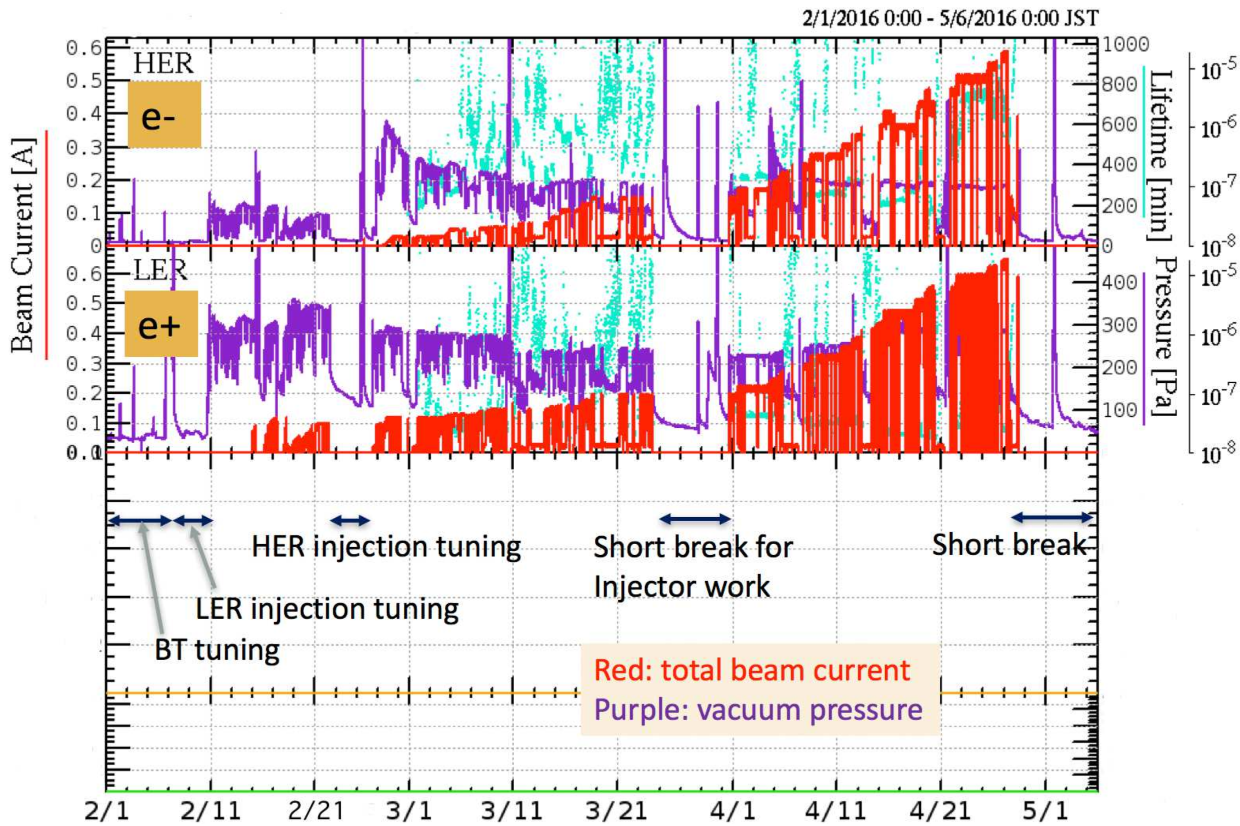

Figure 1: Three-months' history of SuperKEKB.

190 Ah, respectively. The target beam currents and the total beam dose at the end of Phase 1 are 1 A and 720 Ah for both beams, respectively.

No serious problems during vacuum scrubbing have been found. A big concern is that beam aborts accompanied by localized pressure bursts have been frequently observed in the LER. The beam aborts are triggered by the beam losses. The locations of the pressure bursts are spread out over the ring, but the frequent pressure bursts have been observed in several particular beam pipes near the IP. Most pressure bursts have occurred near or inside the aluminum beam pipes in dipole magnets. The reason for the pressure bursts has not been well understood. Possible causes are the discharge at poor electrical contacts against the wall current and the collision with dust particles. We need to be careful about this issue, although some aging effects are also observed. Another problem is a nonlinear pressure rise against the beam current in LER. We found that the vacuum pressure and the electron cloud density at the aluminum bellows chambers without TiN coating show the nonlinear behavior maybe due to the electron multipacting. A test study to install solenoid coils or permanent solenoid magnets showed that the solenoid field of ~100 Gauss can effectively suppress the nonlinear behavior. This type of bellows chamber has a length of 0.2 m and is located every 3 m on average in the ring. We have a plan to install permanent solenoid magnets at all of the bellows chamber in the ring during Phase 1.

Optics Corrections and Others

Optics corrections are the base of the machine operation. Bases of the optics corrections are the system check of the BPMs and the steering magnets with beams. As for the BPM check, we found some problems such as mis-connections of BPM cables with a small number of BPMs by making orbit bumps, gain calibrations of BPMs have been done with beams and Quad-BPM measurements (to measure a difference between the field center of quadrupole or sextupoles magnets and the center of near-by BPM) have been almost finished. As for the steering magnet check, we found an error with the excitation curve of some steering magnets by making orbit bumps. A reliable closed orbit correction system has been established based on the above measurements and modifications. From the orbit measurement data, the circumferences of the rings were estimated. It was found that a difference between measured value and the design value of the LER circumference is as small as ~2 mm and a difference in the LER and HER circumference is ~0.2 mm which is well within the adjustable range of ±3 mm using the LER chicane magnets. This shows that magnet alignments are accurate.

On the base of those measurements, optics study and corrections are in progress. At SuperKEKB, we follow the method successfully used at KEKB. Optics corrections on X-Y coupling, dispersions and beta-beat are done iteratively. Since there are not enough single path BPMs, we rely on

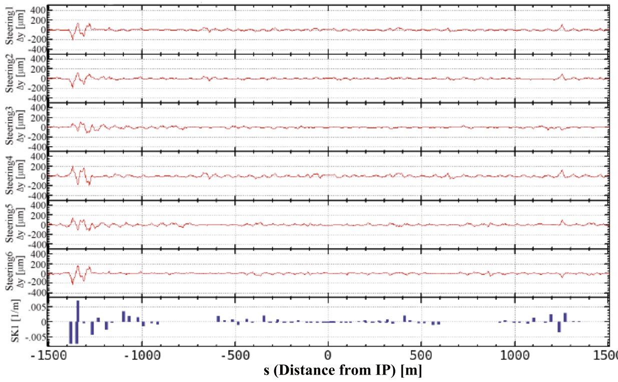

Figure 2: LER X-Y coupling measurement.

conventional BPMs. The optics measurements are done relatively low current of ~30 mA with the number of bunches of 1576. Typical horizontal / vertical tunes of LER and HER were 44.56/46.60 and 45.56/43.57, respectively. For the measurements of X-Y coupling and beta-beat, orbit responses are measured with single kicks by steering magnets. Details of the optics corrections are reported elsewhere [3]. In this report, the status of the optics corrections is briefly summarized. For the low emittance tuning, the X-Y coupling and the vertical dispersion correction are important. Figure 2 shows the X-Y coupling measurement in LER which is the best correction result so far. In the measurement, vertical leakage orbits induced by 6 independent horizontal steering kicks were observed. In the graph, such 6 vertical leakage orbits are shown as function of the ring position where $s = 0$ corresponds to the IP. The horizontal steering kicks were 200 µrad and the horizontal orbit amplitude was about 2–3 mm in its peaks. As for correctors for X-Y coupling, we employ skew-Q windings on sextupole magnets. Around $s = -1300$ m, there remains some large X-Y coupling. At the location of $s =\sim 1400$ m, a Lambertson DC septum magnet used for the beam abort is located. Its leakage field whose main component is skew-Q affects X-Y coupling. To correct the X-Y coupling induced by the leakage field, we activated skew-Q coils of one focusing (SF) sextupole pair near to the septum by using a stand-by power supply. Although all SF and defocusing (SD) sextupole magnets have skew-Q coils, power supplies for skew-Q have been prepared only for SD magnets in Phase 1. Even using the SF skew-Q coils, there still remains some X-Y coupling near the septum. A similar residual vertical dispersion is observed around the septum. To correct the X-Y coupling and vertical dispersion around the septum further, we plan to install additional skew-Q magnets using permanent magnets during Phase 1. Table 1 shows the present situation of the optics corrections together with typical values of KEKB LER. The dispersions and the beta-beats in the list are r.m.s values of the deviations from the design measured at the BPMs around the rings. As seen in the table, the beta-beats are already smaller than the typical values of KEKB, although the distance of the horizontal betatron tunes from the half integer is longer than KEKB. As for the vertical dispersion, the LER residual values are larger than those of HER or KEKB LER. The leakage field from the Lambertson septum is responsible for this. The leakage field of the HER Lamberson septum gives also some effects but it is not serious than the case of LER. A simulation shows that the residual values of the X-Y coupling and the vertical dispersion can be suppressed down to 18 µm and 4.1 mm with the additional skew-Q magnets using permanent magnets to be installed in LER, respectively. The target value of the vertical emittance is <10 pm for both beams. Preliminary values of the emittance measurement by using X-ray monitors are 20 pm for LER and 280 pm for HER. The LER value seems reasonable but the HER value is inconsistent with the optics measurements. The calibration work for the X-ray monitors is on the way. The wiggler magnets for both rings are already fully excited and the horizontal emittance of both rings should be near to the design values. Ignoring the intra-beam scattering, the horizontal emittance of LER and HER are calculated as 1.8 nm and 4.6 nm, respectively. Those values also have to be confirmed by the measurement.

Table 1: Present Status of Optics Corrections

	LER	HER	LER KEKB	Units
X-Y coupling*)	23.6	7.7		µm
$\Delta\eta_x$ r.m.s.	14.8	16.1	10	mm
$\Delta\eta_y$ r.m.s.	9.5	4.8	8	mm
$\Delta\beta_x/\beta_x$ r.m.s.	4.9	4.3	6	%
$\Delta\beta_y/\beta_y$ r.m.s.	5.3	3.7	6	%

*) average of r.m.s values of 6 vertical leakage orbits.

FUTURE PLANS

In the rest of Phase 1, the following machine studies are planed in addition to vacuum scrubbing; (1) More optics studies, (2) X-ray monitor calibration, (3) Beam background study with Beast, (4) Study on LER beam size blowup, (5) Impedance measurement, (6) Test of rotational sextupole magnets, (7) Test of dithering magnets, (8) Beam transport line study, (9) Linac study (RF gun etc.), (10) Longitudinal/transverse bunch-by-bunch feedback system.

The Phase 2 commissioning will start in Oct. 2017. Before Phase 2, the Belle-II detector without the vertex detector, the IR magnets including QCS will be installed and the construction of damping ring will be completed. At the beginning of Phase 2, the commissioning of the damping ring will be done. The period of Phase 2 is about 5 months. The start of the Phase 3 commissioning with the full Belle-II detector is scheduled in autumn in 2018.

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