**The Sixth KEKB Accelerator Review Committee Report**

**Introduction**

The sixth KEKB Accelerator Review Committee meeting was held on February 23-25, 2001. This was the first meeting without Dr. Gustav Adolf Voss who has been the Chairman for all previous meetings. The meeting began with the Committee expressing its thanks to Dr. Voss for his leadership during the construction period. Andrew Hutton from JLab took over as Chairman. The Committee welcomed several new members: Eugene Perevedentsev from BINP, David Rice from Cornell, Georg Hoffstaeter from DESY, and Stephen Holmes from Fermilab. The Committee expressed their appreciation to the outgoing members for their hard work: Nikolai Dikansky, David Gurd, Hasan Padamsee, and Dieter Trines. Appendix A shows the present membership of the Committee.

The sixth 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 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) Foreword**

KEKB has made excellent progress in the year since the last Committee meeting. The peak luminosity has increased by a factor 3.5 to 2.5 x 1033cm-2s-1 and the BELLE detector has accumulated 13 fb-1 compared to 0.5 fb-1 a year ago. This is a remarkable achievement; however there were several issues that kept the KEKB staff busy. In a two and a half day meeting, it was hard for the Committee to fully evaluate the 23 oral presentations that covered a wide range of topics. It was evident that the KEKB machine group had done an enormous amount of work and is to be congratulated on the impressive results that have been achieved.

**B) Summary**

KEKB is now a fully operational facility, delivering beam to the users while simultaneously addressing the various problems that were encountered, and carrying out machine development studies to improve the luminosity. This has put a heavy strain on the machine group that the Committee recognizes. The luminosity had reached 0.7 x 1033cm-2s-1 at the time of the last Committee meeting. The luminosity increased steadily during the year, reaching 2 x 1033cm-2s-1 by July 2000 just before the summer shutdown. During this shutdown 4 superconducting cavities (SCC) were added, many movable masks and some bellows were replaced, and over 800 meters of solenoid were wound *in situ* over the vacuum chambers of the LER. The luminosity climbed again over the next two months reaching 2.37 x 1033cm-2s-1 by the end of the year.

Another 400 meters of vacuum chamber were covered by solenoid magnets during the New Year shutdown. A new record luminosity was achieved immediately after the shutdown, 2.47 x 1033cm-2s-1, and has since increased to 2.53 x 1033cm-2s-1.

The peak luminosity in KEKB has increased at almost exactly the same rate as in PEP-II, but with a delay of about 3 months. KEKB is presently capable of an integrated luminosity rate of 3 fb-1 per month, 25 fb-1 per year. The integrated luminosity in KEKB has increased more slowly than the peak luminosity and is now about six months behind PEP-II.

The hectic pace of machine studies, operational support, and installation has not allowed the machine group much time for evaluating the status of the machine in depth. The Committee hopes that the group will be able to find the time to have an internal conference on machine performance in the coming year.

The most difficult issue continues to be the increase in the positron beam size with increasing total beam current. The addition of the solenoids to reduce the Electron Cloud Instability has improved the situation but not resolved it. The Committee was unanimous in recommending that this work continue to cover the maximum amount of the beam pipe with solenoids. No other remedy has a better chance of rapidly improving the luminosity and the technology is now well developed (but not trivial).

It is also evident that the Electron Cloud Instability does not explain all of the phenomena in the LER. The data is confusing and may be affected by measurement errors. The beam size definitely increases along the bunch train and there is currently no consensus on the theoretical explanation for this. The specific luminosity during physics runs depends on the total beam current, independent of the number of bunches which may be due to beam-beam effects but this is also not clear. Understanding and controlling these phenomena is the key to higher luminosity and further investigation is encouraged.

The masks have suffered failures due to overheating, from direct beam strikes and due to heating from higher order RF modes. Only recently have engineering solutions been obtained which appear satisfactory, at least for the present beam current levels. The Committee suggests using shorter collimators in locations far from the interaction region, as they may be less susceptible to damage. The Committee endorses the proposal of the KEKB machine group to protect the collimators with fast radiation detectors connected to the beam abort system. Other beam line components were also damaged by the high beam power. Many of these have already been replaced during the summer shutdown last year, while the moveable masks in the HER will be replaced after April. As the beam currents increase, the temperature of the beamline components will continue to require careful monitoring to avoid catastrophic failures.

Most of the other technical components have worked extremely well, a tribute to good engineering and execution. The RF system (both the ARES cavities and the superconducting cavities) has performed extremely well and the remaining cavities are ready for installation when required by the program. The control system has functioned well, and the vacuum continues to improve which has had a real positive influence on the beam lifetime and the detector backgrounds. The injection system has proved extremely reliable and has improved the injection rates compared to a year ago.

The detector is working at a high efficiency and two papers have been submitted for publication.

The main request of the users is for increased luminosity, and the machine group is trying hard to deliver it. It will require close collaboration to properly balance machine development and machine operation for the users to maximize the physics output – the ultimate goal of everyone involved.

The Committee recommends that the machine group continue machine studies at about the present rate with the expectation that this will lead to further increases in the luminosity.

In parallel, the KEK directorate should develop parameter sets for future upgrades that reconcile the desires of the users with the realities of what is technically and financially feasible.

**A) Overview of Commissioning**

There has been excellent progress in commissioning the KEKB accelerator over the last year.

There have been approximately eight months of running for physics with 11 $fb^{-1}$ delivered since the last meeting of the Committee. Recently, peak luminosities of 2.5 x $10^{33} cm^{-2} s^{-1}$ were achieved, and the present capability for delivering integrated luminosity is about 3 $fb^{-1}$/month.

These achievements indicate that the KEKB accelerator has been in the transition between commissioning and operations. The entire accelerator staff deserves congratulations for these accomplishments.

The current luminosity represents an improvement by a factor of 3.5 relative to the performance of a year ago. This is a very significant improvement and derives from a large effort to understand the machine and to correct identified problems. The major factors in the improved performance are related to the crash program to install solenoid windings on the LER beam pipe for control of transverse beam growth (believed to be induced by a photo-desorbed electron cloud), and operation at a new tune point. These two factors are discussed in more detail later in this report.

Machine performance is fairly well characterized by experiments, models, and simulations. At its most general level, the accelerator shows a specific luminosity that decreases as the product of the beam currents in the LER and HER increases. This characterization indicates that the primary impediment to increased luminosity is an increase in beam size observed in the LER when operating at total currents in excess of about 500 mA, and a beam-beam tune shift that is limited to about 0.03. Since the LER is designed to operate at a beam current of 2.6 A, the shortfall in the LER operating current represents the most significant feature that will have to be overcome to push the luminosity up toward the design goal of 1 x 1034cm-2s-1. Components of a plan for reaching the design luminosity exist, but at this time, an overall coherent plan does not.

Currently the machine is capable of providing approximately 700 pb-1 luminosity per week to the BELLE experiment. Reliability of operations, defined as the ratio of delivered to scheduled hours of collisions is at a level characteristic of an operating facility. Dedicated machine study time is currently allocated under an arrangement allowing studies to take place as long as an average of 100 pb-1/day is provided to the experiment. This is presently resulting in dedicated machine study time running at about 10% of total scheduled operations.

The Committee offers the following comments and recommendations relative to improving performance, and transitioning to a more fully operational mode:

a) KEKB should be regarded as an operational facility at this time. Performance is at about 25% of the design goal, which is sufficient to support a competitive physics research program. This means that accommodations have to be made both by the experimenters and by the accelerator team to support long-term mutual goals. An appropriate balance has to be achieved between physics running and machine studies aimed at improving performance. The performance improvements have a greater leverage for providing improved long-term integrated luminosity if they are implemented early. We recommend that the experimenters and accelerator staff periodically review their agreement on the allocation of studies time in order to attempt to maximize the long-term performance of the collider.

b) The luminosity as measured by the BELLE luminosity monitor does not agree with the luminosity calculated from measured machine parameters. This is suspected to be due (at least in part) to systematic effects in the interferometer beam-profile monitor. This discrepancy should be confirmed.

c) The accelerator team should identify a strategy for approaching the design luminosity of 1 x

1034cm-2s-1 based on their current understanding of the accelerator limitations. We would suggest accompanying the strategy with a parameter list identifying performance goals associated with various operating parameters.

**B) Solenoid Winding**

Solenoid windings have been wound onto the vacuum chambers to keep low energy electrons away from the positron beam to control the Electron Cloud Instability (ECI) in the LER. About a year ago, a KEKB project was started to design the winding fixtures, the power supplies, the coils, and the winding forms. The design was simple but effective and showed remarkable ingenuity. The coil winding task force did an impressive job winding seven different types of coil around the existing vacuum chambers. About 2800 coils were wound in a three-week period covering 800 m of the LER ring. The coils produce about 50 gauss with 5A. This first round of winding in the tunnel was completed in September 2000. Two thousand more coils were wound in January 2001 over 400 m. The reduction of the single beam enlargement was seen immediately, and the solenoids have been in use everyday since then. However, the gain in luminosity was not as much as had been hoped. Thus, a further round of solenoid windings is being planned to complete the arc and straight sections. The Committee recommends that these remaining solenoids be completed as quickly as is reasonable, so that their effects can be understood and used in operation.

**C) Electron Cloud Instability**

The ECI is one of the most important issues facing KEKB. Both B-Factories, PEP-II and KEKB, observe it, but the observations are rather different in detail. In particular, it appears that:

· In PEP-II, the source of electrons comes mainly from multipacting in the long straight sections, while KEKB has paid most attention to the photoelectrons in the arcs.

· The best luminosity in PEP-II was obtained with a fill pattern consisting of many short trains interrupted by mini-gaps, while the best luminosity in KEKB was obtained by a fill pattern consisting of a single long uninterrupted train of bunches.

On the issue of the source of the electrons, the Committee suggests:

a) More attention is paid to the long straights, e.g. look for possible multipacting,

b) Solenoids are added in all the remaining spaces which are available in both the long straights and the arcs (in spite of the fact that the last installation of 400 m of solenoids in the arcs did not substantially help the luminosity),

c) The possible effect of photo-electron clouds in the dipoles is studied,

d) The wigglers are tested again (compare off and on) to see if they are a source of photoelectrons.

A great amount of effort and a large number of experiments have been invested in the study of the effect of fill patterns on the ECI as well as on the luminosity. The C-yoke permanent magnets were used to reduce the on-axis cloud density before the solenoids were wound. A hypothesis that the single-bunch head-tail instability is due to wakefields caused by the photoelectron cloud was qualitatively confirmed by measuring the bunch-by-bunch vertical size along the test train as a function of (a) charge density in the bunch train with different fill patterns, (b) witness bunch intensity, and (c) the chromaticity.

Unfortunately, many of the experiments are affected both by the beam-beam effect and by ECI effects, and it has been rather difficult to sort out which mechanism is playing the dominating role under which conditions. The Committee believes that this can only be resolved by a set of carefully designed experiments, and therefore strongly encourages the commissioning team to take on this challenge. In particular, how the luminosity is limited by the beam-beam limit needs to be understood, as well as whether/how the single-beam ECI contributes to this limit. The Committee also suggests another systematic study of how long a gap must be in order to clear the electron cloud, as some of the observations seem to be too ambiguous to draw definite conclusions.

An issue that further complicated the study of ECI in the LER was an apparent "hysteresis" observed in the beam size as a function of LER beam current. As the beam current was increased during injection, the beam size increased, but when the injection stopped and the beam current decayed, the beam size decreased following a different, higher, curve. An important question is whether this is an apparent effect caused by instrumentation, or is a true beam blow-up. The Committee suggests carrying out a carefully designed set of experiments, to make sure that this observation is not instrumental. Perhaps one thing to be monitored and varied would be the injection speed.

There is a clear reduction of beam-size growth when the solenoids are turned on. However, even with solenoids turned on, a "slow growth" of beam size with the bunch number along the beam train remains. The mechanism of this slow growth is not understood and remains to be found. Candidates for the mechanism presently include: residual ECI due to ionization electrons, a high-order multi-bunch head-tail impedance instability, and non-optimal tuning of the transverse feedback. It is also not clear how this growth affects the luminosity. The correlation between the bunch beam size and the bunch-luminosity along the bunch train should be studied.

An impressive measurement of the tune shift along the bunch train was presented. It is suggested that this measurement be repeated in the slow growth mode with solenoids turned on to see if ECI might be connected to this phenomenon.

A very large chromaticity (10 units) is introduced in the LER beam to control the ECI. Although necessary before the installation of the solenoids, such a large chromaticity is no longer necessary. The Committee is concerned that such a large chromaticity could introduce an instability due to higher order head-tail modes (through either the conventional impedance instability or ECI), thus contributing to the beam size blow-up. A possibility is that a higher order head-tail instability enlarges the beam size and that could explain the loss of luminosity at low beam currents.

The chromaticity could also use up too much of the tune space because of the large chromatic tune spread taken up by the beam (for example, a particle with 3 sigma $\delta E/E$ oscillation would take up a tune space of $\pm 0.03$, which is larger than the beam-beam tune shift). This large chromatic tune spread could cause a reduction of beam-beam limit, and may make the operation sensitive to tune variations.

The Committee suggests looking for ways to substantially lower the chromaticity for colliding beams. It is hoped that this could relieve the beam-beam limit somewhat, allowing further improvement of the luminosity.

Concerning beam-intensity dependent effects other than ECI, the Committee suggests that the following actions be considered:

i) Provide instrumentation to observe beam oscillations directly using microwave detectors. Such detectors could become standard diagnostics to help understand the behavior of the beam.

ii) Measure the bunch length with a streak camera.

iii) Study the high-order head-tail beam oscillations with a streak camera.

iv) Design and install a BINP electron beam probe for direct observation of the higher-order head-tail modes in the vertical motion of the beam.

v) Measure the dependence of the closed orbit on beam intensity.

vi) Perform a study of the coherent beam-beam instability as a possible candidate to explain the beam-beam blow-up. This is recommended because the parameter range ($\nu s \sim \xi H, V$) makes this instability plausible.

Obviously, the tools recommended here can also be used to study ECI.

**D) Measurement of Photo-Electron Yield**

Experimental simulations were performed, not in the LER, but a beam line in the Photon Factory. Experimental results showed that the photoelectron emission obeys a cosine law. Three kinds of surface conditions were tested: a smooth surface, a saw-tooth surface with a 10mm pitch and a 1 mm height, and a machined surface with a roughness of 20 microns in the beam direction. The photoelectron yield on the saw-tooth surface was about 1/27 of that on the smooth surface. The photoelectron yield on the machined surface was 1/10 of that of the smooth surface. Since the high impedance of the saw-tooth surface may not be acceptable, a machined surface may be the best candidate for treatment of the surfaces of the vacuum chambers. To simulate the beam potential, an experiment was done applying +70V potential to all the electrodes except one observing electrode, but this potential deformed the electric field distribution too much. When the beam potential effect is simulated, a thin wire should be arranged in the center of the experimental vacuum duct, and used both to apply the potential and to measure the photoelectron current.

The contribution to the impedance of any corrugations of the beam pipe has to be carefully examined and included into the HOM loss calculations and in the machine impedance budget.

**E) Beam-Beam Issues**

The beam-beam effect is critical in determining the performance of all storage rings. Significant improvements in performance have been made since the last meeting of this Committee.

The peak luminosity of over 2.5 x 1033 cm-2s-1 is a remarkable accomplishment and is the result of a systematic investigation and correction of a myriad of small field errors and subtle effects which limit performance. The “tuning space” has many dimensions, few of which are independent of the others. The Committee congratulates the KEKB staff on their success in navigating this space so well.

At this time, we draw the same conclusion that was stated in the previous report: “with the beam sizes being enlarged both by single beam effects as well as by beam-beam effects, studies of beam-beam issues have been made more complicated.” The ECI causing an increase in the vertical emittance of the positron beam appears to be the dominant effect at high currents. Since the two beams can behave independently to some extent, and because of the difficulty in making vertical beam profile measurements with the required resolution, sorting out the individual beam sizes, and thus beam-beam parameters, is extremely difficult. Most conclusions must come from the BELLE luminosity measurements.

The data presented in both the main and the breakout sessions suggests that the beam-beam limit is reached at quite low currents, apparently because of the extremely small single-beam, low-current vertical emittance. The estimated values of the beam-beam parameter, $\xi$, cover the range from 0.023 ($\xi$V for electrons) to 0.052 ($\xi H$ for positrons) at the luminosity of 2.5 x 1033 cm-2s-1. The low $\xi V$ value is most likely due to the positron vertical emittance growth from the ECI, and additional beam enlargement at LER currents above 600 mA is likely to be caused by the same effect. While these values are certainly respectable, we believe that increases in the beam-beam limit will be made with further tuning and reduction of the ECI in the positron beam.

We take particular note of several experimental results:

a) Several different filling patterns, on a short time scale (1000, 1100, 100 patterns) have been tried with some effect on high current performance - the data for the 100 and 1100 patterns show lower specific luminosity. This seemed to us to be either an ECI effect or possibly a tuning effect.

b) A single run with 24 bucket spacing had a specific luminosity [*L/nb / (I+/nb* x *I-/nb)*] that seemed to join the luminosity curve of the usual HEP pattern (1000) below 0.2 mA2 but rose about 30% above the usual luminosity curve at higher peak currents.

c) Runs with varying micro-gap lengths showed negligible changes in luminosity performance, though one of the Committee members felt there was a small and possibly significant change in the luminosity along each micro-train.

d) The beam-beam simulation is in reasonable agreement with the measurements in many cases.

We have several suggestions to investigate or improve beam-beam performance:

1) Repeat the experiment of varying the length of the micro-gap, studying the vertical blow-up and the luminosity, to see if some gap widths are better. Likewise, try shortening the length of each micro-train to see if the smaller vertical beam size can be maintained for all the bunches without reducing the total number of stored bunches too much.

2) Make correlated gated luminosity and beam size measurements along the train under varying conditions to confirm that reductions in bunch-position-dependent luminosity are correlated with vertical blow-up.

3) High chromaticity may be unnecessary after the solenoid installation, and is usually found to be a hindrance to good beam-beam performance. Luminosity tuning should be carried out removing this (and any other) special condition(s) originally used to combat the ECI-engendered blow-up. Time permitting, this tuning could also be done with 24 bucket spacing to assure absence of ECI effects.

The Committee members feel that the long time constant (1-2 minute) increase in beam size at the beginning of a run may be an instrumental effect from deformation of the primary mirror of the synchrotron light monitor. We feel that this is more probable than any long time constant accelerator physics effect we could think of. One method of confirming this would be to put a rotating chopper in the synchrotron light beam ahead of the extraction mirror.

It is possible that the difficulty in shaking the electrons (using micro-gaps) could be partly due to trapping in the solenoid fields of the electrons between bunch passages.

We have confidence that with further investigation and decreases in the ECI, the beam-beam performance can be substantially increased. We also feel that the crab cavities may improve performance beyond the estimated 20% and their construction and installation should be encouraged.

**F) Optics**

Sufficient flexibility has been designed and built into the KEKB ring lattices, and this wise decision is now paying off. This flexibility allows the capability of varying beam emittance, momentum compaction factor, tunes, chromaticities, and momentum aperture over wide ranges. More importantly, it also allows a variety of beam-based corrections be made on the linear coupling, beta-beat, and dispersion corrections. The dynamic apertures of the rings have been satisfactory. Optics flexibility together with versatile beam-based corrections is the most important reasons for the luminosity improvements so far. The Committee encourages the continuation of the good work by the optics team. The next issues to address include a better beam-based correction scheme for the Interaction region (IR). The local coupling correction is particularly important in this effort, and this suggests applying the newly developed technique of Model Independent Analysis to the problem. It also suggests the exploration of a lattice for the LER that operates with wigglers turned off. The purpose is to see if this wigglers-off lattice provides a better luminosity, and whether it reduces the ECI effect.

**Orbit Corrector Analysis**

The KEKB orbit drifts rapidly, and the automatic orbit correction program runs every 20 – 30 seconds to maintain a proper orbit. The orbit corrector history contains information that can be used to identify what is causing the orbit to drift. Data for at least one week is required to cover the frequency range from 0.01 Hz to a μHz (needed to evaluate diurnal variations). By performing a Fourier transform on each corrector history file, it is possible to identify the primary frequencies of the movement. A MIKADO-like program can then be used to identify the source of the orbit movement at each frequency. The source could be an active element that acts directly on the beam (magnet, RF, etc), or a BPM that drifts and the orbit correction program then moves the orbit.

**G) Vacuum System**

Overall, the vacuum systems have been working very well, and the performance in both rings is very close to the design.

The beam cleaning process is progressing in both rings and the photo-desorption yields will surely come down to the design value of 10-6molecules/photon. The results of residual gas analysis show that the vacuum quality is also sufficient.

The reliability of the vacuum components is sufficiently high, except for the masks and some vacuum components in and near the IR. The recovery time from a planned access to replace a failed component is less than 10 hours from the start of access to the next beam injection. It depends on the good performance of a dry nitrogen venting system, but since residual gas components CO and CO2 were still large, further improvements of the venting scheme should be made.

Some components, such as the masks, bellows, and the IR vacuum chambers, were overheated. In the previous report, we suggested enhancing the temperature-monitoring system for such components. This suggestion was followed, and has proved to be very effective, saving the vacuum system from accidental failures. The bellows near the interaction point were improved by adding two additional cooling water channels and longer finger-contacts with a mechanism to limit the expansion. The stainless steel IR vacuum chamber was also replaced by a copper chamber with additional cooling channels.

There are still serious troubles with the beam masks. The mask version 4, a movable chamber type, is now working successfully. The mask version 5, with Silicon Carbide (SiC) RF dampers mounted in a fixed cylinder, is also working well at the present beam currents and looks promising for higher current operation. The revised masks should be installed as soon as possible. This issue will be further discussed in Section H.

Two kinds of non-linear pressure increments were observed in the straight sections of both rings. The first kind of pressure rise is caused by a temperature rise of the vacuum chambers due to photon irradiation, followed by thermal desorption together with photon-induced gas desorption. The pressure change showed a time lag with respect to the beam current changes. The thermal desorption was improved by replacing the original vacuum chamber with one made of copper with reinforced cooling channels. Even so, in a HER vacuum chamber, the temperature increased to 50 degrees Celsius, so careful temperature monitoring and further improvements are required for good operation.

The second kind of non-linear pressure rise was observed, in which the pressure was affected by the magnetic field in a solenoid coil. Electrons (photo-desorbed and secondary) were measured using electron monitors installed in the straight section. The observed electron current showed non-linear changes in the low-photon dose region. Based on these observations, a model was proposed in which the photoelectrons are accelerated by the positron bunch and then generate secondary electrons. The non-linear pressure changes seem to be correlated with beam size blow-up. Further observations and discussions are expected. The electron monitor will be useful in evaluation of the ante-chamber structure.

**H) Moveable Mask Issues**

Versions 1, 2, and 3 of the movable masks are being abandoned because of problems. These problems have included sliding spring fingers that arc, and overheating and cracking of SiC absorbers due to absorption of higher order mode (HOM) RF power. Another problem has been melting of the absorber surface, made of either W-Cu or Cu, by the beam. Except for the masks near the IR, the Committee suggests that the last of these issues be addressed by shorter absorbers.

Version 4 of the movable masks addresses these issues by greatly reducing the amount of HOM power generated. This is accomplished by using a vacuum chamber of approximately constant cross section, and of displacing it gradually along z to move the beam from the center to a location near one edge of the chamber, and back. Problems that may exist with this version include continued melting of the surface by the beam, and heating of bellows. A back-of-the-envelope estimate of the fraction of the stored beam energy that needs to be deposited in the copper to cause the observed melting is of the order of magnitude of 10% of the currently stored beam (around 600 mA). It seems odd that the beam excursion that causes the surface melting is in the vertical direction as the number of mechanisms that can abruptly kick the beam in the vertical direction is limited. It was reported that simulations show that the beam can be blown up vertically if a cavity trips off. There were also indications that the beam abort system may not always abort the beam within the intended time period. It is essential to understand what is causing the beam to abruptly strike the masks, and to either eliminate this phenomenon or ensure that the beam is reliably aborted before it reaches the mask. This is especially important in view of the proximity of the water channels to the surface. Regarding the heating of the bellows, it was suggested in the presentation that this might be caused by scattered synchrotron radiation or absorption of part of the HOM power that is produced. Calculation of these effects would yield valuable insight regarding the heating that would occur at higher beam currents. Minimization of the frequency with which these masks are moved, to avoid damage to the spring fingers, would be advisable. Another phenomenon that should be calculated to ensure that it is not a serious issue is the current-dependent and intra-bunch dependent transverse kick caused by having the beam effectively off-center in the chamber.

Version 5 of the movable masks incorporates the ingenious approach of attacking the earlier problems head-on, instead of trying to prevent them. Version 5 allows the generated HOMs to enter the space between the movable mask support and the vacuum envelope, rather than attempting to keep them out using spring fingers. To avoid resonances in this space, the HOM power is absorbed by a 10 kW SiC absorber. This version of the mask appears capable of avoiding a variety of earlier problems. The issue of preventing the beam from abruptly striking the mask still exists, but the other problems appear to be adequately solved. Some things that should be checked, to ensure that the associated problems are adequately under control, include verifying that the absorption rate of the SiC with distance along the coaxial line is sufficiently frequency-independent that the rating remains 10 kW for the HOM frequencies of interest. Not all of the HOM power generated by the mask, the amount of which will be larger than with version 4, will enter the coaxial line and be absorbed; some of it will propagate down the beam pipe. It should be checked that the amount of such power propagated, and the region where it will be absorbed, is acceptable. Also, the current-dependent and intra-bunch dependent transverse kick caused by having the pass close to an obstruction on one side should be calculated to make sure it is not a serious issue. Each type of mask should be characterized for the current-dependent tune shift as the vertical masks approach the beam.

**I) RF System Overview**

At present, 16 ARES cavities (two of which are not in operation) are installed in the LER. Four additional cavities are ready for installation when required to bring the total to the design number of 20. The HER is at present equipped with 10 ARES cavities (all are in operation) and two more are to follow. All 8 superconducting cavities foreseen for HER are installed, although only 6 are in operation.

As a whole, the entire RF system continues to perform very well. It does not limit KEKB performance in any way, and the time lost to physics due to RF troubles is quite low (70 hours in 8 months, including a major repair). An RF trip rate of one per day is reported. The beam frequently survives the RF trip; the beam is aborted due to RF trips about once per two days.

It should be borne in mind, however, that the usable beam currents in both rings are still well below the design values of 2.6 A and 1.1 A for the LER and HER, respectively. However, no fundamental difficulties are expected, since both types of cavity have been tested at beam power close to (ARES) or above (superconducting) the design.

The maximum current capabilities of the present cavity design should be evaluated in relation to any upgrade plan calling for higher currents.

**J) ARES**

As was to be expected, a few faults and problems have occurred during initial operation. One cavity developed a persistent pressure rise with RF power, probably due to a small leak at the connection of the coupling cavity to the storage cavity. The unit had to be left inoperative since November 2000, and will be repaired or exchanged in the summer shutdown. Arcing caused an input-coupler window failure and leak, which remained unobserved. Two serious leaks from water to vacuum occurred in connection with RF windows (one input and one damper window in the same cavity). This was caused by corrosion of the copper water channels, apparently due to the presence of molybdenum wire (back-up support of brazing) in cooling water not sufficiently free of dissolved oxygen. The Committee supports the efforts to eliminate this problem, both by eliminating the molybdenum and preventing the water from being exposed to oxygen.

After two years of operation, the occurrence of problems like these in a new system is perfectly normal, and they had no significant impact on operations so far (35 hours for coupler replacement).

**K) Superconducting Cavities**

Between 4 and 8 superconducting cavities were used in the HER of KEKB since November 1998. These cavities have operated with up to 650 mA of beam current and with up to 380 kW each transferred to the beam. The HOM power generated and successfully damped has been up to 4 kW per cavity. It is found that the cavities do not trip when their vacuum is good, and trip a few times per week when their vacuum is poor.

The cavities have been quite reliable, particularly in view of the high performance demanded of them. Problems that have been encountered have fallen into three categories: vacuum seal failures, cable failures, and coupler failures. Vacuum seal failures are not unique to superconducting cavities, and seem to be a phenomenon that can be minimized but not eliminated. The cable failures were caused by “walking” of the center conductors with thermal cycling; KEK has addressed this issue by using a connector that captures the pin at one end of the cable, which should eliminate this problem. The coupler failures appear to have resulted from processing necessitated by the vacuum seal failures, and do not represent an intrinsic problem with the couplers.

In summary, the superconducting cavities have performed very well, and the system will be ready for higher beam currents as soon as the present problems are corrected. Construction of a replacement test stand is essential to restore the capability to test these cavities off-line.

## L) Beam Instrumentation and Bunch by Bunch Feedback Systems

### Beam Position Monitors (BPMs)

A progress report on beam position monitors, synchrotron radiation monitors and bunch-by-bunch feedback systems was presented.

The resolution of the BPMs was determined by the 3-BPM correlation method and average is 2 – 4 μm for beam currents larger than 10 mA. Certain BPMs were noisy, and the cause was identified to be pick-up of HOM signals where the waveguide cut-off frequency of the vacuum chamber is less than 1 GHz (mostly in or near the IR). Changing the BPM receiver detection frequency from 1018 MHz to 509 MHz cured this problem. This naturally makes the receivers more sensitive to RF system leakage at low beam currents, but the slightly poorer resolution observed in the neighborhood of the RF straight sections is not dramatic, and an overall improvement was achieved. However, the BPMs near the IR are still much noisier than the rest of the BPMs.

The electronics of the ongoing conversion of 120 BPMs in each ring into dual mode (COD/single-pass) operation was presented. Although not strictly essential, this system is certainly useful to pinpoint injection troubles and speed up injection tuning.

### Synchrotron Radiation Monitors

The synchrotron radiation monitors are working well. The surface distortion of the extraction mirror due to synchrotron radiation heating has been measured using a multi-hole array screen.

The change of magnification factors versus beam current due to extraction mirror deformation was measured using a moveable single pinhole mask. The moveable mirror feedback, which compensates for variation in extraction mirror tilt has been commissioned, and resulted in a smaller variation of the calibrated magnification versus current.

A strange and very slow hysteresis in vertical beam size versus current has been observed in the LER. Some of this hysteresis may be due to thermal effects of the extraction mirror, but at least a part of this strange phenomenon may be real as it has also been observed as a corresponding change in lifetime, and the effect also appears at very low currents where the thermal effects are small.

The high-speed gated camera has been very useful for measurement of bunch-by-bunch beam size in particular in the LER, which is troubled by ECI.

**Transverse Bunch-by-Bunch Feedback Systems**

Many improvements have been added to the transverse bunch-by-bunch feedback systems, in particular:

i) Two tap filters cancel the DC component, reducing the likelihood of saturation and making operation easier.

ii) Lower frequency kicker systems have been included in the feedback loop for both rings.

iii) Remote control of many signal switches has been added, for example, switching between selected bunch tune and global tune measurements.

The bunch-by-bunch tune measurements have been very useful to measure the tune shifts versus bunch number in a bunch train in the LER.

Since no low-frequency coherent signals associated with the ECI have been observed within the bandwidth of the transverse damping system, there is not much hope to damp these instabilities with the transverse bunch-by-bunch feedback systems.

There have been frequent breakdown of transverse damper power amplifiers, although none since October 2000. CESR has had problems of slow degradation of output transistors due to reverse propagation of HOM power into the output of the amplifiers. They have cured the problem with passive low pass filters inserted between the power amplifiers and the stripline kickers.

The longitudinal bunch-by-bunch feedback system for the LER is available and could be commissioned with short notice if needed. However, present currents are below threshold with the exception of coherent longitudinal coupled-bunch modes driven by the undamped trapped mode in early version of the moveable masks.

**Photoelectron Monitors**

Photoelectron monitors have been installed both in the arc and in a long straight section. They have permitted valuable observations of the energy spectrum and quantity of the photons collected versus beam current. The energy distribution agrees well with the Zimmerman-Ohmi model. Both AC and DC electron currents have been measured and a wealth of valuable data has been collected.

The observation, cures and understanding of the ECI in the LER are probably the most urgent issue for KEKB. While the present Zimmermann-Ohmi model explain most of the observed behavior for short bunch trains, it does not explain all of the observed behavior.

It is therefore disturbing that so far the high frequency coherent dipole motions predicted by the Zimmermann-Ohmi model have not yet been directly observed. Streak camera observations have not yet identified such a coherent dipole motion in LER, although observations in LEP of a high frequency head tail mode was successful. However, the LER bunches are much shorter than in LEP.

The Committee recommends building a high frequency transverse electromagnetic pickup (say 30 – 40 GHz) to look directly for coherent betatron lines at microwave frequencies using a spectrum analyzer. Elsewhere, very sensitive transverse stochastic cooling pickups have been designed up to 16 GHz and have performed well. In LER, sensitivity is not as much an issue as the dynamic range. This implies good suppression of undesired common mode signals and damping of parasitic propagating modes in the neighborhood of such a pick-up.

Another option could be a profile monitor using deflection of a probe electron beam. Such a device has been developed at BINP, Novosibirsk.

**M) BELLE Status**

The BELLE detector is now operational. The approximately 11 fb-1 delivered through December allowed the experiment to collect 11 million B-Bbar pairs. This data set supported an initial measurement of the CP violation parameter sin$2\phi$ and two papers have been submitted for publication. The measured value of sin$2\phi$ is consistent with the inferred value based on other independent measurements of CKM matrix elements. It was stated that a data set approximately four times as large as the current set, i.e. about 50 fb-1, would be required to start placing meaningful constraints on the CP violation as predicted by the CKM matrix.

The experiment expressed a desire to integrate 500 fb-1 by 2005. A minimum desired integrated luminosity profile was presented as follows:

2001 25 fb-1
2002 50 fb-1
2003 100 fb-1
2004 200 fb-1

It is believed that the silicon detector will have to be replaced after about 100 fb-1 of integrated luminosity, i.e. in late 2002/early 2003. The proposed new silicon detector would feature improved resolution as well as radiation hard silicon. The desire to get the inner silicon layer closer to the Interaction Point (IP) would necessitate a reduction of the beam pipe radius, perhaps by a factor of two, relative to the current 2 cm.

The Committee offers the following comment relative to BELLE and coordination with the accelerator staff. (Related comments may also be found in the sections on “Overview of Commissioning”, “Interaction Region Chamber Upgrade”, and “Long-Term Upgrade Plan”.) :

1. The expectations of the experimenters are not entirely consistent with the views of accelerator staff on what collider performance they may be able to deliver. We believe that the laboratory would benefit from the development of an initial plan for operations and luminosity improvement through the period 2001-2005. The needs of both the experimenters and the best judgment of the accelerator staff as to what upgrades are feasible should be reflected in this plan. The plan should identify in a preliminary way the needs for major access time required either for accelerator or detector upgrades during the period, and align them to minimize overall downtime.

2. The experimenters have identified a number of issues, for example stability of the beam energy, the resolution of which could improve the quality of their data. The accelerator staff is encouraged to work with the experimenters to identify and resolve such.

3. The Committee encourages the BELLE collaboration to continue to work to shorten the detector turn-on time in order to improve the utilization of machine luminosity.

**N) Linac**

The Injector Linac has routinely provided three different beams to four different rings over the past year. The number of injections is about 40 per day, each taking 1-5 minutes. This requires very high machine stability and beam reproducibility. The Committee is very impressed with their dedicated work and accomplishments.

The injection rate for positron beams is 1.3-1.5 mA, which is the design value. On the other hand, the injector group introduced the two-bunch acceleration scheme, and they obtained test results of 0.45 nC for the first bunch and 0.42 nC for the second bunch. This scheme would almost double the injection rate, and the injection time would be reduced by one-half. Since the linac frequency is not a harmonic number of the LER frequency, the best time interval between two bunches is 96.29 ns corresponding to 49 LER-buckets. Even with this limitation, it is undoubtedly a very useful scheme for increasing the positron injection rate.

This Committee would like to congratulate the injector group on their success and for keeping the machine in a stable condition with limited machine study time. The Committee also recommends evaluating all the options that would make the two-bunch injection scheme compatible with colliding beams in the LER. This could involve doubling the spacing between the two bunches or using a different bunch pattern in the LER.

**O) Beam Transport Issues**

The efficiency of electron injection into the HER has been greatly improved from 30-40% last year to the present value of 80-100% by removing one of the masks in the IR region.

The low positron beam transmission (about 65%) in the beam transport line has been studied seriously. It is due to the loss of the low energy tail at the Energy Compression System (ECS) bends. A plan to further improve the ECS system (to add a small dipole after the first ECS bend, which serves as an energy adjuster, and to replace the bend chamber with a wider one) is under consideration. The Committee would like to recommend that the KEKB team build and install this scheme as soon as possible to quickly increase the transmission efficiency of the positron beam.

**P) Controls**

The EPICS based control system has performed effectively during the KEKB commissioning and initial operation. The controls group has traced a subtle hardware design fault to commercial hardware and has informed the manufacturers.

The control system upgrade will facilitate communication with the Photon Factory (PF) and the Accumulation Ring (AR). This appears to us to be a positive benefit.

The EPICS control system software has been used productively in many accelerator laboratories around the world, and KEKB has effectively incorporated EPICS in the control of the accelerators. We encourage KEK to share this experience with neighboring institutions.

**Q) Interaction Region Overview**

The superconducting IR quadrupoles have continued to operate very reliably. The interlock system and the power supplies have been improved. The nitrogen shield and the oxygen extraction system for the cooling water of the interaction region recommended by the Committee in the last meeting were installed, which should prevent a blockage similar to that which had led to an overheating of the QC1LE coil in December 1999. Additionally this magnet is now protected by an improved burnout protection system.

A movement of the QC1RE magnet by 0.02 mm has been observed, and is probably heat related. Other magnets should also be investigated to see whether they suffer similar movements, for example, slow closed orbit changes could be analyzed. These could then be correlated with slow changes in the LER vertical beam size. A singular value decomposition of the rectangular matrix of BPM readings versus time can be a good tool for this analysis.

Vertical vibration amplitudes of 0.0001 mm and horizontal temperature dependent drifts of 0.002 mm were reported for the IR quadrupoles. These vibration amplitudes seem to be tolerable.

**R) Background Issues**

BELLE is operating with a background significantly below the initially expected level, and is presently about 50% of the acceptable level. KEKB can be congratulated on this achievement.

The LER background was originally almost exclusively produced by particles from bremsstrahlung in the LER. Last year, the Committee suggested deliberately creating bad vacuum locally at several places around the ring to determine which region is the dominant source of bremsstrahlung background. The background would then benefit from improved pumping in these regions. These studies were carried out and local pressure bumps at 4 regions in the LER and at 7 regions in the HER were analyzed. The regions at the end of the arcs in both rings were found to contribute most to the bremsstrahlung background in BELLE. Additional pumping in these critical regions has not been installed so far. However, the vacuum in the LER has improved due to beam scrubbing, so that at least 50% of the background now seems to be produced by particles that are lost by Touschek scattering.

It is important to analyze whether Touschek scattering is really the dominant background, since this could impose a minimum beam size and thus limit the luminosity. The RF voltage or the vertical emittance should be varied to verify that the background change is in agreement with Touschek scattering. Furthermore, it is advisable to simulate the particle loss in the detector expected from Touschek scattering, and to compare it to the measured background rates.

The background from the HER was initially dominated by backscattered x-rays from the downstream HER region. Changing the aluminum beam pipe in the critical region to a copper pipe, together with a gold coating of the IP beam pipe, reduced this background by a factor of 10. It is still dominated by lost particles from bremsstrahlung. Improved pumping at the end of the upstream arc and in the straight section would reduce this problem. However, the vacuum in the HER is still improving with time and the HER background will therefore continue to decrease.

The correlation between sudden increases in the electron beam size and sharp rises in the HER background are indications of a tight vertical aperture. The planned optimization of the IR masks should reduce this problem. However, the impact of the planned decrease of the IP beam pipe diameter also has to be taken into account. Operation with higher currents can enhance the tails of the transverse beam distribution so that aperture limitations become more relevant. A study of beam tails can clarify whether an increased background has to be expected.

In BaBar, about 10% of the beam pipe heating is proportional to the product of the two beam currents. Since this contribution can become serious when the bunch length is reduced, the dependence of the heating on the product of the two beam currents should be investigated at

KEKB.
Since the background levels are a factor of 2 lower than what is acceptable for BELLE, it is worthwhile trying to reduce the horizontal beta functions at the interaction point while keeping the background at an acceptable level.

**S) Interaction Region Chamber Upgrade**

The BELLE Collaboration would like to change the vacuum chamber at the KEKB collision point in about two years. At the same time, they would also like to increase the number of layers of the SVD and to replace the (by then) damaged inner layers of the drift chamber. They have designed a new beryllium vacuum chamber and adjacent vacuum chambers to go with these new detectors. The radius of the new chamber will be 1 or 1.5 cm with double 0.5 mm walls to allow for a cooling fluid PF200.

The design group has done an excellent job studying the expected backgrounds from synchrotron radiation and from lost particles. The simulations agree well with those measured in the present accelerator. The extrapolations have been made to the full design currents of KEKB. The resulting design of radiation masking should provide adequate protection.

They have also studied beam-heating issues. The heating comes from HOM and I2R power from the beam. They have made an estimate of the total power and have checked that the new beryllium chamber cooling can handle it. However, the present chamber has a particularly strong mode which is excited by a particular bunch spacing and thus, the chamber can be overheated. This mode is not yet understood. Thus, all the calculations of the mode contributions to HOM heating should be rechecked with the hope that the offending mode is understood and avoided with the new chamber. Perhaps, a longer distance along the accelerator can be included (e.g. out past the beam separation crotches) so that all modes and transitions can be included. In addition, the cross term HOM fields from the two beams should be studied.

No discussion of the beam-stay-clear issues was presented, and the Committee suggests that the accelerator group agree to all dimensions long before construction starts. In addition, the nearby vacuum chambers in both rings should be rechecked to ensure that they are compatible with the full design beam currents.

**T) Crab Cavity Development**

Good progress has been made on the development of the crab cavity system. The priority of this development program is not considered extremely urgent since a dramatic degradation of luminosity due to the IP crossing angle has not been observed. A full-scale superconducting prototype has exceeded the design deflecting field with an adequate margin, and this has even been achieved with the coaxial damper of the fundamental mode installed.

The design and manufacture of the horizontal cryostat is progressing, and the Committee was told that, if needed, the full system could be installed in 2003.

Recent strong-strong beam-beam simulations indicate the luminosity could be expected to increase by about 20%.

For an initial test, the bunch crab motion does not need to be compensated downstream of the IP (local crab motion), which implies that the crab motion could be driven by a single cavity at any appropriate location in the ring which avoided long cryogenic line. This means that head and tail of the bunch have slightly different orbits around the ring leading to a global crab motion. The details of this option should be further studied in view of initial test of a prototype crab cavity. Since no operational experience with a superconducting crab cavity in a collider is available yet, there is obviously a certain risk that such a crab cavities turns out to be difficult to operate. Nevertheless, since the expected luminosity gain is considerable, the Committee recommends continuing the crab cavity development, and initially installing a single crab cavity to confirm the expected gains and to gain operational experience. If the results are positive, the decision could be made to install either one cavity per ring or the full four crab cavity system near the IR.

**U) Plan for the LER Ante-Chamber**

New vacuum chambers with antechambers are being considered for KEKB for use in the arc sections of the LER, with the hope that they will significantly reduce the effects of the ECI on the positron beam. The design is still in the early stages where all the effects are trying to be included. Overall, the design looks feasible and should work. If approved, this project is a sizable construction effort. The Committee recommends that the completion of the beam chamber solenoids be done first to see if that is sufficient for the cure of the ECI issue.

There are several overall design parameters to be decided. For example, the maximum current that these chambers are designed to handle must be decided carefully, as these chambers should probably be able to handle future upgrades to the beam currents. The chamber material is copper but vacuum loading could well make the walls too thick. Cooling channels on the chambers will likely be needed in the quadrupoles and the sextupoles. New vertical corrector magnets need to be designed and built, as the chamber is significantly wider. The photons from the fringing fields of the dipoles should be handled separately in the calculations. The effect on the vacuum chamber design of changes in the vertical closed orbit should be checked. Finally, the circular beam channel can promote multipacting and the chamber shape should perhaps be different.

The Committee suggests that, as soon as this upgrade becomes a likely project, a prototype chamber be built and installed in KEKB to be tested with beam. Finally, if the particle type is changed, then the antechamber should not be built for the LER, but rather for the HER.

**V) Long-Term Upgrade Plan**

The possible components of a long term upgrade strategy have been identified and consist of:

1. Completion of solenoid windings in the LER.
2. Tuning and optimization of the KEKB collider within its current configuration.
3. Installation of crab cavities in both rings.
4. Installation of a new beam pipe in the LER featuring an ante-chamber, or
5. Swapping electrons and positrons between the LER and HER.

The last two of these represent very significant modification to KEKB, entailing both a significant resource investment and considerable downtime. The impact of each of these improvements on luminosity performance is not well quantified now. Goals associated with each of these were presented however, the net effect being an increase in luminosity to 81 $fb^{-1}$/year by about 2004. This vision is considerably less aggressive than the vision presented by the experimenters (see

“BELLE Status”).

The Committee recommends the following:

1. Write down parameter lists that are consistent with operations in the range 1-2 x 1034cm-2s-1 based on current performance and possible upgrades. Evaluate potential upgrades within the context of effectiveness in achieving performance required to support this luminosity.

2. The question of whether performance could be enhanced by running electrons in the LER and positrons in the HER is a key to evaluation of future upgrades. Such a change in operations would be quite significant and costly. The Committee recommends that before committing to such a change the laboratory undertake an experimental study of high intensity electron operations in the LER. The purpose of such a study would be to confirm that the LER can support electron operations at currents required for future operations.

**Appendix A**

**KEKB Accelerator Review Members**

Andrew Hutton JLab Chairman
Alexander W. Chao SLAC
Eugene A. Perevedentsev BINP
Masanori Kobayashi KEK
Won Namkung Postech
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Wolfgang Schnell CERN
John Seeman SLAC
Ronald Sundelin JLab
Georg Hoffstaeter DESY
Wang Shuhong IHEP
Stephen D. Holmes FNAL

**Appendix B**

**Agenda of KEKB Accelerator Review Committee**

February 23 (Friday)
9:00-10:00 Executive session
10:00-10:20 KEKB overview S. Kurokawa
10:20-11:00 Overview of commissioning K. Oide
11:00-11:20 Solenoid winding K. Hosoyama
11:20-12:00 Photo-electron and other Instabilities H. Fukuma
12:00-12:10 Measurement of photo-electron yield Y. Suetsugu
12:10-13:00 Lunch
13:00-13:30 Beam-beam issues Y. Funakoshi

13:30-14:00 Optics issues H. Koiso
14:00-14:30 Vacuum issues K. Kanazawa
14:30-15:00 Movable mask issues Y. Suetsugu
15:00-15:20 Break
15:20-15:35 RF system overview E. Ezura
15:35-15:50 ARES T. Kageyama
15:50-16:05 SCC S. Mitsunobu
16:05-16:45 Beam instrumentation S. Hiramatsu
17:00-18:20 Executive session
18:30-20:00 Reception

February 24 (Saturday)
8:30- 9:00 Executive session
9:00- 9:30 BELLE status F. Takasaki
9:30-10:00 Linac Y. Ogawa
10:00-10:15 BT issues T. Mimashi
10:15-10:35 Controls T. Katoh
10:35-10:45 IR overview K. Tsuchiya
10:45-11:05 Background issues J. Haba
11:05-11:25 IP chamber upgrade issues H. Yamamoto
11:25-11:50 Crab cavity development K. Hosoyama
11:50-12:10 Plan for ante-chamber K. Kanazawa
12:10-12:30 Long-term upgrade plan K. Oide
12:30-13:30 Lunch
13:30-18:00 Executive session
18:00-20:00 Working dinner

February 25 (Sunday)
8:30-11:00 Executive session
11:00-11:30 Interaction with KEKB staff members
11:30-12:00 Closing