The Twenty-Sixth KEKB Accelerator Review Committee Report

19 January 2023

Introduction

The Twenty-Sixth KEKB Accelerator Review Committee meeting was held on 13-14 December 2022. Appendix A shows the present membership of the Committee. Seven committee members attended the 26th meeting in person, and several others on zoom. The meeting was held in hybrid mode and featured two days of oral presentations by KEKB staff members, plus discussions between the Committee members.

The Committee welcomes the new Heads of KEK Accelerator Divisions III (Makoto Tobiyama, formerly Head of Division IV), IV (Mika Masuzawa) and V (Hiroyasu Ego).

The agenda for the meeting is shown in Appendix B. The slides of the presentations are available at https://www-kekb.kek.jp/MAC/2022/ .

By now, SuperKEKB has produced an integrated luminosity close to 0.5 ab^{-1}. Since the 25th review, SuperKEKB has set a new world record luminosity of 4.7×10^{34} $cm^{-2}s^{-1}$, which is a significant accomplishment, namely more than twice the previous KEKB record, but it still is more than a factor 10 below the design. Appendix C compares the present machine parameters with the design values and with those of the previous KEKB. Improvements towards the design value, such as the installation of a nonlinear collimation system, are being carried out during the present long showdown. Beam operation is expected to restart in October 2023. Allocating sufficient machine time for beam studies and tuning will be important to understand and mitigate the present limitations and to further increase the luminosity. Adequate beam diagnostics will help in this endeavor. During its 26th meeting, the Committee has examined the progress of the project and the present challenges.

The ARC commends the establishment of an International Task Force for SuperKEKB, which has engaged a significant number of experts from around the world and already put forward several new ideas for improving SuperKEKB performance. While the volatile electricity prices are a concern, a recent MEXT review lends great support for the future pursuit of a vigorous SuperKEKB/Belle-II programme.

As always, the high standard of the presentations impressed the Committee. Already highlighted in a previous report, the next generation is important for the success of SuperKEKB operation over the coming decades.

The most important recommendations of the Committee were presented to the SuperKEKB staff members before the close of the meeting. The Committee wrote a draft report during the meeting that was then improved and finalized by e-mail among the Committee members. The report is available at http://www-kekb.kek.jp/MAC/2022/ .

Contents

A) Executive Summary

In summer 2022, SuperKEKB achieved a new world record luminosity of 4.7×10^{34} $cm^{-2}s^{-1}$, which is a significant accomplishment, more than twice the previous KEKB record. Among the various issues encountered were (1) the interplay between a single bunch instability and the feedback system, which was successfully solved by feedback tuning, (2) still unexplained sudden beam loss, which is tentatively attributed to “fireballs”, (3) large vertical equilibrium emittances in both rings, (4) emittance growth in the BT, and (5) poor or unstable injection conditions. Many upgrade activities are underway in the current Long Shutdown (LS) 1. Beam operation is expected to resume in October 2023. The age profile of the SuperKEKB personnel is a concern. About a third of the team is rehired retired staff, which is largely outnumbering the staff below 40 years of age.

The ARC has formulated recommendations on how to address the above issues and supports an ambitious luminosity goal for the year 2024.

B) Key Recommendations

Recommendations: The Committee has made recommendations throughout the different sections below. The most significant of these recommendations and a few more general recommendations are summarized here:

1. The ARC committee recommends actively recruiting new young staff members to help with the wide-ranging accelerator work of SuperKEKB and to prepare for the next decades of operation (R1.1).
2. Find a mechanism to engage additional PhD students (perhaps also already master students and even undergraduates), from Japanese universities or from abroad in the exciting and real-time accelerator environment of SuperKEKB, in both experimental and theoretical accelerator-physics studies (R1.2).
3. Develop a new algorithm to correct the orbit in a way that is insensitive to possible motion of BPMs without capacitive sensors and their calibrations (R2.4).
4. Simulate the effect of the measured vertical floor deformation by up to 40 mm on the vertical emittance in the LER and HER (R11.1).
5. Consider realigning the whole ring, especially the Southern part (R11.2).
6. Simulate the injection efficiency to the LER, by changing the injection offset, which may affect the efficiency or the lifetime for large amplitude particles (R9.6).
7. Quantify the expected integrated luminosity improvements for all specifically proposed LS2 projects. Update annually (R21.2).
8. Investigate through a combination of electro-magnetic, mechanical and shower simulations (as performed for LHC collimators) whether a sudden collimator jaw deformation by ~100 micron could occur, triggered by HOM heating or small beam impact, which could then lead to a self-amplifying increasing deformation and catastrophic sudden beam loss (R17.5).

9. Given the ongoing extremely high concern for the cost of electrical power, study configurations for the RF system in SuperKEKB that will allow for full or nearly full beam operation while significantly lowering the cost of RF power generation (R12.2).
10. Complete a comprehensive study of the possible advantages coming from inserting an ECS in the e^- BT before proceeding with the real device construction (R8.2).

C) Findings, Comments, Recommendations

1.SuperKEKB Status

Findings & comments:

In the summer 2022 SuperKEKB established a new luminosity world record of 4.7×10^{34} $cm^{-2}s^{-1}$. Over the past three years, it has delivered an integrated luminosity close to 0.5 ab^{-1} to Belle-II, which is a significant accomplishment. The peak results were obtained while colliding 2346 bunches in each ring with 1.15 A in the HER and 1.46 A in the LER and a β_y^* of 1.0 mm. A β_y^* of 0.8 mm was tried in preparation for a possible future mode of operation.

A recent MEXT review covered two topics: The results of the past ten years and the proposed plan for the next operational period for SuperKEKB and Belle-II. The MEXT review strongly endorsed the future pursuit of a vigorous SuperKEKB/Belle-II programme. The ARC congratulates the SuperKEKB team on this important successful review.

The SuperKEKB Accelerator Divisions III to V gave reports on staffing issues. In overall numbers, these divisions are missing at least 10-20 staff. At present the personnel is about half of what was available at the time of KEKB and, for example in the RF group, only a quarter of the number present during the TRISTAN era. About 35 of the presently active persons, or ~30% of the total, are retired, rehired staff. Only three staff members are younger than 35 years and another four are between 35 and 40 years old.

The cost and availability of electrical power had a strong influence on the beam run 2022b, arising from higher oil prices, surcharges, power contract changes, and the overall Japanese power infrastructure. This run was stopped about a week early due to sudden changes with these power cost issues. Such influences will extend into the future. The SuperKEKB divisions found many clever ways to save power costs over the SuperKEKB complex during the ongoing downtime. The overall implementations for future beam operations will necessitate new relations with Japanese power companies and potentially new modes of beam operations.

Recommendation:

R1.1 The ARC committee recommends actively recruiting new young staff members to help with the wide-ranging accelerator work of SuperKEKB and to prepare for the next decades of operation.

R1.2 Find a mechanism to engage additional PhD students (perhaps also already master students and even undergraduates), from Japanese universities or from abroad in the exciting and real-time accelerator environment of SuperKEKB, in both experimental and theoretical accelerator-physics studies.

R1.3 Optimize RF configurations for SuperKEKB to allow for full beam operations while saving RF related power costs to allow extended running hours, given a likely reduced but fixed power budget.

2. 2021c-2022b

Findings & comments:

Tremendous efforts were undertaken to improve the luminosity of SuperKEKB during this period, resulting in new peak and daily luminosity records. Some of the improvements were increased beam currents with more bunches, improved field reproducibility of interaction-region quadrupoles, two bunch injection, and improved field quality in the injection kickers. Some of the obstacles encountered were sudden beam losses, low injection efficiencies, current dependence of the orbits, and damaged collimators. These obstacles implied medium values for the vertical beam-beam parameters ξ_y in standard operation, whereas higher ξ_y values were reached in operation with a few hundred bunches.

So far the best specific luminosity has been achieved with a nominal value of β_y^*=1 mm. However, the estimated actual value of β_y^* for that case was about 0.8 mm, due to the optics error caused by an orbit shift at the final-focus sextupoles. An open question is why such an optically mismatched 0.8 mm resulted in better performance than a matched 0.8 mm. The latter led to a shorter beam lifetime than the mismatched 0.8 mm.

The daily integrated luminosity exhibits a large day-by-day fluctuation during this period. Aside from injection efficiency and its stability, also the bunch current limit set by sudden beam losses, the abort frequency and optics degradation affect the daily integrated luminosity.

One of the causes of poor injection after an abort may be the sudden orbit change in the rings due to the varying beam-induced thermal effects. The loss of heating of the beam vacuum chambers may push the quadrupole positions after an abort. Although some BPMs have displacement gauges to correct the offsets of these BPMs relative to the nearby sextupoles, other BPMs without sextupoles just move together with quadrupoles. So, advanced algorithms may be needed to correct the orbit by guessing/estimating the displacement of each BPM.

Recommendations

R2.1: Investigate the reason why the beam lifetime was shorter for the matched β_y^*=0.8 mm configuration than for the mismatched 0.8 mm case.

R2.2: Summarize the reason for the degradation of the integrated luminosity, looking at the operation log and create a top-10 list of causes for the losses of integrated luminosity.

R2.3: Understand why adding more bunches does not produce the expected improvements in terms of beam current.

R2.4: Develop a new algorithm to correct the orbit in a way that is insensitive to possible motion of BPMs without capacitive sensors and their calibrations.

R2.5: Examine the history, step size, and frequency spectrum of IP feedback signals.

R2.6: Check, using the stored recorded position data from the last run, the magnitude of the measured vertical motion (jitter) of the individual two beams at the IP as compared with the amplitude changes of the vertical deflection collision to see if the jitter positions are adequately corrected for optimum luminosity. Are the position jitter levels for the case of β_y^*=0.8 mm different from those at 1.0 mm?

3. Belle II status

Findings & comments:

The goals of Belle II are to support the highest possible SuperKEKB luminosity, to ensure optimum and efficient particle physics data collection, to help minimize the beam backgrounds while allowing the peak luminosity to increase, and to significantly reduce unnecessary beam aborts.

The detector team has worked very hard to improve the data collection efficiency of Belle II. They have found that there has been a drift in the center-of-mass energy $E_{\rm cm}$ by as much as 4 MeV, that has cost the equivalent of 5-7% of integrated luminosity over a period of 1.5 yrs. They are now more often checking the $E_{\rm cm}$, in order to stay closer to the peak of the 4S resonance. One of the major concerns is the backgrounds generated by bad injection. They have had to increase the DAQ deadtime for injected pulses, that require an extra-long time to finally damp down to the stored beam. This has increased the overall deadtime of the detector to approximately 10%.

There are several improvements planned for the detector during the LS1 downtime. The TOP detector will have several PMTs replaced with new tubes that have much longer lifetime. The current PXD (PiXel Detector nearest to the beam pipe) is currently a partial installation with only 2 ladders out of a total of 12 installed in the 2nd layer. The plan is to install a complete new PXD detector including the first layer of 8 modules as well as to improve the observed heat-related expansion issues. At the same time, a new beam pipe is being fabricated, that features improved shielding from secondary synchrotron radiation (SR) scattering. These two items are the driving terms for the long shutdown. In addition, more shielding will be installed near the front of the cryostats in order to reduce detector backgrounds from shower debris of beam particles hitting the beam pipe in this area. More neutron shielding will be installed with the intention of reducing the number of FPGA failures. In addition, the software in the FPGA modules is being upgraded to be less sensitive to data degradation issues which seem to arise from neutron background.

The detector and background teams are assisting the accelerator team in improving the beam abort system and in attempting to detect the starting locations of the fast beam loss events.

Monochromatization, with the help of either nonzero vertical IP dispersion (Frascati proposal from the early 1970s) or through a chromatic waist shift (Raimondi proposal from 2022), can lower the effective collision energy spread and increase the event rate in cases where the beam energy spread is comparable to (or larger than) the width of the Upsilon resonance. Upsilon (4S) has a Breit-Wigner width of 20 MeV. The natural rms collision energy spread is around 5.5 MeV, as mesaured by Belle II. For zero collision energy spread, obtained by a perfect monochromatization, the event rate would increase by about 10%.

We applaud and encourage the collaboration of the detector groups with the accelerator groups. The detector team should be able to help the linac and injection teams to understand which injection bunches are extra lossy and which are better. The detector team has developed several beam loss detectors that can help the accelerator team in discovering if there are specific locations in the rings where the fast beam abort events originate as well as shorten the time between beam instability detection and the ensuing beam abort.

Recommendations:

R3.1: Determine the origin of the shift in the collision energy. Consider collision energy feedback based on the SuperKEKB dipole-based energy spectrometer or the Belle II dimuon events, for example.

R3.2: Explore the possible merits of “monochromatization” in terms of increased event rate and beam-beam performance.

R3.3: The detector team should more closely work with the linac and injection teams to understand the varying quality of injection bunches.

4. Machine Detector Interface (MDI) and Backgrounds (BG)

Findings & comments:

Belle-II beam backgrounds did not limit the beam currents in 2021 and 2022, thanks to successful mitigation by collimators, by the vacuum scrubbing progress, etc. The TOP counter is the sub-detector most vulnerable to beam backgrounds. The recent TOP background breakdown reveals that beam-gas scattering in LER, beam-gas scattering in HER, Touschek scattering in LER and HER, respectively, luminosity and injection all contribute at roughly comparable levels to the TOP background, with slightly higher contributions from the LER than from the HER. Data and Monte-Carlo simulations are in fair to good agreement, with higher than expected single-beam contributions from the LER and lower than expected ones from the HER. A Snowmass White Paper predicts that backgrounds will remain acceptable for luminosities up to 3×10^{35} $cm^{-2}s^{-1}$. For the target value of 6×10^{35} $cm^{-2}s^{-1}$ there is quite some uncertainty, however.

For the HER, the measured Touschek background rate is 5 times lower than expected from the Monte-Carlo simulation. The reason for this discrepancy is unclear.

A new machine learning application was developed, which can be used to monitor the real-time composition of the background sources. A “feature attribution” method of this application indicates which parameter has contributed to a change of background rate. In the future, this application can be used for the accelerator tuning. The ARC applauds this excellent development.

At higher beam currents, the duration of the injection background has increased. Other major issues are: the sudden beam loss, which is addressed by abort timing analysis using fast loss monitors; the bad injection, e.g., due to linac energy drift, poor two-bunch injection etc.; and the limited stability of good injection conditions. LER large beam loss aborts caused QCS quenches 8 times in 2022. A much higher rate of bad injections occurs at smaller β_y^*. It takes about 20-30 minutes to recover after each abort, which results in a significant loss in integrated luminosity. Earthquakes have also resulted in 26 beam aborts. Several collimators were damaged by beam losses. The beam orbits before and after a beam abort are completely different, but the earlier orbits are reestablished by the orbit feedback.

To better understand the sudden beam loss events, 7 new beam loss sensors were installed around the ring, and 6 more are due to be installed. The loss monitor at D6V1 was the first sensor to see beam loss in most cases, but not always. This might indicate that the beam disturbance in these cases occurred upstream of the D6 section. The planned installation of additional monitors will help further pin down the origin of the sudden beam loss.

Recommendations:

R4.1: Further improve background models to reduce the last factor of 3-5 discrepancy between measured and simulated Touschek rates.

R4.2: Implement as many diagnostics as possible to identify the origin of the sudden beam loss, including more or different loss monitors, vibration sensors on/near collimators, thermocouples, etc. If possible, trigger and record data from available diagnostics, such as beam size monitors, bunch profile detectors, and turn-by-turn BPMs, for the last few turns before beam abort.

5. Control

Findings & comments:

The successful commissioning and development of the SuperKEKB facility, with many complex and inter-related sub accelerators and diagnostics, is only possible because of the functionality, performance and reliability of the distributed control system. It is a mix of legacy functions with many new requirements and control needs still being added or enhanced. The SuperKEKB Control team can be proud of their contributions to the project.

The review presented some performance enhancements to the system timing functions, as well as some updates on the maintenance and technology upgrades to the core networked computer systems.

The core synchronization and timing functions throughout the SuperKEKB complex and KEK light sources are implemented in Event Timing Generators and Receivers. To better control the damping ring extraction the delay setting in the event was upgraded from 8.7 ns resolution to a 400 ps resolution, which reduces some jitter, and "cogging" in the extraction synchronization. This improves the top-up operation in SuperKEKB for 2 bunch injection and allows the implementation of the BCE (Bunch Current Equalization). This timing improvement is also used for injection into the Photon Factory and PF-AR.

A White Rabbit based timing distribution and event recording system has been added. This functionality is used to improve the time-stamp resolution for injection, beam loss and abort diagnostics. Many examples of this improved functionality were presented, including IP loss monitors near Belle II, injection background studies, bunch ID and history for beam loss events, beam abort sequence history and the like. The flexibility and utility of the new hardware and software are very useful. This is a successful and valuable upgrade.

The core computing hardware and software platforms require periodic upgrades. The SuperKEKB servers, network and storage systems have all been maintained and selectively upgraded.

The use of the White Rabbit timing systems is an excellent pragmatic choice, as sharing the implementation of this general-purpose timing backbone with CERN and other user labs is economical as well as an opportunity for KEK to contribute their software applications to the larger accelerator community. KEK's recent addition of the EPICS code to the White Rabbit server is an excellent example of this two-way benefit. Sharing these kinds of projects and developments is good for everyone in the worldwide accelerator community.

Recommendations:

R5.1: Continue to test and validate the timing and time stamp functions used in the abort and loss diagnostics - when you need them, you want to be sure the system works flawlessly to get the value of the recorded event.

R 5.2: There are some diagnostics implemented in commercial general-purpose instruments (such as the picoscopes used in the loss monitors). Because the product lifetime of commercial instruments is probably much shorter than the operational life of SuperKEKB, be sure that adequate spares are maintained. If a product is discontinued, you do not want to write new software and invest manpower in a different commercial instrument to duplicate this function.

R 5.3: The Committee supports the idea to extend the bunch current equalizer capability in the bunch selection to the two-bunch injection operation mode. It will be beneficial for improving injection efficiency and machine operation stability as well.

6. Monitor (Beam Instrumentation)

Findings & comments:

The operation of SuperKEKB requires state of the art beam instrumentation and beam feedback systems. The review focused on recent new developments in the four subsystems.

BPM systems - An intensity-dependent orbit shift has been observed in the VXI-based HER BPM receivers. These are legacy BPM instruments originally used in KEKB and it is likely this effect has been there for a long time. Studies suggest that this intensity dependent effect is coming from the very wide dynamic range receiver front end, which uses a series of programmable attenuators to scale input signals into the receiver channel. Investigations are underway, if the effect is due to finite RF matching at some attenuator settings, the proposed installation of circulators in the signal path may improve this measurement. The turn-by-turn BPM systems have needed repair. At present the hardware is being repaired by KEK. There is a future upgrade of remaining BPM cards by a commercial vendor.

Beam Imaging Diagnostics - Both the X-ray and synchrotron light monitors were reviewed. The X-ray based beam imaging has had to replace CCD cameras due to radiation damage; also some scintillator damage was seen. A Cu absorbing filter has been installed to reduce the radiation flux in the detectors. There has been a leak in the HER X-ray path; a copper-beryllium window appears to have been damaged by moisture. This is still under investigation.

The visible light imaging uses a diamond mirror to reflect the visible image. This mirror has suffered from heat deformation due to the X-ray flux. The development has moved from a single crystal to polycrystalline mirror materials with gold and platinum surfaces. The imaging system includes a coronagraph, with optics that can block the central beam spot to allow measurement of the less-intense beam halo. Many images were shown. The technique offers a promising path to understand possible contributions of the beam halo to backgrounds, etc. The capabilities include single bunch and single turn images, which are valuable for injection studies.

The bunch-by-bunch feedback systems are critical for SuperKEKB, and these have been in development since the early days of KEKB. The technology is a shared design used at many facilities, with the benefit of shared operational and instrument codes for beam instability diagnostics. In the last year, the noise floor of the transverse receiver has been investigated. To reduce the noise floor a different processing configuration with re-partitioned RF and baseband gain, as well as with a comb generator of a different design, has been prototyped. This modification may help increase the feedback gain and may change the potential emittance increase from extremely-high-gain configurations. This is an ongoing study. The flexibility to change the processing filter bandwidth and phase slope via the filter tap length and coefficients may also give extra capability to add feedback gain and flexibility in tuning. Initial tests show good damping with the alternate filters.

Tunnel environmental monitoring systems have been implemented. These allow remote logging of temperature and humidity.

Recommendations:

R6.1: The orbit intensity shift may be due to mismatches in the attenuators, but in any case, these legacy HER BPM electronic modules may be difficult to maintain over the lifetime of SuperKEKB. An alternate plan might be to use the same BPM modules as were developed for the LER; this was suggested in the presentation. This path should be considered a fallback option with adequate spares of the LER type module.

R6.2: The information coming out of both the X-ray and synchrotron light monitors is potentially valuable in diagnosing beam properties. It is clear the halo studies require labor and time to better understand what they show and how they could be helpful. Similarly, interpreting the X-ray beam size data may take workforce and time investments. With the recent and sad loss of John Flanagan, it is important that adequate scientific personnel is made available to continue developing these techniques.

R6.3: The capabilities of the instability feedback will really be tested as the currents increase to the design values. There may also be issues with heating of the beam line kicker components. Adequate workforce and machine time investments to study the damping systems as the beam currents are increased will be important. Understanding the interactions of the LER longitudinal bunch-by-bunch feedback with the low-mode feedback in the LLRF systems will also be important as currents increase and the instabilities become more challenging.

7. Injector

Findings & comments:

A description of the injector layout is given with emphasis on simultaneous top-up injection in 4+1 rings. The parameter table shows an exceptional improvement in performance from 2018 until the last run, which ended in the summer of 2022. This reflects a deep knowledge of the injector subsystems and the great jobs done until now. However, for the injector, the design value of the positron charge (currently at 85%) and electron charge (currently at 50%) as well as a stable 50 Hz operation with two electron bunches still remains to be achieved. The emittances measured at the linac end (BT1 before ARC1) of both species are at, or better than, the design value for electrons while they are close to the design value for positrons.

Electrons: The thermionic DC gun works as specified. The beam quality in terms of electron emittance from the RF gun with photocathode could be improved by installing a DOE in the laser line to improve the spatial distribution. Charge stability was improved too, by installing charge feedback. High charge operation (5 nC) was also tested, reaching the design value of 4 nC at the end of the linac. The charge losses in the J-ARC and at the target location must be improved. The stability of the second bunch must also be improved. An emittance growth at the linac end with time (a sort of emittance growth drift) is observed if the bunch is not reoptimized while the emittance in the RF gun region remains constant.

Positrons: The positron charge is almost at design value ! However, the transmission efficiency between the target and the end of the linac is 60%. Horizontal emittance after the Damping Ring (DR) is larger than the design value and a new low-emittance optics for the DR will be tested.

Implementation of optimizers for linac tuning can improve performance, but sometimes at the cost of not understanding the machine physics behind the optimized result.

In general, the stability and the beam quality are critical questions for a linac and the following transfer line. Implementation of beam-based feedback with dedicated diagnostics can improve the beam stability and stabilize the beam quality.

Recommendations:

R7.1: Perform systematic measurements of the orbit jitter of the two electron bunches and correlations with possible sources. Advance the synchronous data acquisition between Linac and BT.

R7.2: More generally, perform a feasibility study for the implementation of synchronous beam data acquisition, which will be extremely useful for studying drift and instability.

R7.3: Implementation of an orbit feedback if the use of pulsed magnets allows for this.

R7.4: Continue with the upgrade plan as presented in the summary slide.

R7.5: Concerning the emittance growth of the second electron bunch, study the effect of long range-wakes in the linac.

R7.6: Identify the causes limiting the charge of the electron bunch along the injector.

R8.7: Discover the loss locations and causes for the positron transport in the linac.

8. Beam Transport (BT)

Findings & comments:

Survey results from 2018 for magnets of the LER and HER BT quadrupoles in the injection region showed large misalignments that were mitigated via optics design changes (bend angle in ARC4 for LER and septum angles for LER) at the time. During LS1, a few large quadrupole offsets in HER and residual misalignments with respect to the new reference orbit will be corrected.

It has been found that a fringe field near the septum plate has a sizable multipole component. The field quality would be improved by reducing the pulse width and improving the septum shim shape. Installation of a new shim will be scheduled in summer 2024.

A new vacuum chamber for QI4E was designed with sufficient clearance for the injected beam.

A leakage of LER injection orbit bump was observed, which might arise from differences of the ceramic duct shape. They may need to manufacture new K2-type ceramic ducts and replace K1 ducts by new ones in 2024.

In line with the budget rules, components of a new Energy Compressor System ECS and fabrication of components for a cooling water system were approved and could be fabricated within three years.

A new BT line for the HER has been proposed, aiming at keeping the CSR/ISR emittance growth under control. ISR induced emittance growth of the new BT line decreases to 1/3 of that in the current BT line.

It was highlighted that benefits from most of the upgrades proposed will be reaped in mid-2024 or later, so about one year after the re-start up.

Recommendations:

R8.1: Evaluate the impact, if any, of the new beam pipe for the QI4E quadrupole in terms of impedance.

R8.2: Complete a comprehensive study of the possible advantages coming from inserting an ECS in the e^- BT before proceeding with the real device construction.

R8.3: Quantify, by numerical simulations, the reduction in terms of CSR emittance growth from the new BT line as well as you already did it for the contributions coming from ISR.

9. Injection

Findings & comments:

An overview of the injection issues clarified the injector status, achievements, and planned next developments, intended to improve it towards the target performance and to support the design luminosity. Injection has a strong correlation with the injector and Beam-Transport BT optimization and the speaker gave a positive impression on the collaborations and common efforts between the groups that work on the various parts/issues of the SuperKEKB accelerator complex. After the overview, the speaker focused on two specific issues not discussed in other presentations: The emittance growth in the BT line and the injection efficiency into the main rings. Emittance measurements showed a horizontal emittance growth in the Arc 1, along with a vertical emittance growth in Arc 1 and Slope 1. An effort was devoted to understanding if the cause of the horizontal emittance growth was due to ISR and CSR effects. They found an agreement between simulations and measurements by changing a few of the beam parameters and machine settings, such as the rf phase and the charge. They observed that the emittance growth is consistent with the CSR effect, but the measured blowup is still larger than that of the simulation.

As a suggestion, they should use a 3D model for the CSR because the 1-D model in Elegant provides an underestimation of the CSR effects.

After this comprehensive campaign of measurements and simulations for the e^- BT, a couple of countermeasures were suggested and one of them was that the best solution for the BT line is to install both the new straighter line and the Energy Compensation System ECS, in order to suppress ISR and CSR with minimum longitudinal emittance increase. Other proposals are to generate a CSR shielding by operating with a vertical bump or by reducing the beam-pipe aperture, or to change the BT layout into a new straight one either with or without a smaller aperture.

A new beam transport (BT) line is a big effort, and a detailed study of the new layout should be conducted. In the simulations, a model of IBS should also be included and the effect of CSR on the beam distribution along the BT should be considered, too. However, before a final decision is taken on the implementation of a new beam transport line, a similar detailed study should be done for the vertical emittance growth in BT to understand the cause of the emittance blowup. It is not clear what the source is at this moment. Furthermore, narrowing the vertical aperture in the BT line permanently may be risky, as the stronger wake fields may possibly enhance the fluctuation of the vertical orbit.

One of the outstanding issues is to increase the injection efficiency for the positron beam to reach the target luminosity. Reduction of the positron emittance in the BT is one of the most important improvements to be done together with the investigation of the beam loss during the first 1000 turns after injection. It may be worth trying to simulate the injection efficiency to the LER, by changing the injection offset, which may affect the efficiency or the lifetime for large amplitude particles.

Re-alignment of the transport lines of both LER & HER, especially the parts just upstream of the injection points, can help improve the injection efficiencies and mitigate the emittance dilution.

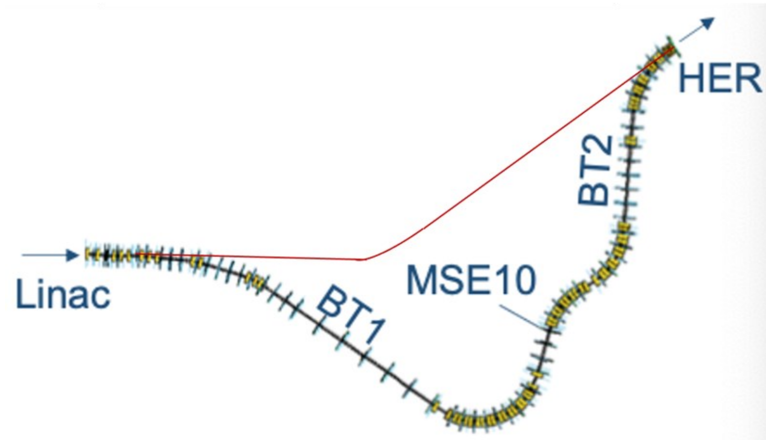
Recommendations:

R9.1: Emittance growth: a 3D model for the CSR should be employed in the BT simulations. IBS should also be considered.

R9.2: A detailed optics investigation should be executed to understand the source of the vertical emittance growth.

R9.3: Look at the history on the vertical orbit deviation of first and second bunches before narrowing the vertical aperture of the BT line.

R9.4: To suppress the CSR & ISR, as mentioned in the presentation, a new straight transport line could be considered. The following straight transport line might be approximately optimized:



A more ideal transport line (red curve) with minimum ISR & CSR effects.

R9.5: Simulate the injection efficiency to the LER, by changing the injection offset, which may affect the efficiency or the lifetime for large amplitude particles.

R9.6: We suggest that some efforts should be made to ensure that if a single injection thyratron spontaneously fires, all the other injection thyratrons will be forced to fire too. This would result in the event becoming a closed orbit kick at the injection point and it would eliminate the possibility of an open beam oscillation and resulting damage to a collimator head. This issue will become even more important as the beam currents increase.

10. Vacuum

Findings & comments:

The dynamic pressure rise is decreasing as the beam dose progressively increases in both LER and HER. In the latter, the pressure rise is four times lower, because 82% of the beam pipes and bellows had already been installed in KEKB (memory effect) and the ring has been less vented during the last years. At the end of the 2022a/b run (6000-7000 Ah), the equivalent desorption yields are $2x10^{-8}$ molecules/photon in the HER and $4x10^{-7}$ in the LER. The slope in the high dose region of the log(P)-log(dose) plots is around -0.8 for both rings, which is a typical value for high-energy electron rings. An integrated beam dose of $5x10^{5}$ Ah (i.e., more than 50x today's accumulated dose) is necessary to reach the same desorption yields in the LER as today in HER. In the DR, the vacuum requirements are reached: Today, with an accumulated dose of 67.6 Ah, the desorption yield is $2x10^{-6}$ molecules per photon.

The LER dynamic pressure does not increase linearly with beam current as it should be if synchrotron light impingement were the only cause of gas desorption. Fitting the experimental data, it seems that thermal effects also play a significant role at high currents; this could indicate a local heating of vacuum components by Higher Order Modes (HOMs).

The beam lifetime is not affected by the residual gas in the HER and only marginally (20-40%) affected by the residual gas in the LER. The Touschek effect is the main limitation of beam lifetime. In addition, electron-cloud effects are not anymore measurable.

Among the troubles that were presented, the one related to malfunctioning of a water-cooling pump caused the most serious issue. The problem should not happen again as the cooling interlock was changed, now inducing a beam abort when multiple water-flow alarms are received. Problems found in two gate valves were solved, but not fully understood. In the future runs, particular attention should be paid to gate valves to understand if the issues were isolated events or signs of persistent weaknesses.

An intense work is ongoing during the LS1, including the replacement of several collimators, modifications of the QCS cryostat and replacement of 50 m of beam line for the NLC.

In conclusion, today, vacuum is not a showstopper and most of the issues were solved and understood.

Recommendations:

R10.1: Continue the excellent operation, monitoring and data analysis of the vacuum systems.

11. MR Magnets & QCS

Findings & comments:

No time has been lost due to the main ring magnet system for the last 31 months.

Owing to difficulties in procuring hollow copper conductor, the required new skew sextupoles will feature coils recuperated from spare normal sextupoles. A good decision.

Around the IP, the tunnel continues to sink, which is being carefully monitored. The main event for the final quadrupole QCS has been the appearance of a vacuum leak, requiring the addition of pumps. After cold examinations with the help of the vacuum group, this leak was found to be on the service cryostat: it will be repaired towards the end of this financial year.

An investigation into flux creep in the superconducting magnets has revealed that this is more marked if the power supply is left in the up-ramp position: in the down-ramp position the flux-creep is much less; so this will henceforth be taken to be the standard for operation.

Recommendations:

R11.1: Simulate the effect of the measured vertical floor deformation by up to 40 mm on the vertical emittance in the LER and HER.

R11.2: Consider realigning the whole ring, especially the Southern part, during LS1.

12. RF

Findings & comments:

The SuperKEKB RF system is operating well. In June 2022, it was supporting beam currents of 1.15 A of electrons in the HER and 1.46 A of positrons in the LER, distributed over 2346 bunches.

The upgrade of the RF system from KEKB to SuperKEKB is complete but several conversions of ARES stations from single klystrons feeding two ARES cavities to a set up with 1 klystron per ARES cavity still need to be completed. The RF team has studied how to maximize the stored beam current without adding more klystrons, including beam loading, cavity power limits, and cavity phasing.

The new Coupled Bunch Instability (CBI) damper system is working well. The Auto-level Control Loop (ACL), the Phase Lock loop (PLL), the Direct RF Feedback (DRFB), and the Zero-Mode Damper (ZMD) are being optimized to maximize the allowed stored beam currents. The studies indicate to increase the voltage of the ARES cavities, to extend ZMD to all stations, and to minimize the gains of the PLL and the ACL. As currents increase, these studies will be critical to understand how to configure the numerous regulator loops for the best station stability as well as for optimum beam stability. There will be many decisions to make on the unique configurations to run the 2 cavities per klystron stations and the 1 cavity per klystron stations.

The design choice of superconducting and ARES-type energy storage cavities means that the high stored energy helps mitigate gap transient effects. As higher currents are reached, understanding the gap transients in HER and LER, and the match between them, may be important. The LLRF design with the Direct Loop means that during the beam gap the direct loop will attempt to drive the klystron with extra power to cancel the transient from the missing beam current in the cavity and estimating this transient power overhead may be important. Similarly, an operational strategy to run the machine with one or more parked RF stations will be necessary. With such parked unpowered cavities, the gap transients will be more pronounced. Estimating these situations and their management seems helpful.

At the achieved currents the RF stations are not yet highly stressed. As currents increase the required performance of the direct feedback and the dedicated mode -1,-2 and -3 loops will increase. If the PEP-II and LHC experience is a guide, the model-based configuration methods may help with optimally configuring the stations. This helps with both the station performance, and the time required for the RF experts to oversee the RF system configurations and operation.

There were seventy-two beam aborts (about 0.6 per day) attributed to the RF systems in the beam run 2022a/b with about ⅔ due to aging controls and ⅓ due to cavity breakdowns in either ARES or SCC cavities. The issues of aging components in the RF control system are dealt with as they arise. The overall RF system is regularly inspected to reduce the rate of these trips.

The HOM power generated by the beam in the SCC cavities is about twice what was expected. In order to run at the needed higher beam currents in the HER, additional HOM SiC dampers are being added to the downstream beam lines near the SCC cavities. The presently installed units have been shown to be effective at absorbing the extra HOM power.

The ongoing high concern for the cost of electrical power will cast a shadow over the beam operations of SuperKEKB for the foreseeable future. The RF system is the largest power consumer in SuperKEKB. In view of these concerns, the RF team should investigate alternative configurations for the RF system in SuperKEKB that will allow for full or nearly-full beam operation while significantly lowering the cost of RF power generation. The alternative configurations may involve parking a number of RF stations, running with reduced voltage to allow longer bunch lengths, running with different bunch patterns to reduce the RF overhead, reconfiguring the RF overhead while operating the longitudinal feedback systems, and running fewer klystrons but at higher power levels where the klystrons and HVPS are more efficient.

Recommendations:

R12.1: Study in simulations whether variations in filling pattern could reduce the overall generated cavity HOM power (see the procedure and results in PRAB 21, 071001, [Phys. Rev. Accel. Beams 21, 071001 (2018) - High order mode power loss evaluation in future circular electron-positron collider cavities (aps.org)]())

R12.2: Given the ongoing extremely high concern for the cost of electrical power, study configurations for the RF system in SuperKEKB that will allow for full or nearly full beam operation while significantly lowering the cost of RF power generation.

R12.3 Develop an estimate of the gap transients at the design current with nominal RF configuration, and for operating scenarios with one or more parked stations.

13. Helium refrigerator for SRF

Findings & comments:

The helium refrigerator system for the SRF is vintage, having initially been constructed for TRISTAN in 1988. The 2 K function required for the SRF was developed by KEK. The system is sufficiently powerful but requires regular maintenance to ensure conformity with the regulations. The original manufacturer has left the business, requiring the procurement of generic spares. There are three spare turbines. The team is evidently very competent.

Recommendations:

R13.1: Undertake a survey to establish which parts may require replacing in the near future.

14. Optics issues

Findings & comments:

In recent high-beam-current operations SuperKEKB struggles to keep the machine performance. Optics aspects contributing to this degradation were presented:

In 2021 a tune drift from QCS field drift along with large vertical beta-beating had been observed. The source was identified as the ‘flux creep’ effect and the implemented mitigation was to exceed operational current and ramp down.

Resistive wall introduces a tune shift versus beam current. However, tuneshift changes on a day-by-day basis. Horizontal orbit changes at the sextupoles shift the tune, and it is seen that the orbit depends on intensity. The horizontal tune shift versus intensity agrees with resistive wall calculations. Vertical tune shift shows a certain consistency with expectations from orbit shifts at sextupoles, when ignoring the expected effect of the vertical resistive wall. This could be just a coincidence, but the origins of the vertical tune shift with current should be further studied. This tune shift with current is accompanied by up to 20% beta-beating, inadvertently reducing β_y^* from 1.0 mm to 0.8 mm. Orbit adjustment at sextupoles improves efficiency and background.

The HER beam becomes unstable after larger earthquakes, needing optics corrections. Also, even without earthquakes, a degradation of emittance and injection efficiency is observed during high intensity operation, calling for optics corrections every 2 or 3 days. A plausible reason is a small orbit fluctuation as the residual orbit correction is of order 20-30 μm only. The BPM readings can be affected by drifts of gain, temperature changes, etc. Reliability of orbit correction is compromised by these drifts. It should be explored how to correct only the real orbit shifts.

Using comparisons between 3 BPM orbit readings reveals significant discrepancies from expectation that could be explained if HER QC1 had 3% transfer function errors. Accurate magnetic modeling from magnetic measurements is not implemented. Oide-san commented that the observed discrepancies could be due to assuming only a 1D model, while both x-y coordinates should be considered for the coupled transport matrix.

Dynamic aperture measurements have not been carried out.

The ARC committee suggests a look at a possible theorem of tune shifts against the closed orbit deviation for a chromatically corrected optics.

Recommendations:

R14.1: Perhaps the step size for lowering β_y^* should be a smaller one, i.e., one could consider a first step from 1 mm to 0.90 mm and then to 0.8 mm, etc.

R14.2: Refine the 3 BPM method with x-y readings and possibly more BPMs, taking 4x4 matrices into account.

R14.3: Explore the possibility of additional orbit correctors around the SLY's to reduce the orbit deviation during operations.

R14.4: Consider developing optics measurements from turn-by-turn BPM data with pilot bunches. These measurements would allow one to monitor and then correct the optics during high intensity operation, reducing the amount of dedicated operation time required for optics corrections with low intensity in the current approach.

R14.5: Implement a more refined lattice modeling using magnetic measurements.

R14.6: Perform more non-linear measurements, including global and local chromatic coupling, detuning with amplitude etc., as this nonlinear domain remains largely unprobed.

15. Collimator issues

Findings & comments:

A great deal of effort and study has gone into the collimators located around each ring. The HER accommodates old KEKB collimators while the LER has a series of newer collimators. There are currently two major reasons that collimator heads become damaged. One reason is the spontaneous firing of an injection thyratron, creating an unclosed orbit kick to the beam, which subsequently strikes a horizontal collimator jaw. The other is a sudden beam loss event, which ends up depositing a large fraction of the beam onto a collimator and consequently damages a (mostly vertical) collimator jaw.

A large study has been launched in order to find a material or combination of materials to use as a collimator head. This material should be robust enough to either survive a direct strike by the stored beam or, if damaged, to not significantly affect the beam. Various materials from tungsten to titanium to carbon-fiber-reinforced carbon have been considered. Several of the original collimators from KEKB, that are in the HER, show evidence of damage, and it is likely that several of these collimators were damaged while SuperKEKB was running. These damaged collimators do not seem to adversely affect the stored beam.

As mentioned in the presentation, it is suggested that all of the collimator heads, no matter which material is used for the head, should be coated with Cu, and the ARC agrees with this suggestion. The coating will minimize the impedance to the beam from the collimators.

We recognize that the effort to further understand the collimators and to maximize protection of the detector and machine components (i.e., QCS cryostats), while minimizing the effect on the stored beam is a difficult problem with several conflicting constraints. We encourage continuing collaborative efforts with the background team, the accelerator team and the vacuum team to resolve this complicated issue.

Recommendations:

R15.1: To track the minimum transverse impedance contributed by a collimator, the product of local β_y and the kick factor is used as a figure of merit. We recommend that for each collimator installed, a special effort in minimizing this product be pursued, considering all impedance contributions (geometric and resistive).

R15.2: Concerning the damaged collimators in the HER, although they do not seem to affect the stored beam, it would be good to repair as many of these damaged heads as possible, in order to keep the impedance from these collimators to a minimum.

16. Impedance Issues

Findings & comments:

A "-1" mode single-bunch instability, which blows up the vertical emittance, occurred at high bunch current, above 0.9 mA, with narrow collimator aperture (resulting in ΔQ_y>0.01) and bunch-by-bunch feedback active. This instability could be suppressed by tuning of the feedback, up to the design bunch current of 1.4 mA or beyond. The instability strength depends on the condition of the feedback and is affected by impedance increase due to collimator damage. The observed -1 mode instability could be reproduced in simulation considering the transverse wake and a high gain (G~0.1) multi-tap feedback. The tune range Q_y>0.58 is preferred for suppresing the instability, but the injection is worse for these higher vertical tunes.

The ARC commends the understanding and successful suppression of this instability. The threshold current for the -1 instability (0.9 mA) was similar to the threshold for the sudden beam loss (0.75 mA). A coupled bunch head-tail instability, with somewhat lower threshold than the single bunch instability, as had been studied by Scott Berg and others, might be one possible explanation for the sudden beam loss.

Recommendations:

R16.1: Study the possibility of a coupled-bunch head-tail instability.

17. Sudden Beam Loss (SBL)

Findings & comments:

Sudden Beam Loss (SBL) produces large current losses in a batch of bunches around either ring, occurring over just a few turns, which then causes full beam loss (abort) and may lead to severe hardware damage, mainly in the LER, to IR quadrupole quenches, and to large IP backgrounds.

These losses and aborts occur independently in both HER and LER. An SBL event only occurs every few days during SuperKEKB luminosity delivery making it difficult to study this effect.

The sources or causes of the SBL are under active investigation. SBL is a major limitation to increasing the beam currents and luminosity in SuperKEKB. An international task force has been created to look at SBL.

New and existing instrumentation have been developed or used to study this important effect turn-by-turn: Bunch Orbit Recorder (BOR), Bunch Current Monitor (BCM) (4096 turns), timed loss monitors, bunch size monitor (XRM), and acoustic monitors.

The observations show that the orbit changes are less than 1 mm (which needs to be further checked), the bunch sizes seem not to change, and there seems to be no bunch oscillations. There is a vacuum pressure change at the place where the beam is lost, but this may be a consequence of the loss, not its cause. Again, studying the cause of SBL is difficult as an SBL occurs only every few days.

The cause of SLB is still under study, but it does NOT appear to be related to vacuum pressure issues, dust events, vertical abort kicker misfire, bunch-by-bunch feedback, coupled bunch instability, or RF feedback issues.

Present potential causes are Electron Cloud (EC) effects in LER collimators, electrical discharges, or “fireball” explosions related to beam heating of metal sputtered particles. However, how a fireball or local electron cloud could cause an extremely fast beam loss without instability has not been carefully explained. To cause a significant beam loss in one turn by bremsstrahlung off nuclei, the beam particles would need to pass through about 1 cm of a solid metal, like copper or tantalum, or through at least several meters length of a typical plasma.

Future plans to study SBL are adding more loss monitors, improving the abort trigger, improving BOR resolution, adding a second BOR at 90 degrees (in betatron phase space), and making collimator jaws from high sublimation materials.

The turn-by-turn bunch-by-bunch vertical size measurements are hard to perform, and these measurements should be rechecked to verify that the bunch sizes do not change with SBL.

Even though the SBL shows no obvious time correlation with the top-up injection events, the injection bunch sequence in SuperKEKB could be checked for all the bunches in a row to see if they are not filled in such an order that some adjacent bunches might be overfilled so that the corresponding bunches could drive an SBL. The SBL may not appear to be caused by injection directly but could arise from over-injection into many bunches.

An investigation should be performed whether a beam-beam flip-flop effect could happen. Such a flip-flop might initiate a rapid vertical beam size increase in one beam and, thereby, cause rapid beam losses on the tight vertical collimators. This could happen to either beam.

One of the slides (p. 8) may show a relatively large (50 sigma) vertical orbit deviation during the SBL. Simple beam scraping cannot generate such a large effective orbit deviation. The betatron phase relation between the BOR and the beam lost point may be interesting, too.

Recommendations:

R17.1: Recheck that bunch-by-bunch turn-by-turn vertical beam size measurements are accurate and do not change during SBL.

R17.2: Check whether the injection bunch filling sequence may overfill bunches and, thus, could be related, in some indirect way, to the SBL bunch current loss pattern.

R17.3: The ARC fully endorses the installation of new BORs in different locations to observe the orbit deviations. With a few more of these, it may be possible to guess the location where the growth or the beam loss started.

R17.4: Investigate whether a beam-beam flip-flop could trigger an SBL given the tight vertical collimators.

R17.5: Investigate through a combination of electro-magnetic, mechanical and shower simulations (as performed for LHC collimators) whether a sudden collimator jaw deformation by ~100 micron could occur, triggered by HOM heating, electron cloud, or small beam impact, which could lead to a self-amplifying increasing deformation and catastrophic sudden beam loss.

R17.6: Install weak solenoids around the collimators, as planned, to suppress any local multipacting, electron-cloud formation or fireball/plasma creation.

18. Nonlinear Collimator (NLC)

Findings & comments:

The nonlinear collimator consists of a pair of skew sextupoles, separated by a quasi -*I* transform, which surround a collimator, D05Va, with variable aperture. Its main merit is a dramatic decrease of the collimator impedance, possibly reducing the overall vertical collimator impedance by a factor of two. The installation requires the removal of about 20% of the damping wiggler units (10/56), implying ~10% reduced damping time, and also some additional shielding. The Touschek lifetime is reduced by about 10% due to the additional skew sextupoles.

Displacement monitors will be installed at the BPMs next to the NLC skew sextupoles.

As an option, if these skew sextupoles are placed on vertical movers, the distance between the beam core and the beam tail at the collimator can be enlarged or the strength of these sextupoles be reduced. By moving the sextupoles, the distance between the beam core and the deflection (extraction) field would be smaller. The compensating sextupole would also have to move accordingly.

Recommendations:

R18.1: Study the possibility to vertically offset the nonlinear element (sextupoles) (movers?) to make the magnetic collimation more efficient.

19. International Task Force(s) (ITF) Summary

Findings & comments:

ITF was established with the goals to achieve 10^{35} $cm^{-2}s^{-1}$ after LS1 without major modifications and to consider ideas to increase this luminosity by a factor of 6. The summary report has been finalized and distributed. Now it has been decided to establish an overall new ITF chaired by Onishi-san.

There were two **Optics** proposals: Sextupole configuration proposed by Yunhai Cai and adding new sextupoles at the IP-image point as proposed by Pantaleo Raimondi. Explorations of these proposals did not yield immediate or obvious improvements.

The **Beam-Beam** task force made the proposals to increase the momentum compaction factor and explore crabbing ratios, however the machine tunings were instead focused on achieving a new record luminosity beyond $5x10^{34}$ $cm^{-2}s^{-1}$ before LS1.

TMCI: Progress was presented in the dedicated presentation by Ohmi-san.

LINAC: The Injector linac sub-group was formed at the 2nd ITF general meeting on Sep. 2, after receiving a recommendation to extend the focused task-force groups to the other key areas. No international members joined. Maybe a smaller subgroup should be established to attract international collaborators.

Sudden Beam Loss: This group was only formed in July 2022. Its progress was presented in a dedicated talk.

The new proposal foresees 5 ITF focus groups: Beam Tuning, Collective Effects, Beam Injection, Sudden Beam Loss and IR Upgrade. Discussions ensued on how to involve and attract international collaborators.

Recommendations:

R19.1: Consider appointing deputy chairpersons from outside KEK for each subgroup of the ITF.

20. Beam-Beam Experiment and Simulations

Findings & comments:

SuperKEKB operates with the nanobeam plus crab-waist scheme, with a large Piwinski angle. Vertical emittance is critical. At the time of the luminosity record, the vertical emittances were of order 50-60 pm, still much larger than design. After tuning of the bunch-by-bunch feedback the agreement of simulations and measurements has much improved. Actual specific luminosity is some 5%-50% worse than predicted by simulations, perhaps due to insufficient tuning during the high bunch current machine study, but the almost constant value of the specific luminosity towards high bunch-current products is consistent with expectation. The measured specific luminosity does not seem to depend on the number of bunches. There is no evidence that SuperKEKB has already reached the beam-beam limit. In machine studies with fewer bunches, vertical beam-beam tune shifts of 0.056 and 0.043 could be achieved. A correlation between top-up injection and specific luminosity was observed. The LER injection kicker contributed to ~3% of luminosity loss.

Multi-physics beam-beam simulation code development including the nonlinear lattice, space charge, and impedance effects, etc., is proceeding at KEK. Similar complementary efforts are underway in Europe, China and the US.

A path to the design luminosity was outlined, with 3.3 times smaller β_y^*, 2.5 times higher beam-beam tune shift, and 2.5 times higher LER beam current.

A significant IR upgrade is required to achieve 0.3 mm β_y^*. The IR upgrade should avoid overlapping solenoid and quadrupole fields. It could, e.g., be based on CCT magnet technology.

Recommendations:

R20.1: Develop a concrete IR upgrade proposal and demonstrate the expected performance gain through comprehensive simulations including beam-beam, nonlinear lattice, and impedance.

21. Long Shutdown 2 (LS2) and IR modification

Findings & comments:

The SuperKEKB should be congratulated on achieving a luminosity of 4.7×10^{34} $cm^{-2}s^{-1}$ in 2022.

With the LS1 work completed, the SuperKEKB will have the capability to reach a luminosity approaching 3×10^{35} $cm^{-2}s^{-1}$. With LS2 work completed (the exact work and scope are still to be determined) the SuperKEKB may have the capability to reach a luminosity approaching the target of 6×10^{35} $cm^{-2}s^{-1}$.

The largest presently envisioned task for LS2 is the replacement of QCSR and QCSL, enlarging the beam pipe aperture from 13.5 mm towards 18-20 mm, and of the nearby compensation solenoids. These changes must encompass all the conditions of the IR, including several constraints and requirements from the accelerator and the detector. Topics include beam aperture, backgrounds, SC quadrupole construction, cryogenics, cooling, collimation, anti-solenoids, and many more.

Other work being investigated for LS2 includes a new e^- transport line for better HER injection, e^- ECS, and large-scale vacuum chamber modifications. The expected integrated luminosity gains need to be quantified.

Recommendations:

R21.1: Make a detailed SuperKEKB parameter table showing the accelerator parameters that are available presently, then after LS1, and, finally, the possibilities after LS2.

R21.2: Quantify the expected integrated luminosity improvements for all specifically proposed LS2 projects. Update as needed; the committee suggests annually.

R22.2: Determine the minimum vertical emittance generated by synchrotron radiation in the fringe fields of the proposed new solenoid/anti-solenoid fields.

22. Others, such as the QCS tour etc.

Findings & comments :

The ARC review committee took a tour of the QCS cantilever rafts near the Belle-II detector in the Tsukuba IR at the end of the review. The rafts had been pulled back to allow work on Belle-II. The amount of work on the rafts and Belle-II is impressive. The complicated interfaces between SuperKEKB and Belle-II show the careful design of the two apparatuses. It is clear that much work will be needed if in LS2 the rafts are changed to include newly designed improved QCS magnets.

Recommendations:

R22.1: None.

Appendix A: KEKB Accelerator Review Committee Members

Frank Zimmermann, Chair	CERN
Ralph Assmann	DESY
Paolo Chiggiato	CERN
Paolo Craievich	PSI
John Fox	Stanford University
Andrew Hutton	JLab (excused)
In Soo Ko	POSTECH
Catia Milardi	INFN-LNF
Evgeny Perevedentsev	BINP
Katsunobu Oide	UNIGE/CERN and KEK (ret.)
Qing Qin	ESRF
Bob Rimmer	JLab
John Seeman	SLAC
Michael Sullivan	SLAC
Tom Taylor	CERN (ret.)
Rogelio Tomas	CERN
Tadashi Koseki	KEK, Director of Acc. Laboratory, Ex Officio Member
Makoto Tobiyama	KEK, Head of Acc. Division III, Ex Officio Member
Mika Masuzawa	KEK, Head of Acc. Division IV, Ex Officio Member
Hiroyasu Ego	KEK, Head of Acc. Division V, Ex Officio Member

Appendix B: Agenda of the 26th KEKB Accelerator Review Committee meeting

December 13 (Tuesday)		
08:30 - 09:00	Executive Session	
09:00 - 09:10	Welcome	M. Yamauchi
09:10 - 09:40	SuperKEKB Status	M. Tobiyama
09:40 - 10:10	2021c-2022b	Y. Ohnishi
10:10 - 10:30	Belle II Status	K. Matsuoka
10:30 - 11:00	MDI (BG)	H. Nakayama
11:10 - 11:30	Control	H. Kaji
11:30 - 12:10	Monitor	M. Tobiyama
13:30 - 14:00	Injector	M. Satoh
14:00 - 14:30	BT	M. Tawada
14:30 - 15:00	Injection	N. Iida
15:10 - 15:40	Vacuum	K. Shibata
15:40 - 16:10	MR Magnets & QCS	Y. Arimoto
16:10 - 16:40	RF	M. Nishiwaki
16:40 - 17:00	Helium Refrigerator for SRF	K. Nakanishi
17:00 - 19:00	Executive Session	
December 14 (Wednesday)		
08:30 - 09:00	Executive Session	
09:00 - 09:30	Optics Issues	H. Sugimoto
09:30 - 10:00	Collimator Issues	T. Ishibashi
10:00- 10:30	Impedance Issues	K. Ohmi

10:30 - 11:00	Sudden Beam Loss	H. Ikeda
11:00 - 11:30	NLC	A. Morita
11:30 - 12:00	LS1 Status	K. Shibata
13:20 - 13:40	ITF Activity Summary	M. Masuzawa
13:40 - 14:10	Beam-beam	D. Zhou
14:10 - 14:40	LS2, IR modification option 3’	M. Masuzawa
14:40 - 15:30	Others, QCS Tour	
15:00 - 20:00	Report writing / Executive Session	
11:00 - 12:00	Close-out	

Appendix C: Required and achieved SuperKEKB parameters and comparison with KEKB.

parameter	KEKB w Belle		SKB 2022b		SKB design	
	LER	HER	LER	HER	LER	HER
E [GeV]	3.5	8	4	7	4	7
β_x^* (mm)	1200	1200	80	80	32	25
β_y^* (mm)	5.9	5.9	**1.0**	**1.0**	0.27	0.30
ε_x (nm)	18	24	**4.0**	**4.6**	3.2	4.6
ε_y (pm)	150	150	**~50**	**~50**	8.6	12.9
I (mA)	1640	1190	**1321**	**1099**	3600	2600
n_b	1584		2249		2500	
I_b (mA)	1.04	0.75	0.587	0.489	1.44	1.04
ξ_y	0.098	0.059	**0.0407**	**0.0279**	0.069	0.060
L_{sp} ($10^{30}cm^{-2}s^{-1}mA^{-2}$)	17.1		**71.2**		214	
L ($10^{34}cm^{-2}s^{-1}$)	2.11		4.65		80	

The beam-beam parameter is computed without the hourglass factor or geometric factor for the luminosity.