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OPERATION OF SUPERKEKB IN PHASE 2

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Abstract

The Phase 2 commissioning of SuperKEKB was performed from March to July 2018. In this report, the operation statistics and the QCS quench issue which we encountered during Phase 2 are described.

INTRODUCTION

The purpose of SuperKEKB is to search for 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 4 GeV and 7 GeV, respectively. The design beam currents of LER and HER are 3.6 A and 2.6 A, respectively. The design luminosity is $8 \times 10^{35}\text{cm}^{-2}\text{s}^{-1}$. More detailed parameters of SuperKEKB is described elsewhere [1]. The Phase 1 beam commissioning of SuperKEKB was done from Feb. to June 2016 without the Belle-II detector and the IR magnets [2]. The Phase 2 commissioning was performed from March to July 2018. The highlights of the Phase 2 beam commissioning are written elsewhere [3]. In this report, the operation statistics and the QCS quench issue which we encountered during Phase 2 are described.

OPERATION STATISTICS

Figure 1 shows operation statistics of SuperKEKB Phase 2 commissioning from April to July. The Phase 2 main ring commissioning started in the middle of March. But the operation in March is not included in these statistics. During the Phase 2 commissioning, the commissioning of the Belle 2 detector was also done and it collected an integrated luminosity of ~ 500 pb^{-1}. Those are counted as "Luminosity Run". The "Machine Tuning" category includes vacuum scrubbing with beams and other hardware tuning without beams such as tuning of the beam size monitors and RF aging. The "Machine Study" category includes a dedicated machine study on the effects of the electron clouds, a collimator study, a radiation measurement and others. "Beam tuning" includes the optics tuning for squeezing IP (Interaction Point) beta functions, the beam injection or injector tuning, the detector beam background tuning, the beam collision tuning, the beam-based BPM tuning and others. A regular maintenance was done as a general rule every 2 weeks for about 8 hours. The "Troubles" category includes the QCS quench problem shown below. As a comparison, the operation statistics of KEKB for 8 years are also shown in Fig. 2. The beam tuning and machine tuning time are much longer than those in KEKB, since SuperKEKB is still in an early stage in its life and the first beam collision was done in Phase 2.

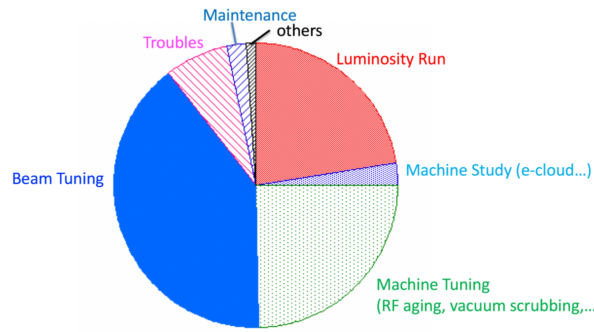

Figure 1: Operation statistics of SuperKEKB Phase 2 (April 2018 ~ July 2018).

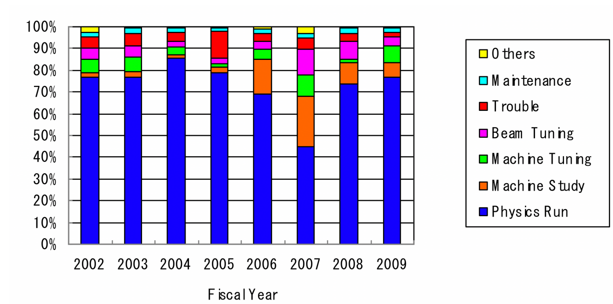

Figure 2: Operation statistics of KEKB for 8 years.

QCS QUENCH ISSUES

QCS is a generic name of the superconducting magnets near the IP at SuperKEKB which includes the final focus doublet named "QC1" and "QC2". The detailed design of the QCS magnets is described elsewhere [1]. Figure 3 shows a schematic view of the QCS magnet system. In addition to the final focus doublet quadrupoles, we need many kinds of corrector coils in order to cancel unwanted leakage fields, to correct effects of fabrication errors or alignment errors of the magnets and to widen dynamic aperture with the extremely small beta functions at the IP.

In the Phase 2 beam commissioning, we recognized that the QCS quench induced by beam hit is a serious issue for beam operation. Table 1 shows a list of the QCS quenches which occurred during the Phase 2 operation [4]. In the table, the injection kicker magnet system for the beam injection consists of two set of pulse magnets, K1 and K2. K1 and K2 make an orbit bump in the horizontal direction around the injection point for the stored beam. The quench on April 1st and 2nd was caused by unbalance of K1 and K2 due to timing errors of the pulse magnets and the orbit

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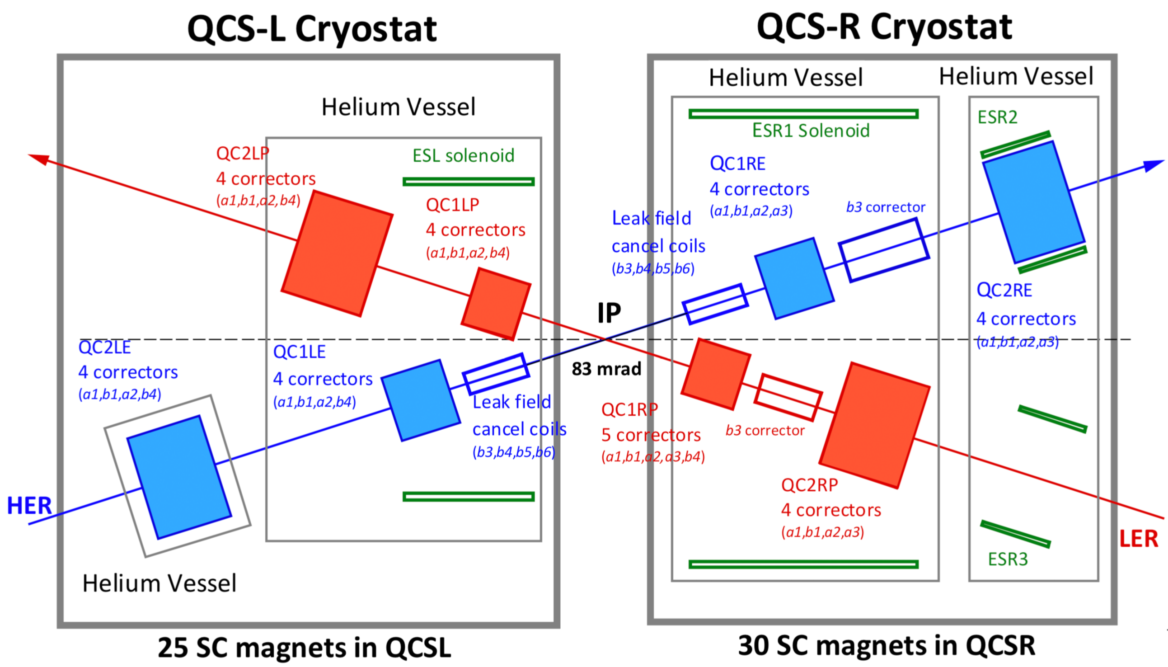

Figure 3: Schematic view of QCS magnet system.

bump was not closed. Each of K1 and K2 consists of 3 magnets. The quench on May 17th was caused by malfunction of one of the K2 magnets (K2-3) of LER. In the table, a1, b1, b3 are corrector coils and denote a skew-dipole (vertical steering), a dipole (horizontal steering) and a sextupole, respectively. On the other hand, QC1LP, QC1RP, QC1LE are main quadrupole coils and denote the final focus defocusing-quadrupole for positron on the left side of the IP, that for positron on the right side and that for electron on the left side, respectively. As is seen in the table, we had no quenches for the focusing-quadrupoles (QC2 magnets) in Phase 2. Figure 4 shows physical aperture and beam envelope around the LER QCS magnets. The blue and red dots show beam pipe aperture in the horizontal and vertical directions, respectively. Except for short sections around QC1 magnets, the beam pipes are circular and have the same aperture in horizontal and vertical directions. The green and orange lines denote horizontal ($80\sigma_x$) and vertical ($105\sigma_y$ for 5% x-y coupling) beam envelop, respectively. The horizontal and vertical beta functions at the IP in this case are 100 mm and 4mm, respectively. The red and blue squares in the figure show the locations of the main quadrupole coils and the other corrector coils of QC1 magnets, respectively. The corrector coils are located on the inner side of the quadrupole coils and are more easily hit by the beam.

During Phase 2, QCS quenches happened 26 times. Once a QCS quench happens, it takes about 1.5 or 2 hours for recovery. Initial quenches in Phase 2 were mainly induced by injecting beams. A simple calculation shows that the QCS quench can be induced by ~ 8000 electrons (7GeV) which lose their entire energy at a small part of a coil [5]. In reality, the electrons lose a small fraction of their energy at the coil

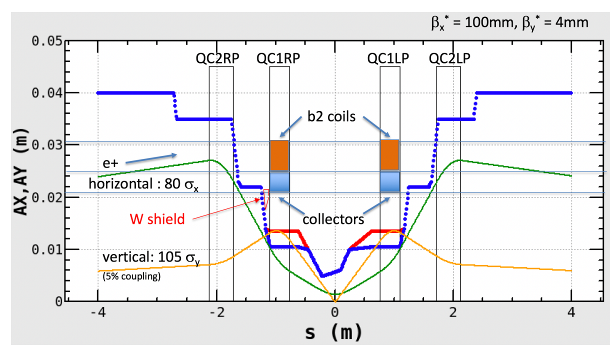

Figure 4: Physical aperture and beam envelop near QCS magnets in LER.

and so more number of electrons are needed for the quench. Even so, it seems that a single pulse of injecting beam from Linac with the charge of ~ 1nC can anyway induce the QCS quench. The quenches by the injecting beams were almost prevented by setting movable collimators properly on April 11th and introducing the Belle 2 abort using diamond sensors on May 28th [6]. We felt that we had overcome the quenches, since we had no quenches for about a month after the quench on May 24th. However, on June 25th, the quench happened again by a stored LER beam and 4 quenches followed in July. At the end of June, we started to increase the beam currents of LER and HER and also we squeezed the IP vertical beta function β_y^* from 4 mm to 3 mm. One of them was caused by an injecting beam. The quench was induced by a continuously bad injection. The Belle 2 diamond sensors and the beam loss monitors showed relatively high rates. The quench would have been avoided by stopping beam injection

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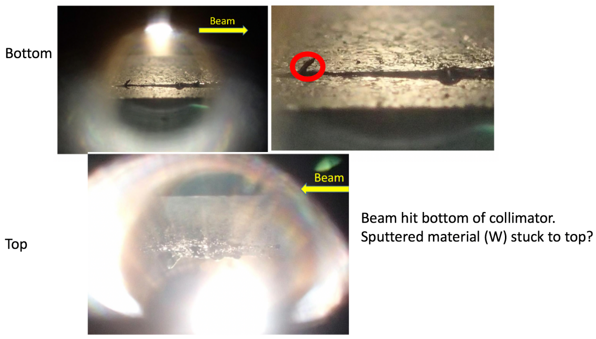

Figure 5: Damaged collimator in LER. The incident happened on June 25th.

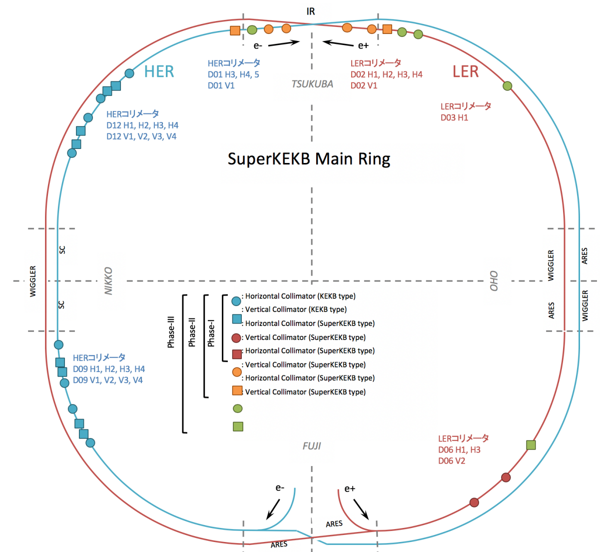

Figure 6: Collimators at SuperKEKB.

with the high rates. Four of them were induced by the stored beam accompanied with a vacuum burst. In 2 cases of the four, a beam hit vertical collimators and gave some damages to the collimators. Figure 5 shows the damaged vertical collimator named “D02V1" hit by the LER beam on June 25th. The collimator is composed of two heads (top and bottom) made of tungsten. It seemed that the beam hit the bottom head and sputtered tungsten material was stuck on the top head. A similar vertical collimator damage was induced in HER named “D01V1" on July 9th. The locations of the collimators in the rings are shown in Fig. 6. The reasons for both collimator damages have not been understood well, since we did not observed any orbit change nor the bunch oscillations in the damage. A hypothesis for the collimator damage is that the beam size was effectively enlarged due to a dust trapping event and some fraction of the beam hit the collimator. If this is the case, not squeezing the IP beta function but increasing the beam currents seems to induce the duct trapping and the QCS quench. We need more study on this issue in Phase 3. The cause of the QCS quench on July 15th was a longitudinal coupled bunch instability in LER whose reason has not been understood well. As a result of the LER QCS quench, the HER beam got unstable and induced the HER QCS quench, since the leakage magnetic field from QC1LP and QC1RP suddenly disappeared.

As measures for the QCS quenches, we will take the following measures. First, we will install more number of collimators before the Phase 3 operation which will start in March 2019. Figure 6 shows the locations of the collimators in both rings [7]. The circles and squares denote the horizontal and vertical collimators, respectively. The collimators in blue color in HER are legacies from KEKB. Since the vacuum chambers in the arc section of HER are reuse from KEKB, we can also reuse the collimators of HER in the arc section. The collimators in red and in orange were prepared for Phase 1 and Phase 2, respectively. The collimators in green will be installed before Phase 3. One more vertical collimator will be installed in LER. Since only one vertical collimator exists in LER so far and the chip scattering at the collimator can be a source of the QCS quench, this additional collimator seems important to reduce the frequency of the quenches. Three and one horizontal collimators will also be installed in LER and in HER, respectively. As an additional measure against the QCS quench, the QCS group proposes to install tungsten shields upstream of QC1RP in LER and upstream of QC1LE and Cancel coils on the left side of the IP in HER [8]. The location of the shield in LER is shown in Fig. 4 with a red triangle. Simulations on effectiveness of the W shields are going on. In the earliest case, the shields will be installed in the summer shutdown in 2019. It is also important to understand the mechanism of the QCS quench. Simulations on the dust trapping from the viewpoint of particle hit to the QCS magnets is under planning. It may also be important to do simulations on the effect of continuous particle losses at the QCS magnets due to the Radiative Bhabha scattering or the Touschek effect. In the long term, we may have to consider to remodel the QCS magnets which are more robust against the quenches.

REFERENCES

[1] T. Abe *et al.*, Technical Design Report of SuperKEKB, in preparation and to be published as a KEK report. An preliminary version is seen in “https://kds.kek.jp/indico/event/15914/”.

[2] Y. Funakoshi *et al.*, paper TUOBA01, *Proc, IPAC2016*, Busan, Korea, May. 9-13, 2016.

[3] Y. Ohnishi *et al.*, "Highlights from SuperKEKB Phase 2 Commissioning", eeFACT2018, Hong Kong, Sept. 2018, paper MOXAA02, in this conference.

[4] N. Ohuchi *et al.*, "Operation of Superconducting Final-Focus Magnet System at SuperKEKB", eeFACT2018, Hong Kong, Sept. 2018, paper WEOBB04, in this conference.

[5] N. Ohuchi, private communications.

[6] G. Bassi, private communications.

[7] T. Ishibashi, private communications.

[8] N. Ohuchi, private communications.

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Table 1: Summary of QCS quenches in Phase 2

Date	Time	Quenched Magnets	LER/HER	Causes	Injection/Storage
2018/4/1	20:55	QC1LP	LER	Injection Kicker K1, K2 unbalance	Injection
2018/4/2	19:29	QC1LP	LER	Injection Kicker K1, K2 unbalance	Injection
2018/4/9	17:31	QC1LE-a1	HER	Trial of β_y^*=2.4mm	Injection
2018/4/9	20:06	QC1LE-a1	HER	Trial of β_y^*=2.4mm	Injection
2018/4/9	20:53	QC1LE-a1	HER	Trial of β_y^*=2.4mm	Injection
2018/4/9	21:40	QC1LE-a1	HER	Trial of β_y^*=2.4mm	Injection
2018/4/10	17:44	QC1LE-a1	HER	Trial of β_y^*=2.4mm	Injection
2018/4/10	21:56	QC1RE-b1	HER	Trial of β_y^*=8mm	Injection
2018/4/11	14:21	QC1RE-b1	HER	Trial of β_y^*=8mm	Injection
2018/4/11	15:25	Cancel-Mag-b3	HER	Trial of β_y^*=8mm	Injection
2018/4/11	18:45	QC1RE-b1	HER	Trial of β_y^*=8mm tune changer	Storage? (10mA)
2018/4/11	20:23	QC1RE-b1	HER	Trial of β_y^*=8mm local bump	Storage (5mA)
2018/4/11	21:15	QC1RE-b1	HER	Trial of β_y^*=8mm local bump	Storage (10mA)
2018/4/20	14:33	QC1RP	LER	RF Phase scan mis-operation	Storage (48mA)
	14:33	QC1LP	LER		
	14:33	QC1RP-b1	LER		
2018/4/21	0:21:49	QC1LP	LER	unknown (after RF phase scan)	Storage (18mA)
	0:21:51	QC1RP	LER		
	0:22:13	QC1RP-b1	LER		
2018/5/6	11:28	QC1LE-b1	HER	Waist knob test	Storage (35mA)
2018/5/13	2:45	QC1RP-b1	LER	Beam injection with large ε_y	Injection
2018/5/17	2:09	QC1RP-b1	LER	β_y^*=6mm K2-3 malfunction	Injection
2018/5/17	4:06	QC1RP-b1	LER	β_y^*=6mm K2-3 malfunction	Injection
2018/5/24	17:17	QCSL-Can-b3	HER	Trial of β_y^*=4mm	Injection
2018/6/25	11:20	QC1RP	LER	D02V1 collimator was damaged.	Storage (728mA)
		QC1RP-b1		Big beam loss was induced.	
		QC1LP		A vacuum burst was observed.	
2018/7/3	5:14	QC1RP-b1	LER	Continuous bad injection	Injection
2018/7/9	11:20	QC1LE	HER	D01V1 collimator was damaged.	Storage(766mA)
		QC1LE-b1		Big beam loss was induced.	
		QCSL Cancel		Vacuum burst was observed.	
2018/7/15	22:32	QC1RP	LER	Longitudinal instability	Storage (793mA)
		QC1LE	HER	Induced by LER QCS quench	
		QC1LE-b1		Vacuum burst was observed.	
		QCSL Cancel			
2018/7/16	17:53	QC1LE-b1	HER	Vacuum burst at D02H collimator	Storage (670mA)