The Fourteenth KEKB Accelerator Review Committee Report

February 27, 2009

Introduction

The Fourteenth KEKB Accelerator Review Committee meeting was held on February 9-11, 2009. Appendix A shows the present membership of the Committee. Warren Funk, Eugene Perevedentsev, and Wang Shuhong were regrettably unable to attend this meeting.

The meeting followed the standard format, with two days of oral presentations by the KEKB staff members, followed by discussion between the Committee members. The Agenda for the meeting is shown in Appendix B.

The Committee was as always impressed by the high standard of the talks, both the technical content and the presentations themselves. The 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.

Contents

A) Executive Summary

The performance of KEKB improved over the last year, but not as much as had been hoped. A calibration error has been discovered in the luminosity monitor, so that the previous luminosity records have been increased by a few percent. The peak luminosity that has been achieved with crab crossing is now 1.68 x 10^{34} $cm^{-2}s^{-1}$, extremely close to the previous record without the crab cavity (1.76 x 10^{34} $cm^{-2}s^{-1}$).

The Belle detector has accumulated a total integrated luminosity of 891.2 fb^{-1} of which 98.2 fb^{-1} was accumulated in 2008, compared with 145.4 fb^{-1} in 2006 and 86 fb^{-1} in 2007. The accumulated luminosity was limited due to reduced running because of budgetary constraints (162 hours in 2008 compared with >220 hours in 2006 and 2007). The BELLE detector has published, or submitted for publication, a total of 294 papers in refereed journals (242 at the last meeting). This year the main focus of the physics program has been on Y(1s), Y(2s), Y(3s), and Y(5s) running, requiring that the accelerator be set up at non-standard energies. The Users seemed to be happy with the beam quality that was provided.

The Committee congratulates the recent Nobel Prize winners Nambu, Kobayashi and Maskawa. Their theoretical work was tested and proven at KEKB and PEP-II, which has demonstrated the importance of the KEKB physics program.

A major focus of the Review was the SuperKEKB Upgrade. The funding outlook for SuperKEKB is extremely positive given its scientific merit. The possible timelines for funding SuperKEKB show the start of construction, at most two years away, and at best, only one year away. This makes this meeting of the KEKB Machine Advisory Committee extremely timely in helping chart a course for KEK towards a major new accelerator project, SuperKEKB.

It will be important to choose a suitable goal for SuperKEKB. It is suggested that this goal be related to the annual integrated luminosity rather than the peak luminosity. KEKB was funded to produce a total delivered luminosity of 1ab^{-1} and is expected to reach this goal within the next two years, depending on the running schedule. A reasonable initial goal for SuperKEKB would be 1-2ab^{-1} per year (for comparison, in the best year of KEKB, the integrated luminosity reached ~0.2ab^{-1}). The exact value of the goal is extremely important: if the initial goal is too low, the physics reach will be compromised, if it is too high, it may force the machine design towards solutions that are too expensive.

In order to significantly increase the luminosity of KEKB, there are two possible approaches: increase the current (more intense beams), or decrease the emittance (brighter beams). To date, the KEKB team has concentrated on the increased current option. Recent developments (particularly in Frascati) have renewed interest in the low emittance option. It is recommended that the KEKB team evaluate the low emittance option to see whether it would provide a suitable basis for SuperKEKB. Particular attention should be paid to limiting both the construction costs and the operating costs of the machine, an important consideration for the funding agency. This initial study is vital to enable the timely development of a complete design for SuperKEKB, preferably one with many options for later luminosity improvements.

A great deal of component R&D has been carried out over the last few years and great strides have been made. Most of this R&D would be applicable to both design solutions, so this work should carry on. However, it is suggested that the machine design work concentrate on the low emittance option for the next few months, with a focus on identifying any possible showstoppers. The design should be brought to a point where an informed decision between the two options can be made.

B) Recommendations

The Committee has made recommendations throughout the different sections below. Highlights of these recommendations are summarized here.

KEKB Operations

1) The Committee suggests that the studies with higher voltages in the crab cavities, reduction of the vertical IP beam sizes by chromatic corrections, reduction of the x-y IR coupling, and studies related to the low emittance option be given high priority.
2) The Committee recommends that studies of the beam-beam effect continue with the goal of matching the simulations and the experimental results, and increasing the luminosity.
3) Pursuing these studies is not only important for the BELLE physics program but is particularly important for the future performance of SuperKEKB.

SuperKEKB

4) The Committee recommends that a detailed timeline for SuperKEKB preparations be developed, including milestones and decision points. This should be consistent with the timescale for the start of construction presented by the lab director.
5) The Committee recommends that the machine design work concentrate on the low emittance option for the next few months, with a focus on identifying any possible showstoppers.
6) The Committee recommends that component R&D continue, particularly for those components that would be used in either option. This list includes superconducting and permanent magnets, low SEY beam pipe and other electron cloud mitigation studies, positron source upgrades, masks and collimators, etc.
7) The Committee encourages the study of high-efficiency klystrons, for example using the depressed collector potential concept.

1 KEK Roadmap and SuperKEKB Upgrade

Professor Suzuki presented the road map for the KEK Laboratory, which consists of a multi-pronged approach to accelerator-based science. J-PARC will become a world leader in long baseline neutrino studies, and will soon initiate material science studies using neutrons and muons. KEKB will be upgraded to study CP asymmetry and new sources of flavor mixing in the quark sector. The physics from SuperKEKB will be complementary to that which can be obtained from LHC. KEK will remain involved in preparing for energy frontier experiments at ILC, and is involved in LHC. SuperKEKB will play a large role in these preparations, both in the physics aspects and the technologies. KEK will also remain in the forefront of photon physics with the Photon Factory and later an ERL.

The outlook for SuperKEKB is extremely positive, with the worst case scenario being construction starting in JFY2011 and in the best case; construction would begin a year sooner. The total construction cost envisioned by the funding agency is $300-400M and the operating cost should not significantly exceed the present annual operating budget of $60M.

2 Progress in Crab Crossing

Findings:

Much progress has been made in understanding the discrepancy between predictions and measurements of luminosity with crab compensation. During FY2008 the daily integrated luminosity with crab has approached the high values of past years. Peak luminosity was $1.5\text{x}10^{34}\text{cm}^{-2}\text{s}^{-1}$ in 2007 and 1.68 $\text{x}10^{34}\text{cm}^{-2}\text{s}^{-1}$ in 2008, compared with $1.76\text{x}10^{34}\text{cm}^{-2}\text{s}^{-1}$ in 2006. More importantly, the primary factors preventing much higher luminosities are better understood (see below).

We give a rather detailed description of findings here since a clear understanding is essential to interpretation of the Committee's recommendations.

A negative 4.5% error in luminosity measurement, presumably slowly growing over time, caused a re-evaluation of luminosity records over the past year, particularly with crab cavity operation, increasing peak luminosity with crab (Y4S) from 1.61 to 1.68 $\text{x}10^{34}\text{cm}^{-2}\text{s}^{-1}$.

Two primary limitations are observed in crab cavity performance - a lifetime imposed limit to bunch current and a drop in specific luminosity at higher currents well below the values indicated by simulation.

The decrease in lifetime at higher bunch currents is believed to be caused by a horizontal physical aperture at the LER crab cavity (aperture limited at the location of a mask). The modification to the beam optics functions from the coherent beam-beam focusing causes the horizontal beta size at the crab cavity to increase by nearly 5 times. A trial of raising the horizontal beta function at the Interaction point allowed colliding bunches at the SuperKEKB design current, although the luminosity was lower as a result. The observed dependence of lifetime on horizontal offset of the beams at the Interaction Point is interpreted to be a confirmation of this model. Options for orbit bumps around the crab cavity are constrained by the need to minimize beam loading of the crabbing mode, exacerbated by a misalignment of the HER crab cavity found during a recent shutdown. It was also concluded from this effort that the aperture center and field center of the LER crab cavity are offset by 4mm.

Plans to mitigate the effects of reduced lifetimes include: reducing β_x around the crab cavity while raising the crab voltage by lowering cavity temperature, increasing β_x at the Interaction Point (from 0.9m to 1.5m), and improving injection rate and stability of beam currents for tuning by achieving pulse-to-pulse switching between electron and positron injection.

With β_x =1.5m, no beam lifetime problem is found at 1.1 mA^2, but the problem recurs at 1.5 mA^2. Using the crab cavities at β_x =1.5m leads to an increase of specific luminosity of 20%, while the expected geometric factor gain is 10%. This is a possible indication that the crab cavity has contributed to a higher beam-beam parameter. The achieved specific luminosity is consistent with a ξ_y (HER) =0.09.

The specific luminosity should be related to the vertical size of the beams and accordingly some effort to relate the two has been made. A direct measurement of the vertical beam sizes yields values ~67% larger than expected from luminosity calculations (crab off). A hint of some of this discrepancy came from single beam measurements in April, 2008 showing a current dependent increase in vertical beam size. This effect could not be reproduced in November, and is felt to have been caused by some coherent bunches motion. The primary source of this discrepancy is unresolved at this time.

The increase of luminosity of a factor of ~2 due to crab cavities predicted by simulations is reconfirmed independently by Yunhai Cai using a completely different code. Both codes are therefore basically in agreement, although a large difference remains when compared with measurements. In addition to beam-beam effects, this independent code has also included the effects of wake fields. The simulations indicate a microwave instability threshold of 1/3 of design current in the LER causing a 20% increase in energy spread at 1.0 mA. This was supported by a cross-section measurement by Belle on the narrow Y(2S) resonance.

Luminosity optimization using a computer–based Downhill Simplex Method, and the manual scans that were presented last year have been continued with larger (4 or 5 units) starting errors on 12 coupling and dispersion parameters at the Interaction Point. Application of the Downhill Simplex Method plus the manual scans could not recover luminosity above 60% of the no-error prediction. These simulations have apparently demonstrated that this level of optics errors prevents effective compensation by the existing methods. In addition the growth in energy spread in the LEB will further increase the impact of chromatic errors.

Other tests were made in the search for luminosity limiting effects, including horizontal emittance of both beams (the present values are the best), negative α optics (unstable beam), and increased number of bunches (vertical beam blowup with 2 bucket LER spacing). The last trial suggests that better suppression of the electron cloud effect would benefit performance appreciably.

Operation statistics show a much higher availability (but with reduced scheduled hours) than in FY2007 where crab cavity commissioning was a major effect.

Committee Response:

The Committee congratulates the KEKB staff for impressive advances in understanding luminosity limitations during operation with crab cavities, as well as overall performance of KEKB. While delivering a larger fraction of operating time to the Physics run some key factors in performance limitations have been better understood.

We approve the direction of effort to further improve performance of KEKB and plan for SuperKEKB upgrade. Better understanding of KEKB performance will directly contribute to higher SuperKEKB performance. In addition we have the following suggestions.

Explore further bumps around the crab cavities to simultaneously achieve the target beam loading and minimize beam losses. Adding angle bumps to displacement bumps may give better results.

Are the larger errors used in simulation of tuning plausible given the known alignment and field tolerances? If not an open-minded search for other stray fields or errors may be productive.

We endorse continuing efforts to resolve the discrepancy between measured beam sizes and those derived from luminosity.

We endorse the pursuit of chromatic coupling effects using skew sextupoles as proposed by the KEKB team.

3 Belle Status

The Belle detector has been producing excellent physics results, dividing up the running time as follows:

√s	Υ(1s)	Υ(2s)	Υ(3s)	Υ(4s)	Υ(5s)
Luminosity (fb^{-1})	9.8	10.1	13.5	74.6	31.0

There have been some significant improvements to the BELLE detector, notably the trigger data is now read out via COPPER and there is a new Global Decision Logic. The rate at which papers are being published in peer-reviewed journals continues to be impressive.

There is also a strong effort to develop the hardware that will be required for SuperKEKB, which is proceeding in parallel with data-taking. This involves most of the detectors and is aimed at accepting an event rate ten times higher than now, but with twenty times more background. The idea for Super Belle vertexing is a silicon strip vertex detector with six layers and an inner double layer of pixels. The pixels will be based on DEPFETs originally developed for the ILC by groups in Germany, Czech Republic and Spain. The double sided silicon strip detectors will be readout with the APV25 chip, originally developed for CMS. A prototype of the barrel time-of-flight detector (TOP) is currently undergoing tests at the FUJI beamline, as is a prototype of the Aerogel Ring-Imaging Cerenkov detector. The TOP is intended to replace the current aerogel and time-of-flight detectors in Belle. The TOP measures times and images rings from internally reflected Cherenkov light produced in quartz bars.

All of these projects seemed to be proceeding well, with prototype hardware already available for testing. The Committee was impressed with the quality and quantity of the work being carried out.

4 Cooling of Crab Cavities below 4K

Findings:

The restricted physical aperture in the vicinity of the crab cavities is one of the lifetime limitations in KEKB when operating with crab cavities. To improve the situation, optics solutions have been found that reduce the beta function in this region and hence the physical size of the beam. Since the reduction in beta also reduces the crabbing kick, it is necessary to compensate with an increase in crab voltage. The cavities already operate near their maximum values, believed to be limited by the Q_0 of the cavities. Previous measurements have shown that the Q_0 can be increased by lowering the temperature below 4K, in fact a factor ~4 increase has been measured when going to 2.8K. Modifications have therefore been made to the cryogenics system to enable the cavity helium bath to run with a vapor pressure of 72 kPa corresponding to a temperature of 3.7K and yielding up to a 20% increase in crab kick voltage.

These significant modifications have been gradually implemented and include, amongst others, considerably increased water cooling chiller power, improved helium bath pressure control, and cooling of the pump oil and discharged He gas.

Unpowered cavity tests have shown that the pressure can be accurately controlled and the temperature maintained at 3.7K for many hours even with 100 W added to represent dynamic loading, the expected maximum operational value for the LER ring.

Tests will be made with RF power in March/April and these should confirm the hypothesis that the Q0 change will increase the available field, though only beam use will provide the ultimate test.

Comments:

Operation at reduced pressure renders the system vulnerable to small leaks and the introduction of purging equipment would be advisable.

Although the situation with oil loss has improved, it is possible that the loss could be reduced further to maximize the times between oil refills.

Experience gained in other laboratories that have many years experience working with warm Helium pumping (such as Jefferson Laboratory) could be profitably used for further improvements to the 3.7K system.

5 Simultaneous Injection

Over the last few years, the Injector Linac Group has successfully developed subsystems and control programs required for simultaneous injections to all four rings (HER, LER, PF and PF-AR). These include a fast bend magnet to PF, a bypass hole for electrons at the positron target, phase-controlled acceleration and deceleration in the common lattice, orbit feedback by optical measurements with wire scanners, and an event system. Up to now, the group achieved fast alternating beam injection to HER and LER. Prior to the introduction of the new system the typical switching time from HER to LER filling was more than 30 seconds. This time has now been reduced to about 2 seconds, providing a ten-fold decrease of the beam current variations in KEKB. Simultaneous injection has significantly improved performance, has shortened the time for luminosity tuning, and the impact of the short beam lifetime on the integrated luminosity has been compensated. The group plans to provide pulse-to-pulse switching between HER and LER in April, and pulse-to-pulse switching between PF, HER and LER in October this year.

The Committee is convinced that the group will achieve the final goal of pulse-to-pulse injections to all three rings this year, a requirement for the SuperKEKB project. The Committee extends congratulations to the Injector Linac Group for the successful achievement of simultaneous injection.

6 Issues on the Upgrade

Findings:

The present phase of operation of the KEKB B-Factory is coming to an end. It has been a very successful run of about a decade. Many significant particle physics results were produced.

The plan forward for the KEKB upgrade has several significant choices to be made. One possible design option has been studied by the KEKB team, but additional study is needed. The two general directions appear to be a) high current and high beam-beam parameters or b) low emittance, small vertical IP betas and modest currents. Both need to be studied to arrive at the best option.

Coherent Synchrotron Radiation (CSR) is a critical effect for short bunch, high peak current machines with curved orbits. An analysis of CSR effects on a SuperKEKB beam was recently performed from first principles, making only those approximations appropriate to the SuperKEKB conditions. A realistic beam pipe shape was used and calculation of the wake field was extended in distance. These calculations show that the CSR wake field dominated all others, and tracking simulations using this wake field indicate large (1.6-1.8) increases in both energy spread and bunch length. Reasonable changes in ring design were explored and did not change the outcome significantly. If uncompensated, the effect of CSR is to lower the luminosity from 5 to 2 $x10^{35}cm^{-2}s^{-1}$.

Several options are under consideration to recover the performance target. Limitations to the ratio of β^*_y to bunch length are exacerbated by bunch lengthening, but may be partially overcome by the "traveling waist" scheme. A combination of crab cavities and sextupoles moves the vertical waist of the beam at the Interaction Point correlated with the longitudinal position along the beam. While difficult to implement in the HER, the need is more acute in the LER and the implementation is easier. Traveling waist optics have been computed and found to have acceptable dynamic aperture. The successful implementation of crab waist compensation would recover most of the luminosity lost by the increase in the LER bunch length. However, traveling waists or crab waists are affected by the dynamic aperture of the accelerator. The Committee believes that additional studies are required, which should include limitations due to the dynamic aperture.

The beam-beam parameter sets an important limit on the operation of KEKB. Operationally, this limit appears to be about 0.09 for the present machine. Computer simulations of this parameter limit have been extensive and attacked from many different directions. Many features of the beam-beam limits appear to be correctly simulated by the codes but not all. The current dependence of the luminosity on current is one area where the computer codes do not seem to match the present machine. This is for both "with" and "without" the crab cavities. One suspicion is that there is some beam physics that is not represented in the right way in the computer codes. These additions or corrections should be pursued. Can the ~0.4 beam-beam parameter limit predicted by the computer code be tested in the present KEKB?

With a beam-beam parameter limit of the order of 0.1, the expected luminosity of SuperKEKB is 1 to 2 $x10^{35}cm^{-2}s^{-1}$. This luminosity level should be discussed with the Super BELLE collaboration to get their comments. A minimum expectation should be established.

These issues, along with the high beam currents requiring major RF system upgrades and high operational costs, have prompted a recent look at ultra-low emittance options such as the large crossing angle scheme proposed for the Italian SuperB project. Preliminary estimates suggest this option would have lower capital and operating costs compared to the original plan. Choosing this option would require redirection of some, but not all, areas of design work for the upgrade.

The design of the Italian SuperB project has several features which could be applied to the SuperKEKB design. Some of these are low emittances, large crossing angles, crab waist and longitudinal polarization at the interaction point. However, some of these will require different optical lattice layouts, vibration suppression, different IR layouts, and electron spin production equipment and transport. Not all may be practical for SuperKEKB.

Comments:

Given the recent information on limitations to beam parameters, particularly in the LER, and the cost analyses presented, the Committee agrees with the decision to investigate the feasibility of a low emittance, large crossing angle option for SuperKEKB. Given the schedules presented by Prof. Suzuki, investigation of options requiring major shifts in emphasis for preparatory work should be carefully considered. The Interaction Region design has significant differences with very low β^* functions and the arcs must be reconfigured to reduce beam emittance. Stability of elements, particularly in the Interaction Region, becomes a major concern and the injector should provide very low emittance beams.

However, the potential benefits of higher luminosity and lower capital and operating costs are very significant. Accordingly the Committee recommends investigating the possibilities of very low emittance with large crossing angle as soon as possible, while continuing design work for systems in common to all options.

In order to plan the studies related to the SuperKEKB proposal, a timeline should be developed to start upgrading the collider on the timescale suggested by the lab director. Working backward will help set priorities.

7 Luminosity with Traveling Focus Scheme

The questions addressed in this talk were: to use sophisticated beam-beam simulations to explain the present KEKB beam-beam results, to address the needed lengthening of the LER bunch in SuperKEKB design because of the Coherent Synchrotron Radiation CSR effect which increases the energy spread of the LER beam, and to look at the Super-bunch/micro-beta approach to beam-beam effects.

Beam-beam computer simulations of the present performance of KEKB have been performed for several years. Many different situations have been studied. With the recent addition of machine errors to the simulations and recent identification of hardware errors in the crab cavity apertures, the simulations now agree better with luminosity observations. The discovery of the small physical aperture near the crab cavity helps explain the beam-beam and lifetime effects in the present machine. With the discovery and cure of this aperture restriction, it may be possible to store higher currents and the KEKB luminosity might be increased beyond the present 1.6 x 10^{34} $cm^{-2}s^{-1}$with crab cavities. However, it will not be possible to re-align the apertures which are within the crab cavity cryostat.

From observations, a vertical beam-beam parameter of ~0.09 has been achieved in the HER since last spring which is a very nice result. This beam-beam parameter seems to remain constant as the beam current is increased. A related observation is that without crab cavities, the vertical emittance appears to be lower than was initially anticipated. This low vertical emittance saturates the beam-beam parameter at a lower current. However, more work is needed to make the beam-beam-simulations agree with this saturated beam-beam parameter, matching the variation observed in the KEKB specific luminosity versus the product of the bunch currents. This is most likely coming from additional machine optics errors which, when identified, should be added to the computer code.

A traveling focus scheme was simulated and appears to be the solution to regain the luminosity lost from CSR effects on the longitudinal bunch dimensions in the high current option for SuperKEKB. This code simulates the most likely parameters of the SuperKEKB design with an increased LER bunch length. A traveling focus scheme in SuperKEKB needs four crab cavities and eight sextupoles to cover both rings. The results show that a luminosity of about 5 x 10^{35} $cm^{-2}s^{-1}$ can be achieved, but that the beam-beam parameters are very large at 0.3 to 0.4. Further studies are ongoing. The dynamic aperture effects of these traveling focus sextupoles have not yet been studied and this should be done.

Simulations were also made of the beam-beam effects with the crab waist scheme from the Italian Super-B design with micro-betas. It was confirmed that this scheme can reduce the effects of the beam-beam forces and allow reduced beam currents to be collided to make the same luminosity. However, there are questions concerning the tighter tolerances on component errors, the more difficult beam tuning with the small emittances, and the heightened sensitivity to component vibration in this scheme.

The Committee highly recommends continued beam-beam simulations with a strong emphasis on matching existing data.

8 IR Design

The new IR design for SuperKEKB needs to provide lower beta functions at the collision point, and be compatible with higher beam currents. These constraints are challenging given the congested space, a background-sensitive detector, precise tolerance requirements, and high power levels. This presentation gave a status report of ongoing work for this new IR design. The impact of the beam-beam effect on large dynamic betas and emittances are being included in the design. The required physical apertures, power deposition locations, beam line separation, realistic magnet strengths and diagnostics are included. However, a realistic solution to provide the desired low horizontal beta function (20 cm down from 40 cm) presently does not exist, though work continues. Soon the IR lattice design will be merged with the whole ring lattice and the beam-beam effect included, which will broaden the design. However, some important requirements for this design are still a struggle to achieve.

The presented optics requires a set of new quadrupole magnets with the QCSLD working at 1.9K and the QCSLFE using permanent magnet technology similar to the PEP-II design. Synchrotron radiation effects and beam induced heat loads on machine components were presented in a later presentation, by Iwasaki, and have a very strong impact on the final solution. As the beams will pass with a large offset through the strong magnets, a hard synchrotron radiation spectrum is produced. This power must be accounted for in the vacuum design.

From a vacuum point of view a 'cold' bore at 80 K does not appear to be very useful, as presented by Kanazawa, and the chamber will likely represent a problem due to gas adsorption/desorption under changing beam loading conditions. A possible alternative for a room temperature vacuum system needs to be investigated. An iterative approach will be required to find a compromise between the optics and the space required for essential hardware like pumps, bellows and position monitors.

A beam position monitor BPM is likely needed inside the cryostat in the near IR design. There are likely cold BPM designs developed for other machines. This design should be used to develop the hardware basis for the SuperKEKB design.

For the low emittance option the tolerances on stability of position-sensitive components such as quadrupoles, sextupoles, and BPMs will be *much* more demanding than for the present KEKB, particularly in the Interaction Region. Sufficient resources must be committed to understanding these issues and providing both passive and active solutions to meet the very stringent requirements. These should be initiated early in the evaluation/design process.

Thus, the Committee recommends a continued strong focus on this interaction region design.

9 Design of New Superconducting Quads

The presented optics requires a set of new quadrupole magnets with a pair of (H) defocusing SC quads pushed very close to the interaction point. Both have room temperature bores. One of them (QCSLD) is cooled to 1.9K with reduced stabilizing copper to achieve the required 121.1 T/m gradient at the magnet center and the effective magnet length of 192.6 mm. Four 2-in-1 SC quadrupoles with modest design parameters and 80K bores make the transition to separate beam pipes and normal conducting magnets. A single permanent magnet quadrupole (QCSLFE) in the HER line completes the complement of near-IR quadrupoles. It is 0.52 m long and is made from R32HS (Samarium-Cobalt) with 43.3 T/m gradient.

The QCSLD quadrupole operates at a moderately high current density (~1975A/mm^2) and with low (1.3) Cu/SC ratio in a high magnetic field of 7.6T before the Belle and compensating solenoids are added. For this magnet, and the QCSRD magnet, a reliable and effective quench protection system will be essential. Other SC quadrupoles are part of 2-in-1 designs, but with lower fields (gradient 34.79 T/m) and a reasonable operating point.

While the QCS quads have a room temperature bore, the QC1 and QC2 quads have a bore temperature of 80K in order to save space. We have some concern about the effect on the quads cryogenic system from possible beam mis-steering events on top of the load of image and HOM currents.

Quite a bit of development is required on all of these magnets. Depending on the choice of options for SuperKEKB, there will likely be some changes in magnet requirements so finalizing the choice of machine philosophy soon will be helpful.

10 Special Studies with Crab Cavities

The crab cavities built for KEKB are operating extremely well. One of the future upgrade paths for the CERN LHC includes the use of crab cavities. Operation in a proton machine presents specific challenges such as the possible influence of noise in the crab RF system on the un-damped beam. A series of studies has been proposed, and is being implemented, to measure these effects in KEKB. It is believed that these tests, done in collaboration with CERN, could also benefit understanding of the beam dynamics issues of crab cavity operation in KEKB.

In a video conference linking the Review Committee with CERN, initial studies were presented describing the measured effect of phase noise on the beam. Single low intensity beams showed emittance increase with excitation but behaved differently in collision. High intensity beams, more bunches, had yet a different behavior. None of this is yet explained. It was shown that the effect of the crab cavity kick when the beam was excited longitudinally with phase noise was to couple the longitudinal motion into the transverse plane.
This collaboration and the associated studies are just getting under way. The benefits to both machines could be significant and so the Committee supports their continuation.

11 Evaluation of Detector Background

Findings:

While several sources may contribute to background in the experimental detector, the high currents and Interaction Region design constraints in SuperKEKB make synchrotron radiation (SR) background the strongest and, most likely, the most difficult source to control. Compared to KEKB, the SuperKEKB design moves the first quadrupoles closer to the interaction point, making masking and handling of the deposited power more difficult. The critical energy of the SR increases from 2 to 14 keV and the width of the SR fan increases also.

Other background sources to be investigated include beam-gas, radiative Bhabha, and Touschek scattered particles. A study of HOM and image current induced heating has just started.

Studies of SR related background using GEANT4 code include avoiding direct hits from the HER, energy deposition in the IP beam pipe, and backscattered photons. Round beam pipes are used for analysis of direct SR, and detailed beam pipe features, especially the central chamber and adjacent transitions, are used for backscatter analysis.

After careful consideration of options, the central beam pipe will be oriented parallel to the High Energy Beam (HEB) to aid in achieving suitable masking. Extensive ray tracing was employed to determine the appropriate geometry to prevent primary photons from striking chamber walls near the central beam pipe. A mask protruding 4 mm from the tapered chamber wall was found to be necessary to stop the photons from the HEB, whose spectrum extends well beyond 50 keV. This mask, combined with the beam pipe alignment described above, prevents most secondary photons from striking the central chamber. Extensive simulation showed just 4 cases of photons entering the detector region with energies around 50 keV, though statistics have been too low to study SVD occupancy.

Power in the photons from the HEB striking the taper and mask may approach 1 kW with power densities from 10 to 100 W/mm^2. A calculation suggests that the temperature at the surface of the mask would exceed 400ºC under SuperKEKB design conditions. The heating from power deposition requires further study.

Comments:

The analysis of photon backgrounds and heating in the interaction region has been well executed and has guided the decision on beam pipe orientation. While the detector appears reasonably well protected from photon background, the heating of the 4 mm mask is excessive. More heat will be added from beam HOM and wall currents. Clearly an alternative design will be needed.

If a low emittance option for SuperKEKB is chosen the SR protection in the Interaction Region will be simplified. A decision earlier, rather than later, would reduce the amount of effort here that may turn out to be unnecessary.

The other background sources must be studied soon, as well as the possibility of tertiary photons and additional checks to be sure no paths are missed. The effect of a misaligned beam on the SR fan should be a priority in these studies. Many of these also will depend on choice of design.

12 IR Beam Pipes and Assembly

An overview of the IR layout was presented showing the proposed layout of the insertion magnets and schematics of the beam pipes, with possible locations for bellows and BP monitors. Pumps have not been included at this stage. The layout of the vacuum system consists of copper pipes with a 50 µm gold coating to reduce photon scattering. In QC1RE and QC2R the beam pipe is in contact with the 80 K liquid nitrogen bath due to design constraints of these magnets. Aperture requirements for the beam pipes take into account the requirement that synchrotron radiation from the QCSR should clear the section up to 10 m from the IP and are compatible with continuous injection.

In principle, the 80 K surface proposed for the QC1R-QC2R cryostat could be a useful pumping surface. Unfortunately, as shown to the Committee, nearly all the gas species desorbed by synchrotron radiation are not cryosorbed at this high temperature. In addition, during operation the cold bore chambers will be exposed to scattered photons, electrons and ions from the beam-gas interactions and from the electron cloud. Therefore, it is not sufficient to use conventional vapour pressure data to evaluate the vacuum performance of such a cold bore. Condensed gas molecules may be desorbed by thermal radiation, and soft photons with a few eV are sufficient to crack chemical bonds. To avoid stimulated desorption it is a common requirement to screen a cryosorbing surface.

It is proposed to provide some means of heating the cold chambers in case of an accidental exposure to atmospheric air, and specifically to water vapour. The Committee suggests that, if such an accident occurs, warming up of the cryostat will in any case be necessary. Flushing with warm nitrogen gas could be a simple method to raise the temperature.

Under the expected high power load of the beam pipe, the proposed gold coating will be subjected to large thermal stress cycles. Any detachment of the gold film from the copper substrate must be avoided, since it would destroy the coating. It is therefore proposed to carry out tests with electron bombardment to qualify the coating method.

In the present proposal, two beam position monitors near the IP are located inside the QSC1R and QC2R cryostat. KEK has no direct experience with the design of cold beam monitors. However, there are many machines with cold beam position monitor and corresponding designs could be adopted.

A very rough and preliminary assembly procedure has been presented to the Committee.

Conclusions: The design presented to the Committee is very preliminary. In view of the high synchrotron radiation load and the estimated parasitic mode power near the IP chamber, the proposed 80 K beam pipe proposal should be reconsidered. A detailed pumping scheme should be included in the next design phase.

13 SuperKEKB Ring Optics

Findings

The main design considerations for the SuperKEKB ring lattice include a lower beam emittance than KEKB, a need for a new coupling correction scheme, and the traveling focus.

Low emittance is obtained in HER by tuning the quadrupole strengths, while in the LER, the bending magnets are replaced by longer ones, in addition to quadrupole tuning. The design emittances achieved are 6nm for the HER and 2nm in the LER, both of which are sufficiently small for the high-current option for SuperKEKB.

Coupling correction in KEKB is made by controlling the vertical closed orbit in the sextupoles. The range of vertical orbit however is limited in SuperKEKB due to synchrotron radiation considerations. To provide coupling correctors in the SuperKEKB design, therefore, auxiliary normal and skew quadrupole windings with individual power supplies are installed on the sextupole magnets.

Coupling chromaticities can be corrected by skew sextupoles. If this is shown to be important at KEKB in its next run, these skew sextupoles will also be installed in SuperKEKB. The Committee considers the test on coupling chromaticities a significant step towards the understanding of beam-beam limitations to both KEKB and SuperKEKB, and looks forward to seeing the results of these KEKB tests.

An initial survey of what is needed for the traveling focus scheme in SuperKEKB is made. It is found that 24 fitting conditions are required. The number of quads in the region involved is enough for the job.

Suggestions

In the emittance requirement, it is suggested that an evaluation be made with and without the effect of dynamic beam-beam distortion so that maximum flexibility can be maintained.

The idea of quadrupole and skew quadrupole windings on sextupole magnets seems adequate and effective.

With multiple fitting conditions to fulfill, the optical matching to provide the traveling focus is expected to be an operational complexity if all conditions must be fulfilled with equal accuracy. It is suggested that the criticality of these conditions be evaluated, including the required tolerances.

A set of real-time tuning techniques, procedures and diagnostics should be developed to establish and fine tune the traveling focus scheme.

14 Evaluation of X-Y coupling / requirements on correction

Findings

Vertical beam sizes at the Interaction Point derived from luminosity assuming equal beam sizes in LER and HER yield 1.1 microns at 0.6 mA^2 and 1.6 microns at 1.5 mA^2. These values disagree with measurements derived from synchrotron light monitors (1.8 microns at 0.6 $mA^2$and 2.8/2.4 microns at 1.5 mA^2), and correspond to very small x-y coupling parameters.

Chromaticities as well as chromatic aberrations of the Twiss functions are measured with care by scanning the RF frequency. The results disagree with those obtained by SAD using an ideal lattice.

A clean and effective algorithm is developed to measure the coupling coefficients R_1, R_2, R_3, and R_4, particularly at the Interaction Point. In this effort R_3 and R_4 are found to be large for the LER Interaction Point. By varying the RF frequency, the coupling chromaticities are then obtained. These results again disagree with SAD calculation. The Committee is impressed by this study and concurs that these results can potentially play a role in IP optics optimization. It was noted that the machine conditions during these measurements were not "virgin" conditions but were the result of extensive tuning for maximum luminosity.

In the process of these studies, it is found that even for a single non-colliding beam, the HER has a surprisingly large non-vanishing α_x* for HER and β_x* is also distorted. On the other hand, α_x* is close to zero for the LER.

Also as by-product of these studies, one can obtain damping rate as a function of beam current. This result then yields the transverse impedance. It is found that tune spread smearing is weaker than radiation damping by a factor >10. This is an indication that the sextupole arrangement at the KEKB is well balanced so that their tune spread contribution is small.

Suggestions

The vertical beam size derived from the luminosity should be reconfirmed allowing the HER and LER to assume different beam sizes, and also assuming beam distributions other than Gaussian.

The disagreement between all the measured chromatic effects and the SAD calculations is disturbing. It is suggested that an attempt be made to compare the chromatic aberrations with SAD calculation using a lattice as closely resembling the operational lattice as possible and not the ideal lattice.

The non-vanishing α_x* in the HER is presumably a result of optimizing the luminosity. Whether that is true and if so, why it is required should be pursued. In particular, such a large distortion to the on-momentum linear optics should definitely be corrected if it is not required for the purpose of optimizing the luminosity.

15 Issues and Plans on Beam Diagnostics

a) SuperKEKB parameters

SuperKEKB is different from KEKB with respect to the vacuum chamber, bunch separation, beam currents, IR and radiation levels. This requires new developments in several areas of beam diagnostics

b) BPM (Beam Position Monitor) System Upgrade.

While a number of components can be reused from KEKB, new BPM modules adapted to SuperKEKB vacuum chambers are being developed with smaller buttons to deal with the higher beam currents. Their linearity has been analyzed, and found satisfactory. As in KEKB, they will be equipped with displacement sensors to compensate for thermal motion of the vacuum system.

The BPM receiver frequency was changed from 1018 MHz to 509 MHz because of the lower waveguide cut-off frequency of the beam pipes with an ante-chamber. A new super heterodyne receiver module has been developed and undergone laboratory tests. These tests indicate that their signal-to-noise ratio should be improved to achieve the required resolution of 1 μm at a current of 30 mA. The use of the same receiver frequency as the RF system makes the BPM system more sensitive to parasitic RF leakage from the RF system, and this issue is being addressed, as it slightly degrades the desired accuracy, particularly at low beam currents.

A commercial Libera Brilliance BPM receiver module has also been acquired for tests in KEKB and might be used for special use like the IR orbit feedback.

Cold bore magnets are proposed near the IR, which may require cold BPMs to be developed. The power loss in the cold coaxial cables has been calculated to evaluate whether the power lost is acceptable for the cryogenics system or not.

The number of BPM's equipped with turn-by-turn capability for measuring response matrices for lattice optics diagnostics will be increased from 38 to 120.

Radiation resistant PEEK (polyetheretherketone) cables have been developed to deal with the higher radiation levels in the tunnel, and have been undergoing irradiation tests.

c) Synchrotron Light Monitor

i) Visible light monitor

From the standpoint of the expected beam sizes, the interferometers, streak camera and gated camera developed for KEKB can be reused. The issue of deformation of the extraction mirror is being addressed through reduction of the bending radius of the source magnets as well as through new mirror structures, such as a beryllium coating on a thin water-cooled copper plate.

ii) X-ray monitor

An X-ray monitor using a coded aperture imaging technique developed by X-ray astronomers is being developed in collaboration with the University of Hawaii and CesrTA at Cornell. This should enable high-resolution turn-by-turn measurements of individual bunch profiles. A high speed readout device (STURM - Sampler of Transients for Uniformly Redundant Masks) is being developed to sample the InGaAs sensor array.

iii) A beamsstrahlung monitor is being developed to diagnose the quality of the beam-beam collisions and the beam sizes at the IR.

d) Development of fast gated module.

A fast gated module is being developed, which can select individual bunches separated by 2ns to measure the tune, orbit and longitudinal phase. A module will be tested with beam in the next fiscal year.

e) Suggestions and comments.

The KEKB team has developed advanced beam diagnostics for many years and the proposed upgrade scheme looks very reasonable.

The RF parasite pick-up in their BPM system seems to have its origin in RF leakage in the connectors and cables, and may need further shielding. But the Committee believes that the dominant source of the parasitic RF emission in the high power RF systems should also be addressed. In the CERN AD (Antiproton Decelerator), parasitic RF leakage was a major problem during early commissioning, and was solved by improving the shielding of BPM connectors and cables by 25 dB, and by reducing the RF leakage from the high power RF system by 25 dB, for a total gain of 50 dB.

Regarding the problems with thermal deformation of synchrotron light extraction mirrors, Jefferson lab has developed extraction mirrors on thermally stable sapphire substrates and this alternative may be suitable for SuperKEKB.

The luminosities to be measured in SuperKEKB will be up to 50 times larger than for KEKB. This measurement is crucial to the real time tuning and the success of the accelerator. The Committee suggests that the accelerator instrumentation group take an active role in the specification and development of the luminosity monitor for SuperKEKB.

16 Plans for the next run

The operation of KEKB has been very busy for the past few years. This accelerator has produced a lot of data for the BELLE detector while allowing the accelerator physicists sufficient time to carry out experiments to improve the machine operation. The accelerator has made great advances over the years. The next fiscal year will be the same, but with the additional problem of reduced running due to limited funding levels and the need to do a the full load of machine studies as well as particle physics.

The number of accelerator studies to do is quite large. They should be prioritized to make sure that the most important experiments and improvements are done first if time runs short. The Committee suggests that the studies with higher voltages in the crab cavities, reduction of the vertical IP beam sizes by chromatic corrections, reduction of the x-y IR coupling, and studies related to the Italian option be given higher priority. The Committee feels that what is meant by the "Italian Option" should be better defined. Furthermore, any new test which aims at demonstrating that the crab cavities work as designed for the beam-beam effect should be done.

The Committee posed a new question to the KEKB team as to whether the traveling focus IR scheme to improve the beam-beam effect can be done with a single crab cavity in the ring in conjunction with the ring sextupoles. This study may lead to a new way of operating the ring or a realization that this has been implemented by accident with the present tuning scheme used during operation.

If the Y2S running planning for JFY2009 is only for a brief time, it may not be worth spending a lot of accelerator tuning time increasing the luminosity. This subject opens the larger suggestion that the entire run be planned carefully with BELLE included to maximize the combined outcome.

17 Studies on Beam Pipes & Electron Cloud

The Committee was presented with a detailed progress report of recent studies for the SuperKEKB vacuum. Since the last MAC, good progress has been made with copper beam pipes. Several pipes with an antechamber have been extensively tested under LER beam conditions. In addition to straight pipes and quadrupole chambers, several bending magnet chambers have been successfully produced. To simplify the fabrication, it is proposed to leave out the e-beam welding of the screen inserted between the beam channel and the pumping duct. A further simplification and cost reduction is obtained with the use of copper-alloy flanges, which make copper-to-stainless steel transitions redundant. A bending magnet and Q-type chamber will be installed in the LER for comprehensive tests this year.

Results obtained with various coatings for low secondary electron yield have been presented. Several vacuum chambers have been coated with 200 nm thick TiN coating and installed in the LER. The achieved SEY_{max} of about 0.84 is similar to that achieved with the coating from BNL. Compared to a bare copper chamber, the near-beam electron cloud density is reduced by about a factor of ~3. A combination of antechamber design and TiN coating should meet the requirements for the SuperKEKB.

Following the recommendations of the previous MAC, the KEK vacuum group has continued to study the surface graphitisation in a new laboratory set-up. Values of ~ 1.1 for the SEY_{max} have been measured in the lab. The reduction factor observed in the machine is less pronounced, and this is tentatively attributed to an insufficient thickness of the layer. This uncertainty should be clarified with a second test.

The study of clearing electrodes, which can be installed inside magnet vacuum chambers (wigglers), has provided encouraging results. In order to be ‘invisible’ to the beam, the electrode consists of an insulator (0.2 mm alumina) and a 0.1 mm tungsten layer, both sprayed onto the beam pipe. An external bias voltage (300V) can be applied with an electric feed through. A test system installed in a wiggler magnet chamber has demonstrated the large potential of this technique since reduction factors between 10 and 100 have been reported.

A more ‘passive’ approach to reduce secondary electrons has been tested by replacing the clearing electrode with a grooved surface (a sample produced at SLAC). A feed through and the external bias can be avoided but the gain is also much reduced (factor 10 reported).

The preliminary result of this work has been that the clearing electrode is by far the best, followed by a grooved surface with TiN coating and then a grooved surface without TiN coating. The bare Cu surface is worst.

The near-beam electron density, and specifically the effectiveness of a solenoid field, has been studied with a newly designed detector installed in the LER. With the new detector design, only those electrons which originate near the beam and spiral out in the solenoid field are measured. The measurement confirms that with a 50 G field, the electron density can be reduced by a factor of 100 and that the solenoid remains the preferred solution for the drift space.

Summary: The Committee is impressed by the large amount of work which has been done on many important vacuum issues for SuperKEKB. The chamber design has made significant progress and many components have been successfully installed in the machine. The most recent progress on the electron cloud is impressive and gives confidence that this crucial issue for the SuperKEKB - or for that matter, for all machines, which are plagued by electron cloud effects- has a solution. The basic understanding has progressed enormously and, at this moment, a considerable range of options have become available to suppress the electron cloud. The clearing electrode solution may still require some development but one important aspect, its compatibility with a high intensity bunched beam, has been demonstrated. The agreement between simulations and measurements of electron densities is particularly encouraging.

18 Upgrade of RF Power Sources & Cooling System

All the RF-subsystems, such as klystrons, RF cavities, klystron power supplies, waveguide networks, cooling systems, have already been operated for KEKB. It will be simple to increase the number for SuperKEKB step by step. The only issue of concern is the total electric power of about 100 MW for the machine operation. More than 75 MW is required for the RF system.

If we are able to improve the klystron efficiency by 20%, by incorporating a depressed collector potential, it would be a great opportunity to save both construction and operating costs. Since the fusion research group developed the concept for high-power gyrotrons, this Committee strongly recommends the RF group to explore the feasibility with industries as early as possible.

19 Crab Cavities for SuperKEKB

Several designs under consideration, but no choice has yet been made. However, the traveling waist crab crossing scheme appears to be the current reference design, and to be ready to run in 2013 or 2014, a choice would have to be made soon.

On the other hand, since the impact of the current crab cavities on the luminosity is not well understood, there is probably still time to choose a design. The Committee recommends continued study of the various crab cavity options with the aim of making a selection within the next year. This timescale corresponds well with the proposed timeline on a decision on the low emittance option which would not require the crab cavities.

Appendix A

KEKB Accelerator Review Members

Andrew Hutton	JLab Chairman
Alexander Chao	SLAC
Warren Funk	JLab (Unable to attend)
Oswald Gröbner	CERN (retired)
Trevor Linnecar	CERN
Won Namkung	Postech
Flemming Pedersen	CERN
Eugene A. Perevedentsev	BINP (Unable to attend)
David Rice	Cornell
John Seeman	SLAC
Wang Shuhong	IHEP (Unable to attend)
Katsunobu Oide	KEK Secretary, Accelerator
Masanori Yamauchi	KEK Secretary, BELLE (unable to attend)

Agenda of the 14th KEKB Accelerator Review Committee

Date / Time	Subject	Presenter
2/9 (Mon.) 8:30-9:00	Executive Session	
9:00-9:20	KEK Roadmap and SuperKEKB Upgrade	A. Suzuki
9:20-10:10	Progress in Crab Crossing	Y. Funakosh
10:10-10:40	Belle Status	I. Nakamura
10:40-11:00	Coffee	
11:00-11:30	Cooling of Crab Cavities below 4K	H. Nakai
11:30-12:00	Simultaneous Injection	N. Iida
12:00-13:30	Lunch	
13:30-14:10	Issues on the Upgrade	K. Oide
14:10-14:50	Luminosity with Travel Focus Scheme	K. Ohmi
14:50-15:10	Coffee	
15:10-15:50	IR Design	H. Koiso
15:50-16:30	Design of New Superconducting Quads	N. Ohuchi
16:30-17:00	Discussion	
17:00-18:10	Special Studies with Crab Cavities	Y. Morita
18:10-	Reception	
2/10 (Tue.) 8:30-9:00	Executive Session	
9:00-9:30	Evaluation of Detector Background	M. Iwasaki
9:30-10:00	IR Beam Pipes and Assembly	K. Kanazaw
10:00-10:30	SuperKEKB Ring Optics	A. Morita
10:30-11:00	Coffee	
11:00-11:30	Evaluation of X-Y coupling / requirements on correction	Y. Ohnishi
11:30-12:00	Issues and Plans on Beam Diagnostics	H. Fukuma
12:00-12:30	Plans for the next run	H. Koiso
12:30-13:30	Lunch	
13:30-14:00	Studies on Beam Pipes & Electron Cloud	K. Shibata
14:300-14:30	Upgrade of RF Power Sources & Cooling	M. Ono
14:30-15:00	Crab Cavities for SuperKEKB	K. Nakanish
15:00-15:30	Coffee	
15:30-16:30	Q&A on Specific Issues	
16:30-	Executive Session	
2/11 (Wed.) 8:30-11:00	Executive Session	
11:00-12:00	Close Out	
12:00	Adjourn	