The Twenty-Second KEKB Accelerator Review Committee Report

March 28, 2018

Introduction

The Twenty-Second KEKB Accelerator Review Committee meeting was held on March 14-16, 2018. Appendix A shows the present membership of the Committee. One member of the Committee, Matt Poelker, was unable to attend, but provided input. The meeting followed the standard format, with two days of oral presentations by KEKB staff members, followed by discussions between the Committee members. The Agenda for the meeting is shown in Appendix B. The Committee further took into account the report from a Domestic SuperKEKB Review held on 8 September 2017, which is included as Appendix C.

The amount of progress that has occurred since the last review is remarkable. The installation of the full accelerator, including linac, rings, and IR, and the Belle II Phase II detector are complete, ready for the Phase II beam commissioning to begin. The Committee examined the progress of the project.

As always, the high standard of the presentations impressed the Committee. The Committee was pleased to see many presentations from newly hired KEKB staff. 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 KEKB 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/**.

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A) Executive Summary

Since the last ARC meeting in June 2016, SuperKEKB progress has been spectacular. In 2016-2017, the SC final quadrupoles QCSL and QSCR were installed and cooled down; and their field was measured. By now the Interaction Region has been fully assembled. The injector complex is already delivering a beam more than adequate for Phase II and close to meeting the requirements for the first year of Phase III.

The Committee finds that SuperKEKB and BELLE II are ready for the Phase II beam commissioning.

The commissioning plan presented appears ambitious but realistic. The available resources are tight, but they have been well used to maximize the likelihood that the beam commissioning can be carried out with reliability and efficiency. Overall the planning for Phase II is reasonable, but execution of Phase II will require careful attention to detail. The availability of budget and manpower is particularly important at this time.

B) Recommendations: The Committee has made recommendations throughout the different sections below. The most significant recommendations are summarized here.

1. Clarify with BELLE II the minimum requirements (in terms of machine conditions, detector background, luminosity, and lifetime) which allow the transition to Phase III. (R2.1)
2. We encourage expanding KCG meetings with members from the BELLE II group to help prioritize the operating schedule in real time. This joint team should take responsibility for ensuring that the Phase III pre-conditions are met by July 17, 2018. (R2.2)
3. Continue to develop the critical injector systems, including the RF gun and the positron source. Identify the sources of emittance blow up and beam jitters through beam studies. Develop a detailed plan for reducing the injection emittances from about 150 micron for Phase II to the needed 20 to 40 micron for Phase III. (R3.1)
4. Perform a new study to improve the work hardening process of the copper FC coils. Compare with the experience at other laboratories, e.g. at SLAC and BINP. (R7.3)
5. Continue the experimental investigation of electron cloud and the conditioning of the TiN coating. Implement the proposed test with permanent magnets on the antechamber of the drift beampipes. (R14.1)
6. Prepare a plan to mitigate the pressure bursts in case it turns out to be a limitation for the operation in Phase III. (14.2)

7. We suggest that the team put together a careful plan describing the IR assembly steps for the Phase III run, that is as detailed as possible and based on the lessons learned during the Phase II assembly. (R17.1)
8. We suggest that temperature sensors be used on all of the cooling circuits located between the cryostats and on parts of the central beam pipe (where possible) that might experience heating. (R17.2)
9. Continue to evaluate the possible effects of vibrations on the luminosity performance, and develop a mitigating strategy. As soon as the stored beam will be available measurements based on a BPM, one in each ring, will help to quantify the impact, if any, and the specific parameters of these vibrations. (R18.1)
10. Perform detailed simulation of the injection process with realistic initial distribution from the Linac, including arc nonlinearities and beam-beam. In order to improve the simulated injection and luminosity performance, the Committee recommends generating new ideas for the injection process and for achieving the optimum luminosity in Phase III. (R22.1)

C) Report from SuperKEKB Domestic Review in September 2017

In the Executive Session, Katsunobu Oide reported from a SuperKEKB Domestic Review held on 8 September 2017 at KEK, which he had chaired. The Domestic Review had issued sets of comments on the Project Overview (in particular conditions for the transition from Phase I to Phase II), the Positron Source (hardening of flux concentrator coil, voltage, possible return to non-flux concentrator scheme), the RF gun (great improvement, separation of operation and development), the Accelerating Structure (beam-induced damage from large-emittance positron beam, 5% loss of acceleration, optimization of location), the Pulse Magnets (66 magnets of this type, timing system), the Timing System for the Damping Ring (integrated environment), the QCS (field measurements, hysteresis of ferromagnetic fields, fringe field of the solenoid), the Luminosity Tuning (collaboration with other laboratories, e.g. INFN), the Electron Cloud (planned mitigation methods look reasonable), the Machine Detector Interface (background, squeeze to Phase III design values for a test), and the Overall Project (charge requirements, budget and resources, design report, 6S experiment, smooth transition between generations of SuperKEKB staff). The report from the Domestic Review is attached as Appendix C.

Recommendation: Organize dedicated small reviews on specific topics more frequently between the main ARC meetings, if necessary. These can be domestic or international, depending on the issue and situation.

D) Findings and Comments

1. KEK Roadmap

This year marks an important date with the start of operation of SuperKEKB and BELLE II, projects which had begun 8 years ago. SuperKEKB had been expected to be realized within about 5 years; but it has taken nearly 8 years instead. Reasons for the delay were the 2011 earthquake and funding problems. SuperKEKB is one of the highest-priority projects at KEK and directly funded by the government. The presently difficult funding situation is likely to remain. The staff situation is also critical, possibly even more severe. Additional human resources are needed. The best approach to increasing the funding is to demonstrate good results. A paramount goal is the integrated luminosity. Further support from the Committee should help reach this goal.

The Committee would like to thank the KEK DG for presenting a perspective of SuperKEKB and the KEK roadmap.

Recommendations:

None.

2. SuperKEKB Schedule

After the announcement of the 2016 budget the commissioning schedule had to be adjusted. A revised schedule had been presented on the occasion of the 21st Committee meeting in June 2016. Afterwards a production delay in BELLE II and a delay of QCSR delivery, due to problems incurred during fabrication process at the company, shifted the start of Phase II to February 2018. Until September 2017 the project followed the resulting schedule. The QCS cool down and field measurements were successfully completed in August 2017, after an aggressive schedule with 3 shifts per day. Some additional delays were caused, in September 2017, by an interference problem of piping and cabling during BELLE-II installation work, and, in February 2018, by an anomalous water leak of the IR bellows cooling loop – which is mitigated by temporary measures instead of a full repair (the temporary measures required 2 weeks compared with 7 weeks for the repair). The latest schedule foresees Phase-2 BT tuning the week of 16 March, and HER tuning the week of 19 March. DR commissioning has already started on 8 February. After Phase II the BELLE II vertex detector will be installed; then the Phase III will begin.

The major goals of Phase II are:

(A) Verification of the nanobeam collision scheme, which means achieving a luminosity of ~$10^{34}cm^{-2}s^{-1}$, confirming the beam optics, and establishing collisions with a β^* 8 times larger than design (i.e. a β_y^* of 2.4 mm).

(B) Study beam-induced detector background and judge if VXD can be installed; this decision ultimately depends on the Belle II group.

Achieving the luminosity of (A) is important for (B) if the detector backgrounds are dominated by luminosity backgrounds, as expected.

Phase II is about one month delayed at this time, but mostly proceeds as planned. The injection to LER via the Damping Ring will be ready when needed (late March 2018).

It is extremely important that Phase II be completed by 17 July 2018, which would allow Phase III to start in February 2019. If Phase II cannot be completed by July, SuperKEKB would need to operate again in October 2018 to finish Phase II. In that case, Phase III would probably begin only after summer 2019 (half a year delay).

Recommendation:

R2.1: Clarify with BELLE II the minimum requirements (in terms of machine conditions, detector background, luminosity, and lifetime) which allow the transition to Phase III.

R2.2: We encourage expanding KCG meetings with members from the BELLE II group to help prioritize the operating schedule in real time. This joint team should take responsibility for ensuring that the Phase III pre-conditions are met by July 17, 2018.

R2.3: Continue to develop the critical injector systems including the RF gun and the positron source. Identify the sources of emittance blow up and beam jitters through beam studies. Develop a detailed plan for reducing the injection emittances from about 150 micron for Phase II to the needed 20 to 40 micron for Phase III.

3. Injector Overview

The injector is basically ready for the Phase II commissioning, incorporating recommendations from the past reviews. It is almost ready for the first year of Phase III, while many challenges still remain to achieve the ultimately required beam qualities.

Progress on the RF gun is remarkable in terms of achieving the required intensity, emittance, and stability. The RF gun is no longer the bottleneck of the system.

Improvements are necessary in bunch charge and emittance at the end of the linac for both electrons and positrons to achieve the goal for Phase III.

A brief table showing the comparison between the design (requirements) and achievements will be informative not only for reviewers but for linac staff. Such a table has been provided at the end of this meeting, and it is included as Appendix D.

Recommendations:

R3.1: Continue to develop the critical systems including the RF gun and the positron source. Identify the sources of emittance blow up and beam jitters through beam studies. Develop a detailed plan for reducing the injection emittances from about 150 micron in Phase II to the needed 20 to 40 micron for Phase III.

4. RF Gun

The s-band RF gun for the SuperKEKB Project needs to provide low-emittance high-charge electron bunches for injection into the HER. Another, thermionic gun delivers electrons to the target for producing positrons. A Yb fiber and a Nd/Yb solid laser are driving a cathode in the quasi-travelling side-coupled RF gun. The RF gun needs to provide beam emittances of 6 to 20 microns and bunch charges of 1 to 5 nC. Specifically, bunch charges of 2 nC are needed for Phase II and 5 nC for Phase III.

The laser pulse length is 20 psec, which reduces space charge effects. For stable operation the electric voltage is less than 100 MV/m. The emittance growth due to the solenoid is avoided by the electric field focusing from an annular side-coupled cavity.

The cathode needs to have high quantum efficiency and long lifetime. Unfortunately, LaB_6 cathode material has a short lifetime. However, Ir_5Ce has a long lifetime and a quantum efficiency QE greater than 10^{-4}. A bulk cathode material is needed rather than a thin film. The project is now looking at Ir7Ce2.

A redundant Yb:Fiber +Nd:YAG hybrid laser system is planned starting with a MENLO oscillator with self-phase modulation (SPM). With two lasers, a low emittance and 3.6 nC has been achieved. Rectangular temporal shaping will be done later to reduce the energy spread.

A single crystal(SC) Ir_5Ce cathode (4 mm) is under study and will be tested soon aiming at higher QE, longer lifetime, and cleaning by the laser. The group will use electron beam heating of the cathode plug which has been tested up to 1000 degree C in the laboratory.

Short term testing of the cathode lifetime has been tried (about 24 hours) showing nearly constant current. Over a running period of 2.5 months the current stays constant within 50%. Longer tests are needed at full beam specifications.

Overall, great progress has been made towards a well-functioning RF gun, and the beam parameters for Phase II commissioning have been accomplished.

The new laser and beam diagnostics have helped with trouble shooting, tuning and reliability.

Recommendations:

R4.1: Prepare a maintenance plan for the RF gun and associated hardware to improve the long term reliability.

R4.2: Develop a detailed plan to make the existing gun and laser meet the beam parameters needed for SuperKEKB Phase-III commissioning, with only modest upgrades since the e-source is very important for commissioning plan. Consult nearby local laser experts as needed.

R4.3: Run the RF gun with full beam parameters for several weeks continuously to make sure no hidden problems arise.

R4.4: Continue to work on temporal pulse shaping to allow higher bunch charges and smaller energy spreads.

R4.5: Work on any new gun or laser ideas and R&D paths with a lower priority.

5. Accelerating Structure (cavity)

The linac has been commissioned well. It supported Phase I operation and damping ring commissioning. However, some degradation has been seen in the oldest PF type accelerating structures due to RF breakdown or beam induced damage. These structures have nominally the same cell RF design as the later BF type cavities, which do not see the degradation, but may feature detailed differences in the input coupler design and construction. The PF cavities were not previously operated with SLED pulse compression and the shorter pulse and higher peak power may have contributed to damage in a number of structures, primarily in the input coupler and first iris, including opening up water leaks. Extensive pitting of the iris and discoloration of the coupler region are observed from multiple breakdown events. These structures have to be turned down, reducing operational overhead at the design energy. The performance is adequate for Phase II, but results in no margin at the desired 6S operating point.

To address these concerns a new cavity design has been developed with lower peak surface fields and the elimination of water-to-vacuum braze joints. It is planned to build 12 new cavities for installation and spares. Meanwhile the remaining PF cavities should be closely monitored to prevent further degradation. Since four cavities are powered from each RF station, it is not presently easy to diagnose which structure is breaking down. Additional instrumentation may be helpful to localize the breakdown events to a particular structure, which could then be replaced at the earliest opportunity.

Recommendations:

R5.1: Complete an adequate number of new cavities to support commissioning and long term operations considering the time line and balance with near-term operation, and explore other options.

R5.2: Continue to monitor the existing structures to minimize further degradation. Consider additional instrumentation to localize breakdown events to individual cavities.

6. Pulsed Magnet

The committee congratulates the team for the successful installation of 64 pulsed magnets, which replaced old magnets, and the renewed parts like power supplies, cooling water system, cables, supports for magnets, control system and software as well in the summer 2017. It is important to realize the shot-by-shot switching of injection destination to the SuperKEKB (HER & LER), PF, and PF-AR, during the operation of SuperKEKB.

The issues observed during 2017 in the performance of this system have been successfully addressed by software fixes. Part of the whole system was already tested in the operation of PF and PF-AR, and it works smoothly.

The efficiency of 68.5% of total energy recovery of the pulsed power supply was measured, and a stability of as high as 0.01% over 24 hours was demonstrated in a test. However, the stability of the pulsed magnet power supply over longer terms and/or during beam operation is likely to be worse than the test result

A detailed plan for the installation of the remaining pulsed magnets in 2018 has been made, but there is no contingency.

Recommendations:

R6.1: Try to find the reason why the stability measurement of the pulsed power supply for quad magnet 3 shows a non-Gaussian distribution form.

R6.2: Measure the stability during a realistic operational cycle.

7. Positron

To meet the SuperKEKB demand, the positron source upgrade aims at a 4-fold increase in the positron bunch intensity. To reach a 4 nC bunch intensity, a number of new components are introduced as well as improvements are envisaged in existing ones. Positron collection and focusing efficiency is enhanced by the Flux Concentrator (FC) coil. The positron beam emittance is squeezed more than 20 times in the newly-built Damping Ring (DR). The intensity of the primary electron beam from the linac needs to be raised.

Since the last review, the positron system shows considerable progress from achieving the Phase I requirements to exceeding the Phase II needs – It is ready for operation at a positron bunch intensity of 1.4 nC, with some further concern remaining about the Phase III demands.

At an early stage of the FC testing, fatal damage from discharging occurred in spite of an interlock system against discharging that can stop operation within a single pulse to prevent FC from fatal damage.

A quick FC exchange mechanism was conceived to speed-up, and reduce radiation exposure during, the replacement of a “hot” component in a “hot spot”.

Installation of the quick FC exchange mechanism resulted in a 1-week replacement time. This can minimize the downtime of the positron source, and facilitate preemptive replacements of the FC head prior to a discharge.

Emittance squeeze in the recently commissioned DR raised the positron intensity by more than a factor of 4, due to radically smaller beam loss between the DR and the end of the linac.

Serious work is ahead to meet the Phase III requirements. The main measures were presented. First, the positron collection efficiency must be raised as much as practically possible. The present positron production simulation is still too idealistic and seems to provide little information about the beam loss at the conversion target. However, it predicts only a 25% gain from operating FC at its full current of 12 kA, as compared with the present operation at a “safe” 6 kA level.

Second, the primary electron charge and energy at the target have to be increased, and all sources of beam losses between the target and DR should be identified and eliminated.

The positron flux concentrator suffered from discharges with a 200 micron spacing in the coil. Such discharges are not expected in the FC since flux concentrators at other laboratories do not show this phrenomenon.

Recommendations:

R7.1: Continue to build-up of a realistic simulation of the positron production and collection. This is needed for a realistic prediction of the gain available from any FC improvements.

R7.2: The Committee suggests to study whether an increase of the coil gaps, to, say, about 250 microns or so, can significantly increase the break down voltage. The resulting central magnetic field will likely be lowered by about 20% for the same current, but with the increased voltage limit the overall magnetic field may go up significantly.

R7.3: Perform a new study to improve the work hardening process of the copper FC coils. Compare with the experience at other laboratories, e.g. at SLAC and BINP.

The Committee would also like to draw attention to the findings and recommendation of the last Domestic Review as of September, 8, 2017, concerning the Positron Source (see Appendix C).

8. Beam jitters

During the domestic review of Super KEKB held in September 2017, evidence for a large blowup of the effective emittance was presented. This blowup in effective emittance is due to an increasing beam jitter through the linac, which does not originate from the RF gun. Similar symptoms were presented in the previous ARC review, but they could not yet be solved.

Careful measurements have revealed beam position jitters and blowup of the effective emittance with both the thermionic gun and the RF gun. The jitter is observed immediately after the J-arc and enhanced after the target hole. Several rigorous studies were performed.

As a first step, the influence of components close to the target hole, such as the flux concentrator (FC), solenoid, bridge coils, pulsed magnets and chicane was suspected as possible cause. The issue of a 2-mm offset of the electron beam position (target hole) from the center of FC field was investigated. Measured results of position jitter before and after the target position have shown a big difference between positrons and electrons. A current dependence of the beam position jitter was found in dedicated measurements. The possibility of wake field induced jitter was, therefore, considered a possible cause of beam jitter. To confirm this effect, the beam position in the target hole was changed by steering magnets. However, no significant correlation between the magnitude of beam position jitter and the beam offsets (steering magnet currents) was seen. Simulation studies showed that the longitudinal wake field depends very little on the beam position while the transverse wake field effect increases nonlinearly. The experimental and simulation studies led to the conclusion that transverse wake fields cannot be the primary source of the jitter.

Finally, the potential influence from energy jitter of the beam was studied. It was shown that the jitter amplitude can be strongly suppressed by correcting the dispersion leakage from the J-arc. Careful suppression of the dispersion brought about a significant reduction of beam jitter for both the thermionic gun and the RF gun. After eliminating other potential sources of beam jitter, the energy jitter of the beam, which originates from the gun, is considered as the most likely driver of the beam jitter.

The scatter plot in the phase space before/after the e+ target clearly reveals an increase of the jitter emittance. So it is likely that the source of the jitter is an energy jitter created somewhere before the J-ARC, which then is amplified by the target hole.

The committee applauds the SuperKEKB team for the careful study of the jitter effect and its possible source.

Recommendations:

R8.1: Perform several further analyses to identify the sources of beam jitter, as detailed in the recommendations R8.2-R8.8.

R8.2: Calculate and study the “Bmag” term, which characterizes a mismatch in the optics functions. Expand the formulae of jitter-induced emittance growth to include this term.

R8.3: Calculate the normalized position jitter amplitude to remove the effect of the beam optics.

R8.4: Compare the normalized jitter amplitude and its evolution to the observed beam loss locations with the helpf of an aperture model.

R8.5: Determine the frequency contents of the beam position jitter. In case dominant frequencies in the position jitter are found, correlate these with possible technical sources.

R8.6: Perform a quantitative analysis of energy jitter, dispersion and observed beam position jitter to see which part of the position jitter can be explained by energy jitter and which fraction remains unexplained.

R8.7: Perform a careful and rigorous study of the timing jitter in the RF trigger and in the gun trigger, which might explain the observed energy jitter.

R8.8: In case that further wakefield studies are performed, investigate the position-dependent direct wakefield kick in linear order, which should be measurable for strong wakefields, like those required for generating the observed beam position jitter.

9. Timing controls

The operation of the many SuperKEKB sub-systems requires a powerful and flexible timing and synchronization system. In past ARC reviews, the basic architecture and design structure of the SuperKEKB timing and synchronization has been described in some detail. The basic synchronization between the linac (at 2856 MHz) and the main rings, damping ring (509 MHz) is done via a master oscillator at a common sub-harmonic near 10 MHz. The other timing functions for the linac repetition rate (50 Hz), the synchronization to the injector, etc. are also slaved to this sub-harmonic clock. The complete timing task must also configure the linac and inject into the PF and AR. Several types of beam diagnostics, including the BPM systems and feedback systems, depend on the timing system and have complex sub-system timing functions of their own.

The majority of the timing and synchronization is done in a series of Event Generator modules, and Event Receiver modules which run on a 114 MHz system clock. The presentation shows an independent “optional extraction system”, which is required in case of a beam abort, or for extraction in case of a dispersion measurement in the DR (where the DR RF frequency is unlocked from the linac and ring master oscillators, and set independently).

The presentation highlighted the specific needs for the damping ring injection and extraction. Several example system timing sequences were detailed for the linac to DR injection cycle, including timing for the kicker magnets. Computer codes calculate the configuration of these event generators and receivers on a shot by shot basis, including requirements from a “bucket list” and knowledge of the allowable linac timing. In operation the linac repetition rate is 50 Hz on average, but each individual timing cycle is unique, so that the timing of the linac can move by up to 2 ms each injection to line up with the desired main ring or damping ring bucket.

The event generator messages include an 8 bit “gate” field, which is interpreted at the receiver as enabler for a beam gate function. This allows 57 MHz rate control of 8 individual devices all synchronized to a common event tag from the generator module. These features are used to control elements of the gun and injector, as well as kicker and septum magnet timings for the DR.

The complexity of the entire timing system functionality was not covered in this review, as it has been covered in past years. This year’s focus is on the necessary functionality for immediate commissioning of the DR and main ring, first operation of the LTR and RTL timed elements, and demonstrated functionality to fill a selected bucket in either the HER or LER.

This system functionality has been exercised in the present commissioning cycle, by successfully injecting or extracting beam into or out of the DR. This is a significant demonstration and builds confidence for future operations. The system may be expanded in the future to incorporate phase shifting techniques for both the linac and DR RF systems, which would allow greater flexibility to inject/extract into arbitrary buckets.

The timing function, and master oscillator synchronization are essential for the successful operation of SuperKEKB, as well as for the PF and AR facilities. Because of the complexity of the system, and the way it uses dynamic configurations that are computed on every linac pulse, understanding what the system is doing and operational diagnostics are essential. This presentation, and past years', show an integrated TDC system which can be used to validate the proper operation of the timing system.

We think investment in the diagnostics will be very helpful in both commissioning and operations. The talk on "Injector Commissioning" in this review mentioned the example of a mystery drop out of an event receiver used to time the thermionic gun, and minutes of recovery time.

We respect the planning and skill that have gone into the successful development of this timing system. Preserving up-to-date knowledge will be important for longer-term operations and maintenance, though will be challenging during the present period, where new machine configurations will be developed, and the timing system will be expanded and re-configured. Maintaining documentation and spreading knowledge from the design group will be helpful.

Recommendations:

R9.1: We recommend that the timing diagnostic features be ready for use as the larger accelerator complex is commissioned, and if possible a fault diagnostic be developed that would capture what the timing system did in case of a sudden unexpected beam loss in a transfer or injection, or beam abort or kicker misfire, etc.

R9.2: Prepare a series of up-to-date system-level block diagrams that highlight the various synchronization paths and timing relationships for the entire complex, including the injector complex (laser gates, timing,...), linac, DR, main rings.

R9.3: Implement as soon as possible phase shifting functionality for both the linac and DR RF systems, which would be of great help in commissioning and optimizing DR performance and, in turn, the injection efficiency of the positron beam in the LER.

10. LTR & RTL Commissioning

Findings:

The first commissioning of the LTR and RTL was done successfully within a limited operation time. The emittances measured at Sector 3 satisfy the requirements of Phase II but not those of Phase III yet. Optics of LRT/RTL has been well corrected except the 1st arc of RTL.

The adjustment of the optics and the RF phase for the LTR first uses a heavily scraped beam with a reduced momentum spread, whch is shifted to the nominal momentum. Then the full beam is injected utilizing the full momentum acceptance.

Comments:

The measured horizontal emittance at Sector 3 was 3 times higher than the design emittance from the damping ring. It is not yet clear whether the emitance growth arises in the DR or in the RTL.

While the energy reference is set by the DR, a cross calibration of magnets in LTR/RTL with those in DR and linac has not been done.

Recommendations:

R10.1: Identify the source of the emittance increase in the DR and RTL.

R10.2: Cross-calibrate the field measurements of magnets between the LTR, RTL, DR, and the linac.

11. Damping Ring Commissioning

Commissioning of the SuperKEKB Damping Ring (DR) started on February 8, 2018, and is proceeding in a very promising way. Preliminary tuning of the ring has been completed already in the first 3 days of operations. In this short time lapse many relevant activities have been addressed.

Timing fine tuning of injection extraction elements, kickers and septa, has allowed to inject and extract beam with very high efficiency, close to 100%. Injected beam has been captured by switching on RF cavities. Single turn BPMs timing allowed to perform basic optics measurements.

Transverse beam profile evolution, measured by a gated camera, gave a clear indication of damping for both transverse and longitudinal beam sizes, although a quantitative evaluation of the beam emittance at the exit of the DR is not yet available.

So far the peak stored positron current, in 4 bunches, is of the order of 11 mA, which was the maximum achievable value in operation without flux concentrator, and considering that injection in stacking mode has not yet been implemented.

Basic beam studies of linear optics and chromaticity revealed non-negligible discrepancies between measured and computed quantities. These discrepancies might well be due to an improper modeling of the dipoles in the DR arcs, which exhibit a non-uniform longitudinal field. In fact, an initial difference of −0.27 (H) and −0.74 (V) between model and measured tunes has been almost cancelled, −0.27 (H) and −0.37 (V), by introducing a proper dipole fringe field in the dipole model. The same dipole fringe field correction also needed to be applied to the Main Ring dipoles, but in this case its effect was negligible.

Recommendations:

R11.1: Repeat and extend the optics measurements in order to refine the DR optics model, especially the dipole parametrization.

R11.2: Complete the linear and non-linear optics measurements. Implement transverse decoherence measurements in order to evaluate damping times.

R11.3: Complete as soon as possible the quantitative analysis of the gated camera measurements in order to have a reliable number for the positron beam emittance at the exit of the DR.

R11.4: Try to store the maximum allowed current of 20 mA as soon as possible, possibly with stacking injection, in order to speed up the vacuum conditioning and explore the impact of possible e-cloud related effects.

R11.5: Explore the physical reasons causing the vacuum pressure rise during 25 Hz injection.

12. Status of DR Cavities

The damping ring RF station is designed to use up to three single-cell HOM-damped cavities with beam-line duct absorbers joined together in the tunnel. A prototype and two production cavities were fabricated and tested successfully. Two cavities were installed in the DR, commissioned successfully, and used for the DR beam commissioning. The spare cavity was used for off-line tests and will be prepared as a full spare for the DR if needed. The DR cavity operation was very smooth with the exception of vacuum leaks that appeared on many of the rectangular HOM absorber flanges. There is a modest heating from the fundamental mode evanescent field at the location of the flange in addition to any HOM power resulting in about a 30C temperature rise. The mechanical support for the HOM loads was rigid and most likely the thermal expansion of the HOM body produced a torque stress on the flange. Increasing the bolt torque sealed the leaks in all but one case, where the gasket needed to be replaced. The flanges have now had local cooling added and rubber bushes have been added to the mechanical support to provide compliance. These steps should alleviate the problem and result in reliable operation going forward. The lip welding in the tunnel was successful and repair and re-welding of this seal has been practiced offline numerous times, so that, if any cavity changeout is needed in the future, it should not be a problem. One consequence of the rigid connection is that misalignments of cavity flanges could lead to position errors on the beam line. All components were pre-measured and sorted to minimize the expected offsets to less than 0.5 mm. Survey after installation resulted in a maximum offset of about 0.3 mm which is within tolerance.

The DR LLRF system is apparently working well and beams were injected, stored and extracted successfully during the 3 weeks of DR commissioning.

As currents are increased, the beam-induced power into the HOM loads will increase, so that temperature monitoring of the high power system and loads is important.

Recommendations:

None.

13. DR Vacuum

The vacuum system of the Damping Ring (DR) is fully installed. It successfully supports the beam operation. Beam vacuum conditioning has progressed as expected. The specific dynamic pressure rise (Pa mA-1) has decreased about an order of magnitude while the beam dose (A h) increased by about two orders of magnitude. The quality of the vacuum system is proven by the limited pressure rise (≈10-6 Pa) measured at the end of February (dose of 0.7 Ah), when a positron beam of 10 mA stored with a lifetime due to residual gas of the order of 1000 s.

Ten times more beam dose is needed to achieve the same lifetime with the design beam current; there is no reason to expect any vacuum-system induced limitation.

The residual gas composition is the one expected for a vacuum system pumped by NEG materials, i.e. H_2, CO and CO_2 as leading gas, and the presence of CH_4 due to the absence of chemical pumping.

The influence of the beam repetition rate on the dynamic pressure rise is puzzling, although a reasonable explanation was given. The influence of the beam size and position on the dynamic pressure rise should be further investigated.

A concern was expressed about the duration of the NEG activation (13 days) due to a fixed pressure limit (10^{-4} Pa). If needed, the pump heating time can be reduced by allowing higher pressures. The gas released by the NEG cannot be detrimental for the NEG itself; gas desorbed from the walls of the system can be drastically reduced by warming the pump to a temperature insufficiently high for the onset of activation, but high enough to desorb water vapour. The sputter ion pumps could be switched off during NEG activation, therefore relying only on turbomolecular pumps.

It seems that the NEG pump performance should not be affected during operation. For that reason, the NEG pump reconditioning would be carried out only during long shutdowns. Possible lower temperatures and faster activation should be tested in case NEG performance needs to be restored during operational phases.

Simulations show that electron-cloud induced effects should not be an issue in the DR: there is a margin of a factor 10 in the electron density. However, simulations are based on assumed values for the SEY and photon transmission that are not yet experimentally verified. Therefore, this aspect deserves particular attention during the remaining part of the commissioning.

Recommendations:

R13.1: Define an activation procedure for the NEG pumps, in order to restore pumping performance rapidly, in case of saturation, until the following long shutdown. Consider the experience at other laboratories, like ESRF.

R13.2: Clarify the effect of the beam repetition rate on the dynamic pressure rise through calculations and dedicated experiments.

14. Updates of MR Vacuum System

The vacuum system of the main rings is ready for Phase II. Modifications and fixing of the vacuum systems were successfully implemented. New collimators were installed. The two main operational issues, i.e. electron cloud and pressure bursts leading to beam abort, have been addressed.

Permanent magnets effectively reduced electron-cloud effects in uncoated aluminium bellows. However, another source of electron cloud appeared for beam currents higher than 900 mA. It generated bunch blow up and pressure rise. The vacuum chambers at the drift space were identified as the cause of the problem. Those chambers are made of uncoated Al (reused from KEKB), and TiN coated aluminium and copper pipes with antechamber. In the former, the electron current was mitigated by solenoids; in the latter, by permanent magnets. Today 86% of the drift space is equipped with additional magnets providing field higher than 20 G.

Simulation showed that maximum SEY could be about 1.4, a value that is too high with respect to measurements performed in the past. The discrepancy can be explained assuming a higher number of photoelectrons than expected in the beam channel. Indeed, if 4% of the photoelectrons were in the beam channel, simulated maximum SEY values would be compatible with previous measurements. Experimental data indicate that this hypothesis is valid; additional investigation will be carried out to check the performance of the coating.

The issue of pressure spikes in the LER has been investigated; it is attributed to dust particles falling into the beam. The pressure spikes are more frequent near the Al chambers with grooves in the Tsukuba section. The presence of dust was confirmed in a beam pipe. Some chambers were knocked to detach particles from the top surface. The effect will be tested in Phase II. The frequency of the pressure spikes was not reported; it is not clear if any conditioning was recorded during the last run.

Recommendations:

R14.1: Continue the experimental investigation of electron cloud and the conditioning of the TiN coating. Implement the proposed test with permanent magnets on the antechamber of the drift beampipes.

R14.2: Prepare a plan to mitigate the pressure bursts in case it turns out to be a limitation for the operation in Phase III.

15. Monitors DR & MR

An impressive effort has been made to have all instruments ready for beam commissioning in the damping ring and in the main ring.

Damping-ring BPMs have shown a remarkable performance during commissioning. They have been successfully used to measure injection oscillations, to correct the orbit and to measure optics based both on orbit response and turn-by-turn data. The resulting measured optics from both techniques are in good agreement, confirming the good performance of the BPM system in terms of resolution, synchronization, calibration, etc.

The DR feedback system was successfully used to damp injection oscillations and to generate forced betatron with stable amplitude.

The bunch current monitors and the tune measurement system work well without any issue to report. The DR DCCT is being used as interlock to stop injection when intensity is above the threshold.

The synchrotron radiation monitor (SRM) is based on a gated streak camera. It has been used to measure the bunch length. After damping the measured bunch length is rather close to the expected value. Nevertheless, calibration factors should be revised as measured bunch length is slightly below the expected value, which could also reveal discrepancies of the momentum compaction factor or RF voltage.

Concerning the transverse beam profile measurements, only qualitative observation of the bunch profile have been reported. The light intensity is not sufficient for the detector, specially if the BPF is used for focusing as required. A factor 2 larger beam intensity might allow accurate transverse beam size and transverse damping measurements in Phase II. According to a plot of the measured beam size as a function of time after the injection shows that the horizontal beam size damps almost with the design damping time.

DR beam loss monitors are critical for controlling radiation levels. They have been working reliably.

The main-ring instrumentation was upgraded or reinforced according to the observations during Phase I to ensure a smooth commissioning: (1) 22 turn-by-turn BPMs were added to improve diagnostics and help commissioning; (2) feedback-system amplifiers, power attenuators and other components were replaced; (3) several improvements were made to the XRM and SRM to address the difficulties in beam size measurements observed during Phase I.

Recommendations:

R15.1: Review the calibration of DR bunch length measurement.

R15.2: Analyze existing data of DR transverse profile data from streak camera to obtain a rough estimate of emittance and evaluate the uncertainty of this measurement. Emittance evolution throughout the injector complex is a major issue for the collider performance (an additional presentation was added at the end of the second day).

R15.4: Explore alternative techniques for transverse beam-size measurement.

R15.5: Investigate the possibility of stacking injection for diagnostics with a higher bunch intensity, while paying attention to the beam losses and other limitations.

16. Belle II detector

The Belle II detector has made enormous progress in getting ready for the Phase II commissioning run. The detector has rolled onto the beam line, the final-focus cryostats were installed, and all of the outer subsystems are complete and integrated into the DAQ system. The BEAST II detectors were installed. They have a separate DAQ that will run continuously. One of the major goals of the Phase II commissioning run is to measure the backgrounds and to validate the simulation code in order to obtain confidence that the simulation projections for high luminosity running are correct. In addition, Phase II running needs to be good enough (a minimum amount of luminosity) and stable enough, so that the various machine related backgrounds can be determined.

It is almost too late to make any changes to the central beam pipe as the assembly of the PXD and the SVD onto the final beam pipe will start to take place very soon. Nevertheless, it is important to discover as soon as possible whether or not there are any unexpected backgrounds or any backgrounds higher than anticipated.

The detector needs to test the overall DAQ under real beam conditions. They can generate a loose or high-rate trigger in order to shake out any problems with high rate data acquisition under real beam conditions.

Recommendations:

R16.1: We suggest the plan for the Phase II commissioning try to achieve the minimal detector requirements as soon as possible, so that background estimates can be made as quickly as possible.

R16.2: We also suggest that the detector get dedicated commissioning time of at least several days of colliding beams delivery (not necessarily all at once). See recommendations for Phase II commissioning.

17. IR assembly

The assembly of the Interaction Region for the Phase II commissioning run has uncovered several issues that will need to be carefully studied. There is an interference in the setting of the bellows limiter and the BPM cabling. The BPM cable needs to be connected before the limiter can be set. The BEAST II detector (in place where the final VXD will be) has only a handful of cables and services compared to the final VXD (SVD+PXD). It has been recognized that the dressing out of the cabling and cooling and other services for the final VXD will be challenging and will require very careful planning and execution. The exact sequence of connecting the bellows section to the cryostat beam pipes and the central beam pipe will need to be carefully planned, especially with all of the extra cabling and services.

Another issue discovered when assembling the IR for Phase II is that there are several leaks in the water cooling systems. Some leaks are small enough (tested by dry N2) that they are not leaking water but at least 2 leaks are so large that they let water out of the system. At least 1 leak is large enough to require changing the water to dry Nitrogen in order to protect the detector from water damage. Most likely another leak will need to have the same temporary fix. The cause of these leaks will have to be uncovered and improvements in either the hardware or in the assembly procedure (or both) will need to be implemented. Unfortunately, this is not possible until the Phase II run is completed, as several months of disassembly and reassembly are needed to access the locations of the leaks.The problem of the water leaks will need to be understood as soon as possible after the Phase II run, as whatever is discovered may alter any plan that has been put together.

The installation of extra temperature sensors will improve the chances of detecting unexpected beam-induced heating. We urge that temperature sensors be attached to the tubes of the circuits that have the temporary dry nitrogen flow as well. If possible, it would be good if sensors can also be applied to the warm beam pipes inside the cryostats. Perhaps the inlet and outlet water tubes are all that are accessible. If sensors can be placed at the inlet and outlet of the cooling circuits then it becomes relatively easy to make a monitoring system that checks for unusual changes in these sensor readings. The PEP-II B-factory had approximately 100 thermocouples placed on various cooling circuits and sections of the beam pipes within ±10 m of the IP.

Recommendation:

R17.1: We suggest that the team put together a careful plan describing the IR assembly steps for the Phase III run, that is as detailed as possible and based on the lessons learned during the Phase II assembly.

R17.2: We suggest that temperature sensors be used on all of the cooling circuits located between the cryostats and on parts of the central beam pipe (where possible) that might experience heating.

R17.3: Develop a vigorous program to solve the issue of the water leaks.

R17.4: Try to store the maximum possible beam current in the MRs by the end of Phase II in order to exclude any bottlenecks due to HOM heating, including a possible detrimental effect coming from the damaged bellows fingers in the QCLS section that required was repaired during installation or from any other bellows.

R17.5: Investigate a more robust design for the bellows chamber.

R17.6: Reinforce the technical support for the IR assembly, for instance on the 3D CAD drawings of the entire system.

18. QCS

The complex magnet system has been fully assembled and tested, followed by comprehensive field mapping. Some faults to ground were corrected, and test and measurement results appear to be within tolerances apart from the mistaken 90 degree rotation of the skew octupole winding (but this is not considered to be critical). Following some quenching of the superconducting bus between magnets and current leads it was decided to double the conductor cross-section, thus increasing the temperature margin, and this is no longer expected to be a problem. Concerns over the effects of the possible vibration of the cantilevered structures are being actively addressed.The system is now ready for testing with beam, and the team is to be congratulated on the success of this program.

Further insight into the importance of IR vibration modes can be obtained from single turn BPMs for each ring. Frequency analysis of the BPMs provides the spectrum of the beam motion, which may allow inferring possible excitation sources by comparing the measured harmonics with mechanical simulations and mechanical vibration measurements.

Recommendations:

R18.1: Continue to evaluate the possible effects of vibrations on the luminosity performance, and develop a mitigating strategy. As soon as the stored beam will be available measurements based on a BPM, one in each ring, will help to quantify the impact, if any, and the specific parameters of these vibrations.

R18.2: To address the concern about the reliability of the aging cryogenic system, study the possibility of installing a sufficiently large liquid helium buffer tank to enable continuous operation during maintenance and repair operations.

19. QCS power supply

The progress on the installation and preparations for the multiple QCS magnet supplies is impressive, and the team can be proud they are moving towards commissioning of the magnet system. The analog circuits for the supplies has been presented in past years. The photos of the assembled systems are very encouraging and show the progress. The scope photo of the powered supply and quench protection transient are nice to see.

The specifications for the supply ripple, resolution, noise and stability are very challenging. This year one of the reviewers raised a question about the origin of these specifications, and how they are coupled to physics requirements (for example, is the ripple specification driven by a limit on tune modulation? Orbit modulation?)

The studies and specification of the load impedance shows frequency components up to a MHz, but a practical upper limit must be related to eddy current effects in the vacuum chamber, etc. which roll off the components that impact the beam.

We appreciate the groups' concerns about the impact of line-driven transients and noise, and the ongoing work to understand the most practical and effective path to reduce these impacts.

The regulation of the QCS power supply was shown to rely on a slow digital control loop to achieve the long-term stability. This very slow loop uses the DVM as the primary reference, and adjusts the 24 bit error value as an extra signal injected into the analog regulator loop. As discussed in past reviews, the monotonic behavior of this error path is very important for this digital loop to not engender hysteretic behavior or limit cycles. For example, the response of the slow digital feedback, described as the error signal, passes over the major carry between the two DAC boundaries and could lead to hysteretic behavior.

Recommendation:

R19.1: A significant test should be made on the monotonicity of the digital feedback path with the two 20-bit DACs, extending over the change-over between the 2 DAC systems (i.e with more than 16 counts, and including studies over a significant dynamic range of the output). This should reveal the impact of the finite accuracy of the upper DAC, and whether or not further development is required.

20. Superconducting cavities

The SRF cavities are working well and are ready to support Phase II. Problems with the piezo breakdown have been solved by adding filters to limit the peak voltage pulse. Three cavities have been re-rinsed by horizontal HPR after being degraded due to vacuum problems or other work. All three cavities recovered to usable gradient, two have been installed and one is ready as a qualified spare. Two new SiC beam-duct HOM absorbers have been installed and will be monitored during Phase II running to verify performance. Although Phase II will not store the full current the initial performance of the loads can be compared to offline tests and simulations. All cavities will need to be outfitted with the new loads for Phase III. Some further RF station upgrades are still planned for full power operation in Phase III. Schedule typically permits one SRF cavity replacement per long shutdown.

Recommendation:

R20.1: Continue to monitor the installed cavities during Phase II for any new signs of degradation such as turn on of new field emitters. Consider in-tunnel horizontal HPR for future shutdowns to improve the remaining cavities, including cleaning of adjacent chambers to prevent particle migration.

21. RF high power system

The high power RF systems supported Phase I operation and are ready for Phase II commissioning. However, many of the components are legacy items from TRISTAN and KEKB and the team has experienced many issues with water leaks and failures of old and obsolete components. The team has worked hard to fix these and to replace vulnerable components to make the systems more robust. This hardening process must continue to enable reliable operation in Phase III and beyond. Two versions of high power klystrons are installed and many have remarkably high operating hours and are still functioning well. An adequate number of spare klystrons is available, and as old tubes are taken out they are reworked into the later more reliable model. The KPS continues to suffer spurious crowbar trips as seen in KEKB operation. These seem to happen overnight and may be related to power line fluctuations or other external events. The team has made some improvements to the system and Phase II running will show if there is any reduction in trips. The team may consider whether there is a more modern alternative to the original ignitron based trigger if this continues to be a source of down time. Another concern is the ageing of the high voltage rectifier stacks. Periodic analysis of the oil has revealed traces of ethanol which may be a sign of degradation. Visual inspection has not revealed any obvious damage. However, a failure would be serious since the rectifiers are obsolete and the manufacturer cannot offer a replacement that will fit in the original enclosure. Though most of the other problems are low tech in nature such as leaks and corrosion in water loads, phase shifters and circulators, these are still time consuming and expensive to repair. A prioritized list of tasks and items should be established to improve reliability and reduce down time. The DR RF systems were constructed from spares and similar components, but are working well.

Recommendations:

R21.1: Continue to check and test the old parts of the high-power systems as necessary.

R21.2: Continue the hardening activities on the RF supplies and components to reduce down time due to water leaks and failures of TRISTAN-era components. Develop a prioritized list for strategic investments to prevent future failures.

R21.3: Investigate if there is a more modern technology for the crowbar circuit to improve reliability.

R21.4: Continue to monitor the KPS high voltage rectifier system. consider developing a new replacement rectifier stack if not available from the original manufacturer.

R21.5: Consider alternative high power loads that do not need high conductivity water to avoid future corrosion problems.

R21.6: Continue to study and understand the gap induced transients in the RF systems and the effect on luminosity.

22. Beam dynamics issues

In line with recommendations of the previous review, realistic beam-beam simulations include interplay of the beam-beam phenomena with different machine lattice imperfections. The effect of IR nonlinearity and chromatic Twiss (beta and coupling) on the luminosity were studied by simulating beam-beam effects, considering the arc as a complicated nonlinear lattice structure.

Substantial simulation evidence has been presented supporting the role of skew sextupole (a3) components and chromatic optics on the effective luminosity loss. This is of special importance as the magnetic measurements reveal unexpected a3 components.

As compared with previous simulations, the new ones seem to better reproduce one of the observations at KEKB, the explanation of which has been pending for years, namely: why did the experimentally observed specific luminosity at KEKB (with and without the crab cavity) not show any flat top in the low-current limit. Instead, it showed a significant roll-off starting immediately at zero currents. A similar phenomenon is seen in simulations for SuperKEKB.

Analysis of the cubic terms in the Hamiltonian was focused on terms which become dominant in Phase II and III optics. A better understanding of the third-order nonlinearity originating from the IR magnets, their fringe fields and feed-down of the octupolar component by the vertical COD will improve the IR correction strategies.

Another issue reported was the prediction of a coherent beam-beam instability of a two-stream nature, reminiscent of a high-order head-tail pattern. The latter feature seems to be specific for the large Piwinski angle collision. This instability is predicted to occur only for the initial stages of Phase II, where β^*_x is larger than in the final design squeeze. A similar instability was predicted for the FCC-ee, for which simulations led to a cure (based on careful tuning of the beam parameters, e.g. the synchrotron tune).

In the optics without crab waist, such as the SuperKEKB, large-amplitude particles in the injected portion experience severe beam-beam effects. For better understanding of the injection process, a detailed simulation of the injection process with realistic initial distribution from the linac, including arc nonlinearities and beam-beam, is necessary.

Recommendations:

R22.1: Perform detailed simulation of the injection process with realistic initial distributions from the linac, including arc nonlinearities and beam-beam. In order to improve the simulated injection and luminosity performance, the Committee recommends generating new ideas for the injection process and for achieving the optimum luminosity in Phase III.

R22.2: Use the magnetic measurements in DA simulations with and without beam-beam, especially for the skew sextupole term (a3), since the latter has been identified as a source of luminosity loss in simulations and the actual a3 component is larger than expected due to the absence of an a3 corrector.

R22.3: Allocate machine time to assess a3 and chromatic optics seen by the beam, determine the luminosity loss versus bunch charge and confirm the predicted instability at large β^* .

R22.4: During Phase II, plan collisions for physics at small β^*_x to avoid the coherent beam-beam instability.

23. Phase II Commissioning Plan

Changing the IR optics from the conservative approach of Phase I to the unprecedented beta squeeze of Phase III is only thinkable if made cautiously step-by-step. The task is further aggravated by serious final-focus nonlinearities placing a tight limit on the dynamic aperture (DA). Therefore following the recommendation of the previous review, a detailed step-by-step plan has been conceived for Phase II Commissioning. It defines the plan how to reach the KEKB peak luminosity of 2×10^{34} $cm^{-2}s^{-1}$ as a final accomplishment of Phase II. In more detail, “Phase II finish marks” are a specific luminosity of 4×10^{31} $cm^{-2}s^{-1}mA^{-2}$ (more than two times higher than at KEKB) a vertical beam-beam parameter of 0.05, an LER beam lifetime of at least 40 min for 1 A beam current, a HER beam lifetime of 150 min for 0.8 A beam current, a functional collimation system and an acceptable BELLE II background.

A well-thought roadmap was presented showing how to reach the Phase II goals in 4-5 stages, based on the limiting beam-beam parameter $\xi = 0.05$ with total currents of 1.0 A × 0.8 A by gradually squeezing β^*_y. “Bifurcations” are envisaged where one can consider changing the number of bunches (filling pattern) in order to gain in luminosity while avoiding the vertical beam blow-up from the Electron-Cloud Instability. (See “Travel Guide for Phase II” in the presentation)

Overall time span of the plan is from mid-March through mid-July, with first collisions scheduled for April 2018 starting with small Piwinski angle configuration and moving step-by-step to the world-record small beta* values of Phase III, or the NanoBeam collider. The Committee highly appraises the elaborate preparation of the commissioning plan for Phase II. In combination with the considerable experience of the SuperKEKB accelerator team, this plan is a key to successful commissioning, and should allow reaching high luminosity as fast as possible.

Recommendations:

R23.1: Include machine protection requirements in the commissioning plan with detailed deliverables (checklist) for ensuring that the accelerator is protected at all times.

R23.2: Develop a more detailed Phase II commissioning plan that foresees that several teams work in subsequent short blocks of beam time (quasi-parallel) on advancing luminosity operation for BELLE, increasing beam currents, commissioning the small beta* optics, injection efficiency, and studying beam-beam. This will provide early feedback on possible problems and breaks for teams to think about solutions.

R23.3: Include time for beam scrubbing if required, parallelizing this as much as possible with other activities.

R23.4: Define a clear strategy including decision criteria for determining that BELLE-II backgrounds are acceptable for moving to Phase III. The strategy should take into account the need for high luminosity as well as the physical origins of various types of backgrounds and sources of beam loss, and respect limitations, e.g., imposed by water cooling problems.

24. Injector Commissioning

The results on the injector commissioning, remaining concerns and plans were presented. The injector has been prepared to serve simultaneously the Phase II of SuperKEKb and the needs of the KEK light sources (PF and PF-AR). Energies from 2.5 GeV to 7 GeV are delivered to the various facilities with bunch intensities between 0.3 nC and 1 nC and rates between 5 Hz and 25 Hz. Simultaneous operation with the RF gun and the thermionic gun has been established. The RF gun operates stably, and, with two-laser injection, it provides an electron bunch charge of 3 nC (in linac sector 5), three times more than needed in Phase II, and not far from the Phase III target value of 4 nC. Everything is ready to serve the top up injection of Phase II with the required beam parameters. Only a couple of critical issues remain, but mitigating measures are being prepared and will be implemented very soon.

The Committee is impressed with the progress achieved and with the high level of readiness. It considers the injector system essentially ready for SuperKEKB Phase II. It fully supports the plans presented.

Recommendations:

R24.1: Measure the energy spread and energy jitter at the end of the linac and demonstrate that the required goals are met.

R24.2: Develop with priority automatic correction algorithms for critical procedures like the dispersion correction.

R24.3: Define a backup strategy for Phase III in case that the primary RF gun cannot be used, e.g. by preparing a scenario of using the second RF gun.

Appendix A

KEKB Accelerator Review Committee Members

Frank Zimmermann, Chair	CERN
Ralph Assmann	DESY
Paolo Chiggiato	CERN
John Fox	SLAC
Andrew Hutton	JLab
In Soo Ko	POSTECH
Catia Milardi	INFN-LNF
Evgeny Perevedentsev	BINP
Matt Poelker	JLab (unable to attend)
Katsunobu Oide	CERN and KEK (ret.)
Qing Qin	IHEP
Bob Rimmer	JLab
John Seeman	SLAC
Michael Sullivan	SLAC
Tom Taylor	CERN (ret.)
Rogelio Tomas	CERN
Seiya Yamaguchi	KEK, Director of Acc. Laboratory, Ex Officio Member
Kazunori Akai	KEK, Head of Acc. Division III, Ex Officio Member
Kazuro Furukawa	KEK, Head of Acc. Division V, Ex Officio Member
Haruyo Koiso	KEK, Head of Acc. Division IV, Ex Officio Member

Appendix B Agenda of the 22nd KEKB Accelerator Review Committee

March 14 (Wednesday)		
08:30 - 09:00	Executive Session	
09:00 - 09:15	KEK Roadmap	M. Yamauchi
09:20 - 09:35	SuperKEKB Schedule	K. Akai
09:40 - 09:52	Injector Overview	K. Furukawa
09:55 - 10:10	RF gun	M. Yoshida
10:35 - 10:50	Accelerating structure (cavity)	H. Ego
10:55 - 11:10	Pulsed magnet	Y. Enomoto
11:15 - 11:37	Positron	Y. Enomoto
13:30 - 13:52	Beam jitters	Y. Seimiya
14:00 - 14:15	Timing controls	H. Sugimura
14:20 - 14:42	LTR & RTL commissioning	N. Iida
14:50 - 15:24	Damping ring commissioning	H. Sugimoto
15:55 - 16:07	Status of DR cavities	T. Abe
16:10 - 16:25	DR vacuum	K. Shibata
16:30 - 16:49	Updates of MR vacuum system	Y. Suetsugu
16:55 - 17:17	Monitors DR & MR	H. Ikeda
March 15 (Thursday)		
08:30 - 09:00	Executive Session	
09:00 - 09:22	Belle II detector	K. Hara
09:30 - 09:52	IR assembly	K. Kanazawa
10:20 - 11:20	QCS	N. Ohuchi
11:35 - 11:57	QCS power supply	T. Oki
13:30 - 13:42	Superconducting cavities	M. Nishiwaki
13:45 - 13:57	RF high power system	K. Watanabe
14:00 - 14:22	Beam dynamics issues	K. Ohmi
14:30 - 14:45	Phase II Commissioning Plan	Y. Ohnishi
14:50 - 15:20	Injector Commissioning	M. Satoh
15:30 - 15:40	Tune difference in DR	H. Sugimoto
15:40 - 20:00	Report writing / Executive Session	
March 16 (Friday)		
08:30 - 11:00	Executive Session / Report Writing	
11:00 - 12:00	Close-out	

Appendix C

Report from the SuperKEKB Domestic Review held on 8 September 2017

Preface

A number of detailed and frank presentations were made on several parts of SuperKEKB. SuperKEKB is the largest project at KEK Tsukuba to be completed not only by the effort of each dedicated group, but with the total strengths of KEK. Such a large project consists of a wide variety of sub-components both in the rings and the injectors, thus the ceaseless communication and scientific discussion among them are absolutely unavoidable. Such a domestic review as this time can provide such a opportunity.

Project overview

Comments:

- An optimized plan of the entire project including the Belle-II detector is necessary.
- The necessary condition other than the luminosity for the transition from Phase II to Phase III should be identified, including the establishment of the collision and the

level of the detector background, etc. A common understanding with Belle-II is necessary.

- A time line for the injector performance improvement through Phase II & III must be produced.

Positron source

Comments:

- The exchange of the flux concentrator(FC) should be done regularly even without damage to reduce the radiation exposure.
- Reconsidering the material of the FC can be necessary. Review the material choice by reevaluating the data in the past.
- A coil with a larger gap width may be possible.
- This time the FC caused discharging after installing into the tunnel, despite the success in the tests on surface. The actual pulse form could differ between them.
- The conditioning should be performed at a voltage higher than the spec by 20%.
- It is important to know whether the discharge at the large aperture S band (LAS) structure was due to the placement nearby the positron source.
- The validness of “hardening” needs more investigation including on the diagnostics. Did it really improved the entire elasticity or just for the surface?
- The estimated improvement on the amount of charge is 20% by increasing the voltage from 6kV to 12 kV. Consider the priority of the higher voltage plan taking the necessary resources and the effect.
- Even a non-FC scheme such as at the previous KEKB is thinkable.

Recommendation:

- Establish an interlock system against discharging to stop operation in a single pulse to prevent a fatal damage.

RF gun

Comments:

- It has been surfaced that a large blowup of the effective emittance due to beam jitter through the linac, which is not originated from the RF gun. An immediate measure for this issue must be taken over the observation, identification of the cause, and allocation of Human Resources.
- The thermionic gun needs care for maintenance and repair.
- The quantum efficiency of the IrCe cathode reached 10^-4 only at the test bench, not after installed to the gun, due to the actual vacuum condition in the gun. Further investigation is necessary for the QTW gun.
- How much margin is there for the laser power? Does the amplification by Nd solid amplifier keep the quality and stability at the high power?
- The operation stability in a long time span continues to be the issue.
- The remaining burden for pulse-shaping, which has been said to be necessary for Phase III, seems nontrivial. Further investigations and reviews are necessary.
- A prioritization of the work should be done by the entire injector group to maximize the integrated luminosity.

Recommendations:

- A tendency is seen to employ a new technology or to replace existing schemes, before detailed analysis of present achievements with deep discussion and information exchange by broad members including other projects.
- Considering the critical role of the RF gun in the entire project, it is necessary to separate the operation from developments by sticking to an existing technology as far as possible. Accelerating structure

Comments:

- The replacement of aged accelerating structures must be planned persistently considering the allowable budget and resources.
- The energy gain per unit may be increased by the new replacement structures. Thus the locations of such new structures should be optimized. The maximum achievable energy can be increased by rearrangement of good structures over the linac.
- There are variations in the output power of the klystrons, even under a constant Es = 42 kV. The reachable energy should take this into account.
- It is important to establish strategies to identify wrong structures, the necessary time to replace them, and reliability of the diagnosis. Also the maximum usable period of good structures should be defined.

Pulse magnets in the linac

Comments:

- The performance and stability of the timing system is a key for the pulsed magnets. The allocation of resources on this subject seems weak compared to its expected role. It should be solved by involving the entire linac control group and ring people.
- The hardware of the pulsed magnets seems more or less completed.
- A overall test is urgent to check the synchronization of all 66 pulsed magnets.
- Recalibration will be necessary at each time to replace a broken magnet. A protocol is needed for such replacement and recalibration. It is important to ensure enough startup time for such a replacement. The calibration must be confirmed by the beam.
- The remaining issues including the stability at low currents, repeatability of the field, a long-term durability must be presumed within a month from now.

Timing system for Damping Ring

Comments:

- Make clear the time line and milestones from TRL3 to TRL9. The scheduling is necessary.
- An integrated environment covering both linac and rings will be necessarily.
- The requirements for the injection/extraction should be reconfirmed.
- The timing system will be common for operations of Photon Factory and PF-AR.

QCS

Comments:

- The field measurement has assured the validity of the design even with the hysteresis of the ferromagnetic shields. The field measurement of higher order components has been improved by canceling the main component by a backing coil.
- No fatal issue has been seen on the preparation of QCS system.

- The lifetime of the cryogenics inherited since TRISTAN needs attention.
- Examine whether the measured sextuplets components are explained by the fringe field of the solenoid.
- The measured longitudinal shift of these magnets should be reflected to the optics model.

Luminosity tuning

Comments:

- Although experiences at PEP-II, the dithering method is new to KEK. An intensive beam study must be carried quite through Phase II operation, by comparing to the design and simulations.
- The system for the luminometer and dithering involves components mainly developed by foreign labs. The beam studies must be arranged to ensure the involvement of such foreign researchers.
- It is important to evaluate the tolerance of the imbalance of the bunch intensity between two beams considering the flip-flop effect.
- It may be worth extending the collaboration with LAL further beyond the fast luminometer.
- How is the collaboration with INFN going?

Electron cloud

Comments:

- The mechanism of the generation of e-cloud has been well understood theoretically and by simulations, to be consistent with measurements done at Phase I. The planned mitigation methods are rational and expected to work properly.

Machine-detector interface (MDI)

Comments:

- The sources of detector background critical at Phase III must be fully understood at Phase II.
- The commissioning must be done efficiently, by ensuring tight communication between the machine and detector groups. Necessary software and hardware must be ready in time, including the interlock system.
- It may be fruitful for both optics and background studies to challenge squeezing the beam down to the design of Phase III values, even for a single beam.
- a simulation study for the scattered particles from the collimators to the detector,
- Understanding of the losing particles at the injection is important.
- Evaluate the effects on the detector by the misalignments if QCS.

Concerning the overall project

Comments:

- The amount of charge from the RF gun and the positron source can stay 1/2 of the design for the first a few years. The top up injection may relax the requirement further. In this sense the priority should be put more on stability and operability of existing schemes than new challenges, at least for the first a few years.

- The badger and resources are extremely short. However some maldistribution of resources may have been observed, making too light the existing technologies.
- The project has been going on without publishing the design report. This should be done immediately.
- More flexible schemes to obtain new people with operation budget should be perused, under necessary supports by KEK.
- Extend international collaboration by overcoming several apparent obstacles. They will return eventually.
- The experiment at 6S can be unique in the world and may bring attention.
- It is important to ensure a smooth transition between generations, since this project will need a very long period of time toward the completions the goal. It is very important to keep and enlarge the motivations for SuoerKEKB by all members of the project, through everyday's scientific communication and discussions.

Date & time : Sept. 8, 2017, 9:00 - 19:00

Program: http://accphys.kek.jp/indico/conferenceDisplay.py?confId=122

Reviewers: A Enomoto, J. Haba, K. Harada, Y. Honda, S. Michizono, F. Naito, T. Nakata, K. Oide(Chair), K. Satoh,

Appendix D

Required and achieved parameters in the injector complex

Stage	KEKB Achievements		Phase-I Achievements		Phase-II Requirements		Before Phase-II Achievements		Phase-III 1st Year Plan		Phase-III Final Requirements	
Beam	e+	e–	e+	e–	e+	e–	e+	e–	e+	e–	e+	e–
Energy	3.5 GeV	8.0 GeV	4.0 GeV	7.0 GeV	4.0 GeV	7.0 GeV	4.0 GeV	7.0 GeV	4.0 GeV	7.0 GeV	4.0 GeV +	7.0 GeV+
Stored current	1.6 A	1.1 A	1 A	1 A	1.8 A	1.3 A	–	–	3.6 A	2.6 A	3.6 A	2.6 A
Life time (min.)	150	200	100	100	–	–	–	–	–	–	6	6
Bunch charge (nC)	e- 10 → 1	1	e- 8 → 0.4	1	0.5	1	1.4	2.5	e- 10 2 - 3 (?)	2 - 3 (?)	e- 10 → 4	4
Norm. Emittance (gbe) (mrad)	1400	310	1000	130	200/40 (H/V)	150	200/5 (H/V)	20 @ Sector B	100/15 (H/V)	40/20 (H/)	100/15 (H/V)	40/20 (H/V)
Energy spread	0.13 %	0.13%	0.50 %	0.50 %	0.16%	0.10%	?	?	0.16 %	0.07%	0.16 %	0.07%
Bunch / Pulse	2	2	2	2	2	2	2	2	2	2	2	2
Repetition rate	50 Hz		25 Hz		25 Hz		25 Hz		50 Hz		50 Hz	
Simultaneous top-up injection (PPM)	3 rings (LER, HER, PF)		No top-up		Eventually		Only for LER, PF, PF-AR		4+1 rings (LER, HER, DR, PF, PF-AR)		4+1 rings (LER, HER, DR, PF, PF-AR)	