The Eighth KEKB Accelerator Review Committee Report

Introduction

The Eighth KEKB Accelerator Review Committee meeting was held on February 10-12, 2003. The Committee welcomed one new member: Warren Funk from JLab. One member of the Committee retired this year: Wolfgang Schnell from CERN. The Committee expressed its appreciation for his efforts during all the previous Reviews, leading the evaluation of the RF Systems for the Committee. Appendix A shows the present membership of the Committee.

The eighth Committee meeting followed the usual format of oral presentations by the KEKB staff members and discussion by the Committee members. The Agenda for the meeting is shown in Appendix B. The younger members of the Group made many of the presentations this year. The Committee was nevertheless impressed by the high standard of the talks, both technically 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.

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A) Executive Summary

1) Foreword

KEKB has made excellent progress in the year since the last Committee meeting. The peak luminosity has increased to a new world record of 8.26 x 10^{33} $cm^{-2}s^{-1}$ (at this time last year it was 6.65 x 10^{33} $cm^{-2}s^{-1}$, the year before 2.5 x 10^{33} $cm^{-2}s^{-1}$). The BELLE detector has accumulated 107.4 fb^{-1}, another world record (56 fb^{-1} last year and 13 fb^{-1} the year before) and published 55 papers in refereed journals (23 the year before). KEKB also holds the world records for most integrated luminosity in a shift, in a day, and in a month. In the two-day meeting, most of the talks dealt with present status of KEKB showing the attention to detail that has made KEKB such a success. The remainder covered the plans for upgrading KEKB to a luminosity of 10^{35} – 10^{36} $cm^{-2}s^{-1}$. The KEKB machine group had done an enormous amount of work, and is to be congratulated on the impressive results that have been achieved.

2) Summary

KEKB has made spectacular progress over the last year, breaking all of the worldwide luminosity records: highest peak luminosity: 8.26 x 10^{33} $cm^{-2}s^{-1}$, highest daily integrated luminosity: 434 pb^{-1}, highest 7-day integrated luminosity: 2.58 fb^{-1}, and highest 30-day luminosity: 8.78 fb^{-1} (PEP-II still holds the record for highest stored beam current). All of these records were set last October, just before a failure of the interaction region vacuum chamber that stopped the operation for two months. After installing a replacement chamber, the BELLE detector group requested that the beam current not be increased until an anomalous temperature rise in the IP vacuum chamber has been understood, so there have been no further records. The KEKB team has made many hardware and tuning improvements in order to reach this performance and they are to be congratulated on the excellent results.

The BELLE detector has now accumulated 107.4 fb^{-1}, compared with 104 fb^{-1} logged by BaBar. The BELLE detector is working extremely well and has had no major difficulties. Backgrounds are low, and losses during beam injection are generally small; this will make continuous injection acceptable to the detector when some triggering problems have been solved. Overall, the BELLE collaboration is extremely pleased with the quality and quantity of the beam being provided by the accelerator. Their only request (as usual) is for more luminosity!

3) Comments

The Committee has made recommendations throughout the different sections below. They are collected here for convenience.

1. The Committee believes that improving the luminosity of KEKB is the highest priority, and experimental and theoretical studies to improve luminosity should be given precedence. These studies should also include the design of a major luminosity upgrade (SuperKEKB) aimed at a luminosity of $10^{35} – 10^{36}$ $cm^{-2}s^{-1}$. The Committee endorses the direction of the present studies and recommends that they be continued.
2. The Committee recommends that high priority be given to understanding the cause of the anomalous temperature rise in the IR vacuum chamber, which is presently limiting the total circulating beam current.
3. The Committee strongly endorses the proposal to install a crab cavity in one ring as soon as possible, and recommends that a second cavity be installed in the other ring as soon as funds permit. In the meantime, detailed theoretical studies of the beam dynamics of the ring with a single crab cavity should continue.
4. The Committee strongly encourages machine studies to develop continuous positron injection, as this is the best way to increase the integrated luminosity when the beam current is limited.
5. The Committee also encourages machine studies of 3-bucket spacing, as this is the best way of increasing the luminosity if there are no beam current limitations.
6. The Committee recommends that studies that lead to high-current, short bunches should be pursued, including a negative dispersion lattice.
7. The Committee supports continued simulation studies of the transverse wake from the trapped cloud to assess its effect on the coupled-bunch instability.
8. The Committee encourages further efforts to find a configuration for electrostatic clearing electrodes that can effectively clear the electron cloud in the magnet vacuum chambers.
9. The Committee recommends that the experimental and simulation studies of the Transverse Coupled Bunch Instability (TCBI) should continue
10. The Committee recommends continued participation in the collaboration with SLAC to develop a new digital signal processing system for the multi-bunch feedback system.
11. The Committee suggests that the turn-by-turn and bunch-by-bunch data from the BPMs might be used as a tool to tune up the luminosity.

B) Findings and Recommendations

1) KEKB overview

KEKB has made excellent progress in the year since the last Committee meeting. The peak luminosity has increased to a new world record of 8.26 x 10^{33} $cm^{-2}s^{-1}$ (at this time last year it was 6.65 x 10^{33} $cm^{-2}s^{-1}$, the year before 2.5 x 10^{33} $cm^{-2}s^{-1}$). The BELLE detector has accumulated a total of 107.4 fb^{-1}, another world record (56 fb^{-1} last year and 13 fb^{-1} the year before). This means that the accelerator has provided more than 50 fb^{-1} last year – an impressive result. In the period up through June 2002, the accelerator current was limited by heating of the masks and other components. These were changed out in the summer shutdown and the luminosity increased steadily through October when all of the luminosity records were set. In October, a failure of the interaction region vacuum chamber stopped the operation for two months. The problem with the beryllium chamber was apparently due to corrosion but it is still being evaluated (see Section 5 below). During the shutdown, more solenoids were added to the LER so that there is now no blow-up of single beam currents up to 1.6A and the threshold is now estimated to be 1.8A. High current operations are still a big issue, despite a lot of improvements. The hardware issues are with the movable masks and heating of other components. The physics issues are the control of instabilities and improving the feedback systems. It can be expected that both of these areas will continue to be the limiting factors as the beam current increases.

The long-term future of KEKB is an upgrade to 10^{35} – 10^{36} $cm^{-2}s^{-1}$. The studies that are being carried out on the present machine will not only serve to increase the luminosity in the short term but will serve as the basis of the upgrade. The Committee strongly supports these studies and endorses the direction taken.

Simulations indicate that an extremely high tune shift can be obtained if the collisions are head-on using a crab crossing and with a horizontal tune close to the half integer. This makes development of the crab cavities a high priority, with first tests foreseen in 2005. If successful, this way of operating would provide a luminosity boost in 2006 with the present beam current capability. It would also provide the basis for the upgrade.

2) BELLE Status

The BELLE detector has now accumulated 107.4 fb^{-1}, compared with 104 fb^{-1} logged by BaBar and has recorded >100 million B-meson decays and reached a sensitivity down to 10^{-8} branching ratio. One of the principal Physics goals of the detector is to find evidence for CP violations in B-meson decays and to measure the CKM parameters precisely. The measurements of $\sin\phi_1$ at BELLE are a major contributor to the present world average. This year, by studying the decay of B mesons to two π mesons, the first estimate of $\sin\phi_2$ was made. These are extremely important results which KEKB and BELLE were designed to obtain. These results have been presented in a total of 55 papers that have been published in refereed journals.

The BELLE detector is working extremely well and has had no major difficulties. The replacement beryllium vacuum chamber exhibits some anomalous heating at one end. Until the cause of this heating is understood, the detector physicists prefer not to push the beam currents higher. Even though the chamber will be replaced this summer as part of the SVD2 upgrade (see Section 26 below), they want to cautiously take data as long as possible with the present chamber. Understanding this problem should be given high priority as it restricts the machine development studies that will enable BELLE to make full use of the SVD2 detector.

Backgrounds are low, and losses during beam injection are generally small; this will make continuous injection acceptable to the detector when some triggering problems have been solved. Because of the present beam current limitation from the beryllium chamber, the ability to operate with continuous injection is extremely important.

3) Machine Performance since February 02

The improvement of KEKB over the past year has been very impressive. The luminosity has increased by 25% to 8.26E33 cm-2s-1 that is now over 80% of the design value and remains the world's record. The integrated luminosity per month has increased by 15% to 8.78 fb^{-1} per month that is very near the target goal set last year of 9 fb^{-1} per month. These performance increases are a testament to the dedicated teams of KEKB and the KEK Linac who have brought this accelerator to the forefront of particle physics. There have been many accelerator improvements over the past year resulting in these luminosity gains.

The Low Energy Ring LER has had several upgrades, including completing the complement of RF stations with 20 ARES cavities. The beam current has reached 1.8 amperes. More solenoid and permanent magnets covering about 50 m were wound or mounted over the vacuum system to successfully suppress further the Electron Cloud Instability (ECI). The total solenoid and PM magnet coverage is now 2275 m. With bunches every 4 RF buckets there is no blow-up of the positron vertical beam size up to a beam current of 1.6 amperes. More studies with bunch spacing of 2 and 3 buckets are suggested.

The High Energy Ring HER has now stored just over 1.0 ampere. This is a great achievement as this is the first time that a 1 ampere current has ever been stored in superconducting RF cavities. The HER will complete its full complement of RF stations with the addition of two ARES stations this coming summer. With this complete RF complement, the design current of 1.1 amperes will very likely be achieved.

The tuning of the interaction region has become very sophisticated with the use of iBumps, tune corrections with current, dispersion and coupling knobs, circumference corrections, and tests of continuous injection. This collection of tools has brought the luminosity performance of KEKB to it present record level.

The injection rate of positrons has now been doubled by the injection of two bunches per linac pulse. This strong achievement is the culmination of considerable work by the Linac Group over the past several years.

One disturbing event is the recent development of a vacuum leak in the IR beryllium vacuum chamber. This chamber has recently been replaced with an older spare unit. This replacement chamber is now limiting the peak performance of the KEKB collider. The cause of the vacuum leak(s) in the beryllium chamber is not known but is under active investigation. The committee suggests that the cause of the leak be found as quickly as possible so that the new beryllium chamber that is to be installed this summer can be thoroughly checked for any possible compromises.

4) IP Vacuum

An abnormal pressure rise was observed in the IR section. The structure of IR beam chamber is coaxial, and the inner tube is made of beryllium of 0.5mm thickness. The pressure increased by about two orders higher than observed in usual operation. Leak testing using a helium gas spray was tried, but the vacuum group staff could not find any leak from outside of the IR beam chamber. They observed the partial pressure of helium, and it gradually increased. They understood that the leak had occurred not at the outside of the IR beam chamber but at the inside coaxial tube. They replaced the cooling gas from helium to argon, and then nitrogen, and observed the appropriate partial pressure, and, in both cases, found an increase in the partial pressure of the gas used for cooling. This was evidence that the leak occurred from the beryllium pipe. The leak detection processes were carried out correctly following the proper procedure. In the process, an increase of the hydrogen partial pressure was observed, but the origin was not clear because the surface pumps that are used (NEG and ion pumps) may have outgassed when they were switched off in the leak hunting process.

5) Beryllium Chamber

The IR beam chamber has a coaxial structure with a narrow passage between the inner and outer tube, through which helium gas flows to provide cooling. The vacuum side of the inner beryllium tube was gold-plated to protect the tube from radiation damage. After the leak was clearly demonstrated to be in the beryllium pipe, the staff disconnected the outer tube and found that the outer surface of the inner tube was discolored. There were no cracks, either in the beryllium tube itself or at the joints between materials. This indicates that a chemical reaction occurred on the beryllium surface with water vapor contamination in the helium gas. A bubble test was applied and bubbles were seen in the liquid indicating that the leak is limited to a very small hole or channel. These suggest that chemical reaction may not be the cause of the leak, but rather that grain boundary oxidation of the beryllium is more likely to be the source of the leak. Further checking the dark spots on the gold plated surface may help in understanding what happened.

In this coming summer shutdown a new IR beam chamber will be installed. The Committee recommends that the beryllium material itself be checked and inspected and that a detailed depth profile of the chemical components be obtained using SEM, AES and other inspection techniques. These inspections should be completed before installation of the new IR beam chamber in the summer,. As a countermeasure to the oxidation of beryllium tube, additional surface protection is recommended on the outer surface of the inner tube.

6) Movable Masks

Peoples have continued to improve the movable masks from Versions 1 to 4, but, even so, Higher Order Mode (HOM) (TE- modes) were excited at the mask head and penetrated into the vacuum chamber with beam currents over 900mA stored in the HER. Simulation indicates that the ramp length of the mask should be increased from 30mm to 400mm to reduce HOMs. A new long movable mask was installed in the ring and was tested successfully.

In the LER, an abnormal pressure rise was observed and the most probable cause was that the horizontal masks generate TE-mode HOMs. To absorb these modes, a winged HOM damper was designed and installed near the horizontal mask. This reduced the pressure rise to less than one tenth of the previous value. Further operating experience in both rings should be obtained and simulation studies should be continued to confirm that these absorbers are sufficient with higher beam current and for shorter bunches.

7) RF System

PEP II and KEKB have chosen different approaches to solving the problem of the coupled-bunch instability driven by the fundamental mode impedance of the RF cavities. PEP II has elected to use a sophisticated and flexible array of feedback loops. KEKB reduces the detuning needed to compensate for reactive beam loading by increasing the stored energy in the accelerating cavities. This has been done using a judicious combination of superconducting single-cell cavities and copper 3-cell coupled cavities, operated in $\pi/2$-mode, where the beam passes through only one of the cavities, and the high-field off-line cavity is designed for high stored energy with low losses.

Although the KEKB scheme has been demonstrated to be effective and sufficient for the conditions encountered to date, analysis of operating conditions at design intensity has shown that it will be necessary to supplement it with feedback systems for the longitudinal coupled bunch mode ($n = -1$ mode) in the LER. Furthermore, operation of SuperKEKB, where the LER beam will be increased from 2.6 to 9.4 A, will require implementation of feedback loops for the –2 and –3 modes, as well.

To prepare for this transition, a fairly straightforward narrow-band, single side band, digital feedback circuit has been designed and built. It has been successfully tested on the LER, where two ARES cavities were detuned to excite the –1 mode. With a bandwidth of 1 kHz and feedback gain of 15 dB, the system was shown to be effective in counteracting the instability and achieving stable operation under conditions which led to beam abort in less than one second when the feedback loop was switched off.

The method and technology used is certainly the right one for the problem presently at hand and the system is simple to set up and operate and cures the problem at minimum cost.

For significantly higher currents such as the 9.4 A foreseen for the Super KEKB, some further developments in signal processing may be required as the growth rate of the –1 mode approaches 10^4 s^{-1}, a rate comparable to the synchrotron frequency itself. The presently used narrow band filter will probably not be able to provide the required damping rate due to its large group delay, but it may be more appropriate to use a wider filter acting on both +1 and –1 modes with a notch at the revolution harmonic to eliminate the spectral line caused by the unequal bunch population.

Additionally, feedback may be needed at more than one ARES station. The feedback phase will probably also need to be programmed versus beam current as the phase shift at the modulation frequency from the drive signal to the cavity voltage will vary as function of beam loading and cavity detuning.

8) RF Dielectric properties of SiC ceramic absorbers for the ARES cavity

Operation at the higher currents planned for Super KEKB will lead to substantial increases in the amount of Higher Order Mode (HOM) power deposited in the cavities. Development of suitable absorbing materials and design of HOM dampers, for both ARES and superconducting cavities, based on those materials, is an essential activity, and the effort to do this is well underway.

The work to date has been the characterization of two kinds of SiC absorbers and has given reason to believe that mechanisms are available to control the material dielectric constant. The Committee encourages the Laboratory to continue this effort, and in particular, to move rapidly from simulation to testing of prototypes.

9) Superconducting Cavities for KEKB

The superconducting cavities installed as part of the scheme to counteract the impedance of the fundamental accelerating mode have continued to perform well. Operational experience since the last review was presented. The maximum operating current has increased from 870 mA to slightly over 1 Amp, while the maximum power transmitted to the beam has remained at 380 kW. HOM power absorbed has increases slightly from 8 to 9 kW per cavity. The problems experienced have been infrequent, and not indicative of any fundamental problems for KEKB.

Operation of Super KEKB will require significant increases in fundamental power coupler and HOM damping capability, as has been discussed in previous reviews. In addition, a modest increase in normal operating gradient is needed. The desired gradients have been demonstrated in the past, so there is little concern on that score and, although there have been indications of a systematic drop in Q_0, there seems to be sufficient refrigeration power available to deal with it. New fundamental power coupler designs (generally based on KEKB) being contemplated for other projects, call for substantially higher power transmission than has been achieved here, and although these have been achieved on a test stand (APT, SNS) and on a cold cavity (SNS), they have yet to be demonstrated on a cavity with beam. There seems to be an inconsistency in the amount of HOM power anticipated (50 – 80 kW during the previous review, 20 kW now) that needs to be resolved. Overall, investigation of these issues has not progressed significantly, and the Committee renews its recommendation that this be started as soon as possible.

10) LER Blowup and HER Transverse CBI

Good progress was made on the control of the electron cloud effect. During last year, 266 short solenoids and 106 permanent C-yoke magnets were added to the LER. (A total of 350 permanent magnets are planned to cover all BPMs in the arcs.) As a result, 91% of drift spaces and 78% of total length are now covered. At present, no ECI has been observed in the LER if the beam current is below 1.6 A and with 4-bucket spacing, and the threshold is now predicted to be 1.8 A.

Further studies of the ECI effects are continuing to yield more understanding of its physical mechanism and hopefully potential cures. One study analyzed the beam spectrum observed with solenoids on and off, and concluded that the spectrum is consistent with the case when an overwhelming portion of the electrons originate uniformly from the vacuum chamber pipe walls. A second study performs a 3-D simulation of the electron dynamics and found that electrons can be trapped for a long time in quadrupoles and sextupoles. A third good way to study the ECI mechanism uses a streak camera measurement looking for bunch-by-bunch shape differences. In particular, there was an intriguing observation of seemingly random bursts lasting about 5 msec on individual bunches along the bunch train.

The Committee wishes to commend the ECI team for an excellent job done, and encourages the continuation of these studies. It is also suggested that a means to examine the electron trapping mechanism in quadrupoles and sextupoles be investigated.

The next important ingredient of pushing to higher luminosity will necessarily involve reducing the bunch spacing. Presently there is little information for 3-bucket spacing under the present LER conditions. The Committee feels that this step should be taken early to gain the maximum benefit and recommends that the KEKB Management examine the possibility of allocating machine development time to study the running of 3-bucket spacing. This study should be done as soon as possible, even when there are strong reasons to continue production running.

A horizontal coupled bunch instability has been observed in the HER. Its growth rate is substantially higher than expected from a calculation of the resistive wall effect (the resistive wall calculation agrees with the growth rate in the vertical plane). The instability is of concern because an extrapolation predicts a growth rate of 2000 s^{-1} at the design current. This rate will challenge the transverse feedback system. The mechanism of the instability has not been identified. If it turns out to be ions, then there will be implications for plans of future upgrade scenarios.

11) <u>Simulation study of electron cloud</u>

Since the parameters of the electron cloud in an operating machine are hardly ever available from direct measurements (if at all), simulation studies are of great importance for understanding the electron cloud impact on beam dynamics. The efforts of recent years resulted in the development of versatile simulation tools for analysis of the electron cloud formation and also the interaction with the beam that often causes unwanted effects.

At KEKB, the previous cloud simulations supported the crucial decision to install the solenoids around as much of the LER circumference as possible, and the present high-luminosity performance of the machine is a successful outcome of this decision.

The 3D PIC code *CLOUDLAND* belongs to a new generation of electron cloud simulation codes at KEKB, and provides plenty of information on the time-dependent 3D distribution of the electron cloud and its energy spectrum, and their dependence on dozens of model parameters. These include different configurations of the magnetic and/or electric field applied to the cloud volume.

Among the new effects predicted by this code is trapping of electrons in fields with quadrupole and sextupole symmetry (e.g., those produced by the machine lattice elements). As for the cloud in dipoles, this problem cannot be avoided in regular lattice magnets using cloud confinement by a solenoid field. Although the on-axis cloud density resulting from the trapped portion is low, the average cloud density is far from negligible, particularly in the case of the much higher beam currents required for SuperKEKB. An interesting feature of the new phenomenon is a very long density decay time after the end of the bunch train.

In this simulation, a dipole (or quadrupole) clearing electrode array introduced into the vacuum chamber of lattice dipole (or quadrupole, respectively) results in a drastic reduction of the electron cloud density.

The Committee recommends carrying out a simulation study of the transverse wake from the trapped cloud in order to assess its effect on the coupled-bunch instability.

The Committee encourages further efforts aimed at finding an electrode configuration that would be efficient for clearing the electron cloud.

12) Instability Observations via Streak Camera and PMT

The new LER SR extraction chamber and reflective optics give significant improvement in performance with much better stability and reduced heating. Optical axis feedback is no longer needed in the LER*.

Preliminary streak camera observations (Jan 2003) show bunch lengthening in a single bunch from 5.8 mm at zero bunch current to 9.5 mm at 1.5 mA. In a bunch train, the bunches in the tail show ~20% less bunch lengthening than the head.

Observations using a masked PMT signal and BPM oscillation monitor show random coherent vertical blow-up events along the bunch train with a few tenths of a micron amplitude. The frequency is shifted from the single bunch tune by as much as $\delta Q = 0.055$. The coherent signal decays faster (1-2 ms) than the incoherent (measured with PMT only) (~10 ms).

At present this seems to be a curious phenomenon and its relation to luminosity performance is uncertain, but further investigation would likely lead to a better understanding of beam blowup phenomena. The proposed correlation of streak camera and PMT/BOM measurements should improve understanding of this phenomenon.

The Committee strongly encourages more studies with these diagnostics.

* The hysteresis reported last year in the observed beam size vs. current now seems to have been an instrumental effect.

13) Transverse coupled bunch instability by electron cloud in LER

In combination with simulations of the electron cloud formation and its long-range wake, the experimental study of the Transverse Coupled Bunch Instability (TCBI) in LER proved to be an efficient tool for characterization of the electron cloud. In contrast to the vertical beam blowup in LER that is no longer observable with all the solenoids on, TCBI mode spectra and rise times can still be measured in both "solenoids on" and "solenoids off" modes, provided that the transverse feedback loop is set open.

Shortly after switching the feedback loop off, the front-end of the transverse feedback system detects the growth of the multi-bunch instability that eventually causes (partial) beam loss. The Bunch Oscillation Recorder (BOR) samples the transverse beam offsets, bunch-by-bunch and turn-by turn, and the bulky data stored in the BOR can be processed off-line. The measurement does not require dedicated machine study time and could potentially become a cloud-status monitoring technique.

The Committee applauds the efforts which led to consistency between the experimental observations and the simulation results, and recommends further studies of TCBI, particularly in finding a qualitative interpretation of the observed mode spectra and an explanation for the electron production pattern which is uniform over the beam pipe surface.

14) <u>Fast beam loss monitor</u>

A fast beam loss monitor system was developed to reduce damage to the BELLE detector and beam masks from uncontrolled beam losses. The beam abort kicker responds in 1 μs, and the time delay from the input signal to beam abort is 60-120 μs (6-12 turns). Potential beam loss trigger signals (PIN loss monitors, RF status) and beam current were monitored over a period to assess the reliability and response times of various signals for beam loss triggers.

Mask PIN detectors must be vetoed during injection (3 ms) and the current loss trigger was tightened to provide some protection during this period. Operation of the system during continuous injection should be evaluated.

Beam losses dominate aborts. They were found to be associated with coherent oscillations, or changes in betatron tune. Operating procedures have been modified to reduce these incidents.

Mask damage has been eliminated and radiation damage to BELLE reduced, but monitoring of excessive false trips or missed beam losses should be continued. The fast beam loss monitor appears to be effective and well implemented. Planning for upgrades, such as continuous injection and higher currents, should be undertaken soon if it is not already in progress. The trip thresholds should be re-evaluated for the new IP chamber.

15) <u>Tune, bunch length, bunch-bunch position</u>

The gated tune-meter technique is known to provide important data on bunch-by-bunch tune-shifts caused by the electron cloud in the LER. At present, this technique is used to measure the beam-beam tune shifts (closely related to the beam-beam parameter). The tunes of bunches in collision are compared with those of off-collision pilot bunches, i.e., placed in each beam of LER and HER so that they are close to the bunch subjected to the gated tune measurement, but their partner bunches in the opposite beam are missing.

The observed beam-beam tune shifts are in qualitative agreement with the beam-beam parameter value inferred from the luminosity monitor data. The estimated emittance exceeds that calculated from the lattice analysis, presumably due to additional beam-beam focusing. The Committee recommends pursuing this study because direct (and more accurate!)

measurement of the beam-beam tune shift would be of vital importance for understanding the beam-beam phenomena that limit the machine luminosity.

The bunch length measurements based on the bunch spectrum width showed a serious bunch lengthening, roughly equal in LER and HER (in excess of 8 mm at 1.5 mA bunch current). The current-dependent bunch lengths are measured at different values of momentum compaction and effective peak voltage. More work is needed for quantitative understanding of the observed data as well as for identification of sources of unexpectedly high impedance in both rings, taking into account the contribution due to the movable masks.

Preliminary data from the turn-by-turn and bunch-by-bunch BPM showed the feasibility of measuring the bunch-by-bunch orbit distortion and relating it to the beam-beam collision conditions. The technique looks promising as a potential tool to tune-up the luminosity; that is why the Committee recommends exploring this possibility, with the emphasis on evaluation of accuracy limits and the reproducibility of the measurement.

16) Bunch by bunch feedback

Transverse bunch-by-bunch feedback dampers work well, and raise the threshold for transverse coupled bunch operation by more than a factor of 20 in both rings.

In additional, these systems provide a wealth of valuable diagnostic information: bunch current monitors, global and gated betatron tune measurements, instability mode analysis and bunch oscillation monitor systems with beam abort triggers.

There is significant heating of the vacuum components of the transverse stripline kickers, and cooling is marginal up to the present maximum currents. An upgrade was made during the summer of 2001 but nevertheless, a breakdown occurred in March 2002 due to an inadequate mechanism of dealing with the thermal expansion of the kicker stripline. Since the summer of 2002, a third version with an improved BeCu flexible feedthrough has been installed and has worked well so far.

Although the digital signal processing of the present systems is working well, the technology is about 10 years old, and digital signal processing technology has been progressing fast in terms of memory space and processing speed.

A new development of the next generation digital signal processing systems for transverse and longitudinal bunch-by-bunch dampers has started in collaboration with SLAC using the latest high performance FPGA technology developed in industry.

Hopefully there will be some performance gain from this development. Will a 20 tap bunch-by-bunch FIR filter perform better than a two-tap filter? In principle long filters have longer group delays than shorter filters. Long group delays increase the sensitivity to tune changes (more difficult to operate) and impose an ultimate limit on the maximum damping rate that can be achieved.

The main function of the presently used two tap filters (with no DC response) is to filter out the average bunch position and thus reduce kicker power, which enables higher gain. The effective group delay of a two-tap filter system with a one-turn delay between pick-up and kicker is a group delay of 1.5 turns. With a 20 tap filter, where the first tap gives the damping kick, while the remaining 19 taps are set to give no DC response, the system group delay can be reduced to about one turn, which in principle increases the ultimate damping rate by a factor of 1.5.

For phase control, it is more effective to use two pick-ups about a quarter wavelength apart (as is presently used in KEKB) than to use the filtering function in the signal processing. The latter increases the group delay with the associated drawbacks discussed above.

17) IR BPM

The Octopos BPMs near the collision point were specially manufactured with 8 button electrodes and were fitted into a very narrow space near the IP. The gain coefficients for each electrode were calibrated with position mapping data for single-beam operation. The Octopus BPMs work well and have been very useful in physics running.

18) Progress in Linac: 2-bunch injection etc.

The Injector Linac Group reported on two subjects: two-bunch injection and pulse-coil breakdown. Two-bunch injection has been a routine operation for positron beams to LER with an injection rate of 3.0 mA/sec, the same rate as for electron beams to HER. It made a great contribution to KEKB operation by reducing the injection time by one-half. The Committee congratulates the Injector Linac Group for its excellent performance last year. Since it would take about 45 minutes to fill 2.6-Ampere current in LER, the final design goal, the Committee recommends a further study of increasing the positron injection rate in the future, including continuous injection operation. Continuous injection for the electrons should also be evaluated, even though injection may be less frequent than for positrons.

Pulse-coil breakdown is considered to be one of possible events in practice. The breakdown phenomena will be corrected for the new replacement coils, without any great design difficulty. Since the injector linac is now very well stabilized for the complicated tasks of providing various beams to 4 different machines, the Committee praises the linac group for their dedicated hard work.

19) Beam Energy Spread Monitor in the Linac

A non-interfering beam size monitor has been designed and constructed that uses the higher-order-multipole signals of a beam position monitor to extract the beam size in the KEK linac to measure the beam energy spread in the J-Bend. This monitor uses a stripline position monitor specially constructed for the linac with eight strips. The monitor extracts both second order as well as third order moments. A careful data analysis of the signal moments obtained with a linac beam in this monitor was compared with similar data taken with an interfering profile screen. The monitor was tested at the 1.7 GeV point in the linac J-arc with a beam-size calibration obtained from beam images. Both data sets agree very well to within a precision of order of a few percent. The Committee believes that the beam size measurements using this stripline position monitor are most likely the best implementation of its kind in the world. It will certainly be a very useful device for improving the injection efficiency to the rings. The

Committee strongly encourages this kind of innovative diagnostic development. Congratulations to the linac team.

20) Magnet issues, circumference drift

a) KEKB magnet system

The KEKB magnet system works very well with the exception of two wiggler magnets that had coil-layer short problems. No burnt spots have been found by using an impulse test at the manufacturer. Further investigation into the location and causes of the problem is continuing.

Even though this problem did not have any major impact on KEKB operation, because the affected pair of wiggler magnets could be temporarily bypassed, and the damaged coils replaced with spare coils, it is recommended to check all the other wiggler magnets during the machine shutdown periods.

b) Tunnel level changes

Since June 1996 to August 2001, the tunnel level markers on the tunnel wall have been surveyed 6 times. The results of these surveys show that the tunnel level has changed since 1996, and the changes are very similar as those occurring in the nine years of TRISTAN operation. This change is not uniform for the whole ring. The largest drift of about 2.5 mm/year is in south tunnel section but this has not created any major problem with KEKB operation until now. The KEKB team has made a preliminary identification of the source of the largest drift; it is most likely due to the fact that the surrounding area is more heavily built up and there are three wells in this section.

c) Circumference drift

The Circumference Closed Orbit Correction (CCC) program maintains the circumferences of the rings within tolerance by changing the strength of chicane magnets in the LER and by changing the RF frequency in the HER. Some qualitative analysis of the circumference drift has been carried out by the KEKB team, such as correlating a long-term drift with the outside temperature, and identifying the fact that Typhoon No. 21 on 10/1/2003 and the resulting rapid atmospheric pressure drop caused a temporary circumference expansion, and so on. The Committee endorses the KEKB team to continue quantitative studies of the contribution of each environmental variable to the circumference drift of the KEKB rings, even though it has no real impact on operations.

21) Progress in the Control System

The Control System has continued to function with few problems. Recent hardware Upgrades include upgrading the Ethernet network and buying additional servers. The primary software upgrade is to provide additional capabilities for data archiving. About 800 GB per year of data is now archived in discs or NAS RAID5 storage. Further back-up storage is available in a tape storage facility.

The Controls group maintains strong collaborations with laboratories in China and Korea, as well as being an active member of the EPICS collaboration.

There is a problem with VXWORKS, the operating system for the IOC front-end computers. The manufacturer will no longer support VXWORKS on new HP platforms, so all of the EPICS Collaboration members need to find a long-term solution. The KEKB Controls Group is encouraged to develop a solution and implement it before this has an impact on operations.

22) iBump Feedback Tuning

Vertical steering at the IP is based on the beam-beam kick and works well. This is not the case in the horizontal plane, and maintaining optimum steering to maximize luminosity requires significant operator skill and experience.

A clever and complex feedback system has been developed incorporating a large amount of this experience into a software tool which can operate in several modes: i) injection, ii) direct tuning, iii) lifetime feedback and iv) size feedback.

The Committee would like to congratulate the Operations Team from Mitsubishi Electric Service Company on this remarkable achievement and encourages further development.

23) Facilities and operation

This is the first time that KEKB facilities and operation have been presented to the Committee. The report is very impressive and interesting, not only in the reliable and stable operation of the facilities, but also because of many practical operation data that were reported. To reduce the KEKB construction budget, most KEKB facilities (including electricity, cooling water, air conditioning, building and the tunnel) made use of the existing TRISTAN facilities that have more than enough capacity for KEKB operation. All of these facilities worked very well since KEKB commissioning. However, since most of these facilities are already about 20 years old, aging problems may appear in the near future. The Committee recommends that the KEKB team prepare a long-range plan to upgrade the facilities, taking into account the needs of the upgrade.

24) Beam-beam simulation and experiment

The beam-beam simulation presented uses a 3-D strong-strong model with longitudinal slices to simulate the effects of the crossing angle and the variation of beta through the collision region. Using an interpolated kick that depends on the longitudinal position of each particle in its slice significantly reduces the number of slices needed to produce stable results. The simulations are in good agreement with measurements with respect to variation of bunch current, coupling, and operating tunes.

The prediction of an improvement in luminosity by a factor of 2-4 using crab compensation of the crossing angle (presented in section 27) is very encouraging. It is reasonable to expect, however, that new disruptive phenomena may develop with flat beam $\xi_Y > 0.1$.

The Committee applauds the KEK staff on the development of this code and encourages continued work with frequent comparison with experimental data.

25) Further luminosity upgrade

The spectacular increase in luminosity in KEKB over the past two years is a result of many carefully organized changes to the operating parameters of KEKB including the reduction of betay*, the increase in the number of bunches and current, the reduction of the electron cloud effect, and the move of the horizontal tunes to near the half integer. These changes have been scientifically studied and documented to make sure the optimum parameters have been chosen. However, there are fewer choices to be used in the future to improve the luminosity and finding the best path becomes a challenge.

One obvious path is to increase the number of bunches and, correspondingly, increase the beam currents. Since all the buckets are used in the present "every fourth" bucket pattern, a new pattern is needed. "Every third" pattern is likely the next. However, there is a fear that the electron cloud effect (ECI) may reappear with this pattern. Accelerator studies are recommended to study if the "every third" pattern has ECI consequences.

Another method to increase the luminosity is to shorten the bunch length below the approximate 9 mm at high currents. A shorter bunch would allow a slightly reduction of betay*. The bunch length may possibly be reduced with a new low momentum compaction lattice or possibly the "negative alpha" lattice. These possible lattices should be tested on the present accelerator.

The use of crab cavities to horizontally rotate the beams as they enter the collision point could reduce or eliminate the adverse effects of the crossing angle on luminosity. The development of crab RF cavities at KEKB is now at a stage where an accelerator beam test would be very timely and could potentially increase the luminosity significantly (20 to 50%). The Committee recommends the rapid implementation of the first crab cavity in the HER, and then the LER, as soon as possible.

Finally, the use of continuous injection could increase the integrated luminosity per day by about 15 to 25 %. Continuous injection could eliminate the lost time due to injection and the decay of luminosity with declining beam currents. Continuous injection tests have been tried on KEKB and the accelerator worked well. The BELLE detector had problems with event triggering that are now, apparently, fixed. Thus, the Committee suggests that continuous injection be tried again with the hope of increasing the integrated luminosity per day.

26) SVD2

The SVD1 is scheduled to be replaced by a new SVD2 in the coming summer. In SVD2, the radiation hardness has been increased from 1 Mrad to 20 Mrad, the number of silicon layers has increased from 3 to 4, and its IP chamber radius reduced from 2 cm to 1.5 cm. An additional Tantalum shielding pipe is installed, while the SR masks are removed to avoid HOM heating. These seem to be good innovative changes and should improve the robustness of the SVD design.

Careful studies were made to estimate the radiation dose as well as developing a heating load budget of the SVD2 design. Radiation doses from particle background were estimated using GEANT and TURTLE, while the SR background was simulated using EGS4. These dose rates are found to be acceptable.

The weight stress of the beryllium pipe assembly was carefully checked by a 3-D finite element analysis using SOLID and is judged to be acceptable.

The budget of the heat load from SR, direct beam current ohmic heating, and HOM heating was estimated using MAFIA and ABCI. Heating on the IP chamber is found to be 70 W, a pleasant factor of 5 reduction from SVD1.

The cooling system uses liquid (normal paraffin) flowing in a 0.5mm gap in a double walled beryllium pipe. A corrosion test has been performed. The flow rate of 2 l/minute is high and it is suggested that its turbulence effect be checked. Relief valves have been included.

27) Luminosity boost by head-on (crab) collision

The demand to boost the luminosity 10 or even 100 times in the SuperKEKB design means searching for radical ways of raising the currently achieved beam-beam limit, provided that other factors, which limit the bunch intensity, have eventually been overcome.

Preliminary results of the recent beam-beam simulation with a 3D PIC code have shown a critical influence of the crossing angle on the attainable beam-beam parameter and hence on the luminosity limit. Both weak-strong and strong-strong models indicate a substantial increase in the beam-beam parameter for the case of head-on collision with the SuperKEKB design parameters, the latter shows a saturation at $\xi = 0.11$ for a bunch current of 1.5 mA, the former does not show any beam-beam limit with $\xi > 0.2$. These values are adequate for the SuperKEKB design luminosities of 10^{35} and $10^{36} cm^{-2}s^{-1}$, respectively.

One possible explanation of the unusually high beam-beam parameters achieved for the flat colliding beams in simulation and adopted in the new project is related to the unique experience of the present KEKB machine which operates very close to the half-integer resonance; the working point now is x/y = 0.51/0.56.

Implementation of the crab-cavity scheme gives a way of testing the head-on collision geometry at KEKB, which is important for the future upgrade. The Committee recommends re-considering the current plan for the crab cavity installation in order to speed-up the installation of the crab cavities in both HER and LER.

The Committee also recommends pursuing detailed studies of alternative ways to boost the luminosity. The Committee encourages further development of the 3D beam-beam simulation at KEKB, benchmarking it against analogous codes at other labs as well as carrying out systematic comparison of the simulation results with experimental results available from modern high-luminosity colliders.

28) Crab Cavity R&D

Since the last review, there has been good progress in understanding the processes that limit the cavity performance and testing has proceeded well.

At the previous review, it was proposed that the crab cavity would be fabricated from niobium sputtered on a copper base, but during this review it was clear that work is focusing on a conventional sheet niobium construction. The second prototype cavity has been completed, and has achieved the desired gradient and Q_0 performance, and work is proceeding on the design of the cryostat. The measured performance has been very consistent over multiple tests of the two cavities, even when the unusual beam-line power coupler for 'non-crab' modes is installed. Cavity production processes, based on electropolishing, have been established, and produce a modest margin of Q_0 above the required value of 10^9, and a comfortable gradient margin.

A conceptual design of the cryostat has been prepared, and detailed design work is underway, but this task is unusually difficult, given the complexity of the basic cavity geometry and the extremely cramped space into which it must be squeezed.

29) Lattice design for Crab Cavity

KEKB staff have presented the hardware changes necessary to provide a high horizontal beta for the crab cavity in the HER as well as the required phase advance to the interaction point to fully compensate the crossing angle of the HEB. A target β_X(crab cavity) of 200 m with zero $\alpha_{X,Y}$ was achieved while maintaining other important optics constraints in the HER. The number of separate quadrupole power supply circuits must be increased from 8 to 18. The new optics scheme provides ample flexibility ($70m < \beta_X$ (crab cavity) $< 800m$) and the phase advance to the IR may be varied by ±28 degrees. Dynamic aperture is unchanged from that of the present KEKB.

The Committee approves of this work and supports the development plan to assess crab cavity dynamics and move ahead to designing LER crab cavity optics.

30) IR Design for SuperKEKB

Considerable work has been performed on the design of an upgraded interaction region for KEKB with the aim of achieving a betay* of 3 mm. The design work so far has been excellent. The new interaction region layout has incorporated a crossing angle of 15 mrad and has the final quadrupole doublet moved closer to the collision point. The local high field solenoids used to compensate the BELLE solenoidal field will now be superimposed on the field of the superconducting quadrupoles. The superconducting solenoid coils will be wound over the quadrupole windings with some additional dipole correction elements added. These magnet designs seem reasonable and carefully estimated.

However, the forces on the superconducting magnets inside the BELLE solenoid are quite large (several tons) and the containment of these forces must be carefully considered in the design of the supports, and include forces created due to current ramping or possible quenches.

In the present KEKB interaction region, the outgoing beams have damaged downstream vacuum chambers from high power synchrotron radiation. These heating problems have been repaired on the present accelerator. However, special offset orbits are now used with the HER and LER beams as they enter the interaction point to help reduce the downstream heating. The purpose of these offset orbits should be investigated so that the reasons can be included in the new interaction region design. The future interaction region must also deal with about ten times the beam current. Therefore, the Committee suggests that the vacuum chamber design be started with the aim of solving the synchrotron radiation heat loading downstream.

31) <u>Dynamic aperture of SuperKEKB</u>

A reasonable first lattice design has been made for SuperKEKB. The LER in this design keeps half of the wiggler magnets as the present LER, and therefore maintains part of the flexibility in its emittance control. On the other hand, momentum compaction is sufficiently flexible to allow a negative alpha lattice. It is suggested that some test of negative alpha lattice be performed in the present KEKB to explore its effectiveness in reducing bunch length as well as its limitations.

The dynamic aperture of the SuperKEKB was obtained by applying SAD 3-D tracking for 1000 turns. So far only the bare lattice has been studied. The dynamic aperture found is quite reasonable, and satisfies the injection and lifetime requirements. Momentum aperture is found to be more than ± ½% with a reasonable Touschek lifetime of 230 min. This work should be continued to included magnet errors and beam-beam effects.

32) <u>Impedance estimation</u>

Impedance estimation by calculation (with 2D code ABCI and 3D code MAFIA) is very important for KEKB as transverse and longitudinal coupling impedances are important limitations to machine performance. These limitations are due to excitation of coupled bunch instabilities as well as HOM heating.

Beam based verifications of the total loss factor (synchrotron phase versus current) indicates that the integrated loss factor is larger than expected. On the other hand, numerous elements installed in the machine have not been included in the impedance budget.

Also bunch lengthening versus current is much larger than expected although it is not clear whether the bunch lengthening model is only based on potential well model or includes turbulent bunch lengthening.

Good agreement was found by comparing measured HOM power levels with expected HOM loads from calculated loss factors.

An approximate criterion for mesh size required for calculation of shallow tapers.

In view of the importance of impedance issues for further upgrades in beam currents and luminosity, the Committee recommends that this activity continues and that all elements installed in the machine should be calculated and the calculations verified by experiments

33) Vacuum Chamber R&D

The presentation includes challenging ideas, especially the RF shield. The newly proposed RF shield has teeth and grooves alternatively along the duct periphery. The gap clearance between them is too narrow, so technical difficulties are predicted, but this ideal design is expected to give good performance. It is recommended that a mock-up be built and installed in the KEKB ring as soon as possible. Based on the experience of manufacturing copper ducts and of operation in a real machine, the proposed antechamber structure seems safe and a sound design. The duct has cooling water passages that are arranged on the entrance slit shoulders of the side channel; this is useful to protect the vacuum duct from high power radiation generated by bad steering under high beam current conditions. Following the test of the RF shield, it is planned to manufacture, install and test a new type antechamber in the KEKB ring.

The Committee recommends that system-engineering studies of the new vacuum chamber be carried out, including the fabrication tolerances and the new installation techniques that will be required.

34) C-Band R&D

The development of the C-band equipment needed to increase the energy of the positron beam from 3.5 to 8 GeV is very advanced. The Committee was presented with information on all elements: modulator, driver klystron, RF window, accelerator guide, SLED cavities and waveguide components. The Committee concludes from this that there is relatively little technical risk associated with the linac upgrade.

Appendix A

KEKB Accelerator Review Members

Andrew Hutton	JLab	Chairman
Alexander Chao	SLAC	
Warren Funk	JLab	
Georg Hoffstaeter	Cornell (excused)	
Won Namkung	Postech	
Fleming Pederson	CERN	
Eugene A. Perevedentsev	BINP	
David Rice	Cornell	
John Seeman	SLAC	
Wang Shuhong	IHEP	
Shin-ichi Kurokawa	KEK	Secretary, Accelerator
Fumihiko Takasaki	KEK	Secretary, BELLE

Appendix B

Agenda of the Eighth KEKB Accelerator Review Committee

Feb. 10 (Mon.)		
8:30- 9:00	Executive session	
9:00- 9:15	Introduction	K. Oide
9:15- 9:35	BELLE status	F. Takasaki
9:35-10:05	Machine performance since Feb. 2002	Y. Ohnishi
10:05-10:20	Break	
10:20-10:40	IP Vacuum- from the first anomaly to the final large Helium leak	K. Kanazawa
10:40-11:00	Beryllium Chamber	S. Uno
11:00-11:20	Movable masks	K. Shibata
11:20-11:40	RF System	S. Yoshimoto
11:40-12:00	ARES（RF Dielectric Properties of SiC Ceramics）	Y. Takeuchi
12:00-13:00	Lunch	
13:00-13:20	SCC	S. Mitsunobu
13:20-13:40	LER blowup and HER transverse coupled bunch instability	H. Fukuma
13:40-14:00	Simulation study of electron cloud	L. F. Wang
14:00-14:20	Instability measured by streak camera	J. Flanagan
14:20-14:40	Transverse coupled bunch instability by electron cloud in LER	S. S. Win
14:40-15:00	Fast beam loss monitor	H. Ikeda
15:00-15:15	Break	
15:15-15:35	Tune, bunch length, bunch/bunch position	T. Ieiri
15:35-15:55	Bunch by bunch feedback	S. Hiramatsu
15:55-16:15	IR BPM	M. Tejima
16:15-16:35	Progress in Linac: 2 bunch injection, etc.	T. Kamitani
16:35-16:55	Beam size measurement at Linac	T. Suwada
16:55-17:15	Magnet issues, circumference drift	M. Masuzawa
17:15-17:35	Progress in control system	T. Nakamura
17:35-17:55	“iBump” Feedback Tuning	Y. Satoh
18:00-18:45	Executive session	
Feb. 11 (Tue.)		
8:30- 9:00	Executive session	
9:00- 9:20	Facilities and operation	M. Yoshioka
9:20- 9:40	Beam-beam simulation and experiment	M. Tawada
9:40-10:00	Further luminosity upgrade	Y. Funakoshi
10:00-10:20	Break	
10:20-10:40	SVD2	T. Abe
10:40-11:00	Luminosity boost by head-on(crab) collision	K. Ohmi
11:00-11:20	Crab cavity R&D	H. Nakai
11:20-11:40	Lattice design for crab cavity	A. Morita
11:40-12:00	IR design for SuperKEKB	N. Ohuchi
12:00-13:00	Lunch	
13:00-13:20	Dynamic aperture of SuperKEKB lattice	H. Koiso
13:20-13:40	Impedance estimation	S. Stanic
13:40-14:00	Vacuum chamber R&D	Y. Suetsugu
14:00-14:20	C-band R&D	S. Fukuda
14:30-18:00	Executive session	
18:00-20:00	Working dinner	
Feb. 12 (Wed.)		
8:30-9:00	Interaction with KEKB staff members	
9:00-9:30	Closing	