KEKB Accelerator Review

Introduction

An international advisory committee to review the KEKB accelerator design and status of development and construction was appointed by Chairman of LCPAC (Lepton Collider Program Advisory Committee) in March of 1995. The membership of this committee is shown in Appendix A.

The review meeting for the KEKB-facility took place between June 7 – June 10, 1995 at KEK. This meeting consisted of a number of oral presentations by members of the KEKB-project and discussions by the committee. The program of the first two days with the oral presentations is shown in Appendix B. A first draft of the design report for the KEKB-accelerator had been made available to the members of the review committee shortly before the meeting. This first draft of the report of the KEKB Accelerator Review was discussed by the committee on June 9 and 10. An improved version of the report was then mailed by e-mail to the committee members and after some more corrections finalized in July. This then constitutes the final version of the report by the international advisory committee on the KEKB accelerator design and status of development and construction.

Contents

Executive Summary

B-factories belong to a new generation of e^+e^- colliders that exceed in many aspects known performance data of existing electron positron colliding machines by large factors and present a real technical challenge: The desired luminosity of $10^{34}cm^{-2}s^{-1}$ in B-factories is by a factor 50 higher than that of highest luminosity in presently existing e^+e^- storage rings.

The large luminosity values can only be reached by the use of two separate rings, each filled with very large number of positron and electron bunches, respectively. The resulting circulating positron and electron currents of a few Amperes are larger by factors of 10 to 100 compared to those in existing e^+e^-colliders.

Not only that two separate rings must be used in B-factories (something so far not of successful use in any e^+e^-colliders), but these two rings also have to be operated at two quite different energies (3.5 GeV and 8 GeV, respectively) for purposes of B-meson identification.

The resulting interaction region design is very complicated, particularly in view of large backgrounds possibly produced by synchrotron radiation from beam magnets close to the interaction point.

The large circulating currents produce synchrotron radiation power in the MW-range, resulting in big technological problems. But even more significantly the conpensation of these power losses of the beams by high power RF systems requires novel approaches to the technology of RF-acceleration.

Beam instabilities of the high current multi-bunch electron and positron beams become some of the most worrisome and important aspects of the successful operation of a B-factory.

Powerful injection systems are necessary to maintain large average luminosities.

The KEKB-design approaches these challenges in a bold and highly original way.

The most salient new features are:

1) A crossing beam geometry at the interaction point to relieve the design constraints at this highly complex machine intersection area and at the same time reduce greatly synchrotron radiation background problems.

2) A novel optics for the arcs (2.5π-lattice) which gives great flexibility for important machine parameters (e.g. emittance, momentum compaction) and through a non-interleaved sextupole chromatic correction scheme reaches unusually large dynamic apertures.

3) A highly original acceleration scheme (ARES) which combines a higher-mode-damped accelerating cavity with a large low-loss storage cavity for better stabilization of large circulating beam currents.

4) A rebuilding program for the existing 2.5 GeV injector linac to boost its top energy to values higher than 8 GeV (the electron energy of KEKB) while also increasing the positron yield at 3.5 GeV (the positron energy of KEKB) by more than one order of magnitude.

The committee was impressed by the originality of these design features and wants to congratulate the KEKB team for their inventiveness and thorough work. It concurs with all of the major design decisions but would like to add some cautionary words:

1) There is no evidence that the chosen crossing beam geometry at the interaction point will not work but there is also no proof as yet that beam lifetime problems can be safely excluded. The continuation of a vigorous program to investigate the beam-beam interactions in this crossing beam geometry and the continuation of development work on fall-back-solutions (crab scheme) is strongly recommended.

2) There is good reason to expect the ARES-RF system to be highly satisfactory, but the superconducting cavity approach under development at KEK must still be considered a viable alternate solution and work on its development should be continued.

3) Positron filling times seem to be sufficient, though not by a large margin. The committee would feel more comfortable if the option of using the accumulator ring in the filling scheme for KEKB would not have to be foreclosed until satisfactory injection rates have been verified.

4) There are number of other potential problems such as ion and photoelectron instabilities which are described in the body of the text and warrant intensive study.

The committee feels that the proposed design presents a solid basis for the B-factory and is confident that the design objectives can be met.

Findings and Recommendations

A. Parameters, Lattice and Errors

The KEK B Factory relies on getting high luminosity $10^{34}cm^{-2}s^{-1}$ and this is a rather difficult goal that will not be achieved without considerable effort. The committee believes that the parameter list is a good compromise between the conflicting requirements and will eventually provide the desired luminosity.

The beam currents are high (2.6 A and 1.1 A) and are significantly greater than the currents routinely used in other accelerators. The number of bunches is also high (5000) but the individual bunch currents are small. This means that multi-bunch effects are expected to be more serious than single-bunch effects.

In order to bring the beams into collision at the interaction point without additional parasitic collisions nearby, a crossing angle of +-11 mrad is planned. The committee concurs with this choice while recognizing that there are still many unanswered questions. There are still a lot of theoretical studies which can be done to increase confidence in this choice and these are discussed in the section on beam-beam effects. The committee fully supports the continued development of the crab crossing cavities as a back-up and recommends that space be reserved for the cavities in the ring at the required positions. This is particulary so because there are still questions that will only be addressed when the machine is being commissioned.

The committee recommends that the machine commissioning be addressed in phases, focusing on the different problems in sequence. The committee suggests that the project leader develop a strategy for the commissioning which also provides an estimated schedule. This can then be used to plan the installation of the components in a coherent fashion, consistent with funding constraints. The possibility of single beam (LER) operation ahead of HER completion should also be investigated as part of this strategy. The strategy should also include the time needed for the detector to optimize data taking to fully take advantage of the luminosity available.

At this stage it is unclear how best to optimize the collisions in the initial stages of the machine commissioning. On the one hand, if the detector is out of the way, temporary diagnostics can be installed at the interaction point. These can be used to cross-check the luminosity optimization algorithms (this was the technique adopted at SLC where a moving wire monitor was installed at the interaction point during commissioning). On the other hand, there is an advantage in getting an early look at all of the problems inherent in the machine/detector interface and this would be best accomplished with the detector in place right from the start. The committee recommends that the project leader evaluate whether this phase is best accomplished with the detector in the ring or out of it.

The committee was extremely impressed with the 2.5π lattice. The final phase of the commissioning will require a very careful optimization of all of the beam parameters in order to maximize the luminosity and the background in the detector. Obtaining the desired tune shift may prove difficult, but obtaining the required specific luminosity should be possible if there is sufficient flexibility designed into the lattice. The possibility of varying the momentum compaction factor and the emittance independently is extremely elegant and will be vital to achieving the ultimate performance from the machine. The lattice also provides a large dynamic aperture compared to the injection requirements and this will also help improve the backgrounds.

The optics design of the interaction region included the possibility of doing local correction of the chromaticity in the LER. This makes a considerable improvement in the dynamic aperture of the ring. These studies should be continued to include a de-tuned beta configuration for the initial commissioning. The tracking studies should be continued to include errors in the interaction region quadupoles to develop tolerances which can be used by the magnet designers.

For optimum beam-beam interactions, it is assumed that both rings have identical fractional parts of the betatron tunes i.e. 0.52, and 0.08. The possibility of coupling between the two rings via the beam-beam interaction will reduce the threshold for transverse multi-bunch instabilities. The tune separation required to eliminate this effect should be studied and compatibility with the beam-beam interaction evaluated. This question is closely related to the space available in the tune diagram discussed in the beam-beam section.

There is an extremely high premium on achieving small vertical beam size. It would be desirable to make an analytical estimate of all the contributions to the vertical emittance as a function of the mean vertical orbit error in the sextupoles and as a function of a mismatch of the solenoid compensation. This would also be useful if smaller coupling would be desirable e.g. if the background in the detector requires larger horizontal beta function at the interaction region. The need for active coupling control (skew quadrupoles) needs to be investigated.

The committee recommends looking at improved alignment techniques to perform smoothing of the local vertical misalignments and performing a simulation of the alignment procedure (including beam-based alignment) to estimate correlated and non-correlated errors. Beam-based alignment is the key issue to realizing the merits of the 2.5π cell. The committee encourages further study and development of the beam-based alignment algorithm and particularly encourages taking advantage of light source operation of TRISTAN this autumn to make practical studies. The time taken for the beam-based alignment should be estimated as well as the frequency that the procedure will have to be carried out. This estimate should be used to decide if the beam position read-out is fast enough. The use of independent observation tools for alignment in the experimental and RF halls should be looked into.

The optical tolerances for the crab cavity system should be evaluated, i.e. how precise the phase advance of $\pi/2$ between cavity and interaction point can be achieved and how different the beta values at the cavities are likely to be. These tolerances should be compared with simulations for crab crossing with imperfections. There are also tolerances on the RF system for the crab cavities which need to be examined.

The dispersion correction algorithm should be studied including the tolerances for the errors of the interaction region magnets.

B. Beam-Beam Interaction

The IR geometry is such that if the beams cross at an angle > 8 mr, there is no need of separation dipoles in the IR. This allows substantial simplifications of the IR design. The KEKB design has adopted this approach and the crossing angle is nominally set at 11 mr. The disadvantage of this approach is the crossing angle excites synchro-betatron resonances. In efforts to minimize their effects, KEKB has chosen a small synchrotron tune, and a set of crab cavities have been considered as a backup cure if needed later in actual operations.

The beam-beam interaction with crossing angle has been taken seriously by the KEKB design team. So far all studies have been carried out using simulations. A sophisticated 6-D computer code has been developed for this purpose. The committee concurs with this general approach of crossing angle and suggests to proceed as planned. It also suggests that more studies (described below) be carried out to optimize the design.

In particular, it suggests to simulate the lifetime effects. Many simulations have been done for KEKB. In most cases the luminosity was considered, i.e. particles in the core of the bunch were simulated. These simulations have shown that there are strong limitations in the tune diagram but that there is still place for a working point. Furthermore it was shown that there is no large difference for the luminosity simulations with a linear lattice or a nonlinear lattice. This is plausible since the nonlinearities will notaffect particles in the beam core.

Simulations for large amplitudes have not been done to the same extent as for the luminosity study. The maximum amplitudes which occurred during one or two damping times were observed for initial gaussian distributions of 50 particles. Then the largest initial amplitudes were in the order of three or four sigmas. A few simulations were done for initial amplitudes of six sigmas which led to maximum amplitudes of 20 to 25 sigmas. All the simulations with large amplitudes were done only with a linear lattice and not yet with a nonlinear lattice and machine errors.

The experiences with DORIS I and also old simulations have shown that the synchro-betatron resonances due to the crossing angle first of all reduce the lifetime whereas the specific luminosity is less affected. Since the lifetime is the crucial point the horizontal acceptance of the machine is of great importance.

We propose therefore to do more simulations for particles with large amplitudes and for a realistic lattice. Nonlinearities, solenoids, and machine errors (in particular those in the IR, which can cause off-centered collisions) should be included. Since the width of the resonances is narrow ($<10^{-3}$), one should scan the tune diagram in very small steps. One should also apply more sophisticated methods (Irwin, Shatilov, etc) for simulations of the tails of the beams which allow an approximate determination of the lifetime.

It is suggested that careful evaluation of working point choice be carried out. The choice of working point should take into account the beam-beam effect with crossing angle and the dynamic aperture effect. It is also suggested to avoid operating too close to half-integer resonances if at all possible.

Effect of tune ripples (10^{-3}) should be included in the evaluations of lifetime and choice of working point.

Some efforts have been made in terms of a quasi-strong-strong simulations. These simulations however would not exhibit all the important strong-strong effects. It is suggested that the simulations of luminosity optimization take into consideration the strong-strong effects.

C. Magnet System

The magnet systems needed for both the LER and the HER have been specified and designed. It is fortunate that a good fraction of the TRISTAN magnets can be reused for the HER. The field quality of these magnets is good enough to be used for KEKB. It remains to be decided whether the coils have to be replaced.

The TRISTAN tunnel is large enough to install the LER and the HER side by side. An installation scheme has been presented showing that both machines can easily be installed within the allotted schedule. However, as remaining lateral space in the tunnel is only 1.1 m, the potential future replacement of a magnet may need special tooling and effort. The installation procedures and sequence plan including replacement and repair work should be developed.

For the horizontal correction magnets needed in the HER the committee recommends not to use backleg windings on the dipole magnets due to annoying hysteresis effects. Furthermore, additional optics correction studies should be done to determine if every quadrupole needs a vertical corrector nearby.

D. Vacuum System

The layout of the vacuum system is already well advanced. The design of the integrated NEG pump system is especially elegant. The use of copper chambers is considered a good choice for KEKB.

The beam based alignment technique may be sensitive to eddy currents induced in the vacuum chambers. Consequently, the chambers in the LER have been equipped with water cooling channels on both sides of the beam tube to insure symmetry. For the same reason measures should be taken to position the chambers in the center of the quadrupoles and sextupoles.

The committee members are concerned about the forces induced on the magnets by the vacuum chamber due to thermal deformations. It is suggested that the vacuum group check whether the present layout could suffer from such effects.

The RF transition and finger arrangement in the bellows sections seem to be an excellent solution concerning vacuum properties, mechanics, and RF properties. The recent mechanical and RF power tests of the bellows prototype are very impressive. However, since the bellows modules are a particularly fragile part of each ring, continued studies of failure scenarios should be done.

It is recommended to check whether enhanced cooling at the peak of the synchrotron radiation absorption in the LER can further reduce thermal stresses.

The committee appreciates that the vacuum group tries to supply as much pumping speed as possible in a cost effective way. There is some concern, however, whether the beam induced desorption of $\eta = 10^{-6}$ molecule/photon after 1000 A-hr can be achieved.

A detailed lifetime "budget" including Touschek, beam-gas, beam-beam, and quantum effects should be completed. The consequences of these lifetime effects on the detector backgrounds should be studied.

The committee suggests that the maximum operating current be specified for the two rings during operation given the currents needed for collisions, for filling the ion gap (LER), and for overhead if the tune shift of 0.05 is not reached initially.

The number of heat cycles on the vacuum chamber from filling cycles has been estimated. An estimate of the number of heating cycles from orbit steering, feedback jitter or mis-adjustment, coupling corrections, etc..., should be made.

Transverse clamping around the bellows module to prevent large offsets is quite important. A detailed mechanical design should be completed.

E. RF System and Beam Feedback

General

The RF systems of the KEKB machine can certainly be described as difficult due to high beam currents, short bunches, transient beam loading due to clearing gaps in the electron ring, and the required low impedance of the RF systems to avoid too fast growth rate of multibunch instabilities. Two alternative solutions are being pursued - the normal-conducting ARES system and a superconducting system - and, at least for the HER , a choice has yet to be made.

Very impressive progress in both the normal-conducting and superconducting RF system options has taken place over the last two years. In particular the brilliant invention of the ARES system of 3 coupled cavities makes the normal conducting RF option a very attractive option for both LER and HER without relying on RF feedback.

Normal-Conducting Cavities

The choke mode cavity has been successfully tested in the laboratory at full power and MAFIA calculation have demonstrated the required low values of HOM impedances. If operated without the storage cavity (ARES), the phase transients due to beam gaps are large, but can possibly be reduced to an acceptable level by means of the compensating beam gap in the LER ring. The required detuning for reactive beam loading compensation exceeds the revolution frequency in the LER and the apparent impedance of the fundamental mode must be reduced about two orders of magnitude by means of RF feedback.

The very cleverly designed ARES cavities permits an increase of stored energy per cavity by an order of magnitude while only increasing the wall losses by a factor of two. This reduces the beam gap transients to such a small value that a compensating gap in the positron bunch train is barely necessary, and reduces the detuning to a small fraction of the revolution frequency such that the growth rate of the coupled bunch mode driven by the fundamental mode is slower than the radiation damping time in both rings.

The parasitic modes can be selectively damped in the coupling cavity without affecting the desired mode. Their Q values and symmetry are such that the resulting growth rates of coupled bunch modes can be dealt with by multibunch feedback.

The higher order modes in the choke mode cavity have been studied very carefully with the MAFIA code for their R/Q and Q values. The Q values have been estimated to be adequately low by modelling the properties of the SiC absorber. We recommend that these HOM Q values be confirmed by measurements with the intended absorber, and also with the storage cavity attached in case of mode splitting or frequency shifts.

If the full scale tests scheduled for March 1996 and beam tests in AR during fall of 1996 are successful, the choke mode cavity combined with the ARES scheme is an attractive solution for both rings.

Superconducting Cavities

The SC cavities appears also to be a satisfactory solution, especially for the HER. For the LER, the number of cavities is determined by beam power limits per cavity rather than voltage per cavity, and the lower voltage per cavity results in a higher detuning and lower loaded Q. The resulting growth rate of the n = -1 mode is about 30 times faster than the bunch feedback damping rate. Since it is a single mode it can however easily be cured by either a simple RF cavity feedback scheme or a single mode beam feedback scheme using the RF system as kicker.

The SC RF group at KEK has excellent experience with the development and successful operation of SC cavities for the TRISTAN main ring. This experience is very well suited to the task of developing the SC cavity system proposed as one option for the KEKB HER. KEK also has in house a cryogenic plant that would be more than adequate for the 10 cavity SC system proposed for the HER.

Progress on development of the SC accelerating cavities for KEKB-HER is very impressive. Nb cavities of the needed design have been tested to substantially exceed the design 6 MV/m gradient. A beam line cryostat has been designed, fabricated and is now near test.

One of the major challenges for the RF system for any B-factory is an input power coupler and window capable of delivering 500 kW to the beam. Two high power couplers/windows were tested in tandem to 800 kW traveling wave power and 150 kW reflected power. This successful test is a very important milestone in the RF development program.

Higher order mode loads need to provide strong damping and to handle 10 kW of beam induced HOM power. Both these needs have been demonstrated with the HOM couplers developed for the SCC. The damping predicted by codes has been carefully checked by Q measurements.

The program to assemble all these components together is well under way and a high current beam test is foreseen in the AR in a timely manner.

Crab Cavities

Extensive simulation studies indicate that the proposed 11 mradian angle crossing is a very promising scheme for beam separation for KEKB. A 2-mradian crossing has already been successfully used in CESR. There is always the concern of surprises at the larger crossing angle proposed for the KEK-B design, so that it is wise to prepare for head on collisions with crab compensation. Accordingly a program for crab compensation system was presented. A key ingredient of this system is the development of superconducting crab cavities. It is our recommendation that this program be aggressively pursued (as planned), since superconducting crab cavities of the type proposed have never been tested in full scale. Development of SC cavities in general is a long lead item and therefore we support the idea of getting an early start. If needed, a 4 cavity crab system will take at least two years to develop and fabricate.

The design of the deflecting cavity and the proposed scheme for damping the parasitic and HOM modes appears promising, especially since a 1/3 scale Nb cavity with many of the features of the proposed design was tested and found to exceed the required deflecting field. An important design feature that was missing for this first test was an adequate scheme for separating the unwanted deflecting mode. A squashed cavity approach to address this need was therefore presented along with a plan to test this idea with a 1/3 scale Nb cavity, followed by a full scale cavity. MAFIA calculations and Q measurements with a 1/3 scale Al cavity have shown that the squashed scheme will take care of all the unwanted modes.

Several aspects of the mechanical and cryogenic design of the squashed crab cavity remain to be addressed. For example: how to avoid vibrations of the center conductor of the coaxial damper, and how to cool the center conductor. Higher order mode and input couplers need to be developed for the crab cavity. An estimate needs to be made of the power deposited in the HOM loads. The power for the input coupler of a crab cavity was shown to be well below the power demand for the input coupler of an accelerating cavity, but the detail coupler design needs to be completed. The KEK experience in SC cavities, high power input couplers and HOM couplers is well suited to meet these challenges in the time scale proposed.

It was reported that some studies have been done to estimate the tolerances acceptable on the need for exact crab compensation, but these studies need to be documented.

RF Feedback

RF cavity feedback is not needed to control the effects of the fundamental mode in the cases of ARES in both rings or superconducting RF in the high energy ring. RF feedback would be needed if superconducting RF is used in the low energy ring, but this case is rather easy to solve (single mode).

RF cavity feedback is therefore really only considered a back-up solution if neither ARES nor superconducting RF would be used. The following comments apply to this case.

The rather long group delay of about 1.6 μsec of existing klystron, waveguides and cables limits the feedback bandwidth to about 150 kHz, and only a very small impedance reduction from direct RF feedback can be obtained. This very long delay makes the RF feedback a difficult task. [SLAC's PEP II is aiming for a group delay about 400 nsec.]

In this case the proposed single sideband impedance reduction with a parallel comb filter is an interesting proposal. The advantage of damping the cavity impedance associated with only one sideband (below f_{RF} for n = -1, -2, -3, etc.) is that the damping associated with the positive real part of the other sideband (above f_{RF}) associated with the same mode is retained. The feedback transfer function does however significantly modify the phase of the impedance for the neighboring sidebands (associated with n = 1, 2, 3, etc.), and the if the phase exceeds +/- 90 degrees a negative real part results, which contributes to antidamping for the positive modes results. This shoud be corrected. The growth rate for the positive modes (normally stable with a passive cavity ($Re\{Z_C\} > 0$) detuned below f_{RF}) must therefore also be calculated.

Although the proposed filter is very simple, it appears that tuning of gain and phase for each comb channel as function of cavity detuning (which is a function of beam current) is required to maintain stability and good damping of the modes. The closed loop impedances and growth rates for both positive and negative modes should be calculated for any detuning between zero and maximum value. As the proposed transfer function does not have zero transmission at the revolution harmonics, beam gap induced transients may cause problems.

As correctly pointed out in the design report (chapter 4.3.3), the stability margin relative to *the static Robinson limit* becomes very small if optimum input coupling and optimum detuning is used. This is especially true when the beam power is much larger than the cavity loss power, which is true both for ARES and the superconducting cavities. The stability margin can be increased by overcoupling ($\beta > \beta_{opt}$) or increasing the detuning beyond optimum detuning or both. The price paid is extra power due to the mismatch.

It should be pointed out that a very simple direct RF feedback with gain H can be used to increase this static instability limit as the apparent loaded Q is reduced by the factor ($1+H$). No extra power is required in this case and only a very moderate loop gain (1 to 3) and bandwith (< 50 kHz) is required, so even the long delay in the existing TRISTAN RF systems will not be restrictive. This even allows for static Robinson stable operation with substantial undercoupling, which may be desired if the RF voltage is reduced below the value for which the coupling was designed. One should not put in too much gain as this raises the real part of the closed loop coupling impedance outside the bandwidth of this feedback loop and therefore the rise time of the n = -1 mode. This technique has been used with great success in the SLC damping rings and several other machines.

Beam Feedback Systems

The detailed design of both longitudinal and transverse multibunch feedback systems are well advanced. The pick-up and front end of the systems are similar to what is proposed for other machines with similar bunch repetition frequencies (ALS, PEP II).

The signal processing using 2-tap filters with coefficients equal to +1 and -1 are simple to implement and the processing hardware can all be fitted into one 3-unit VXI module per plane per ring. The scheme satisfy the filtering and phase control requirements and adequate flexibility to adapt to varying machine parameters by changing tap positions is available.

Although adjusting the tap positions can be used in the transverse case to compensate for changing betatron phase advance, filters longer than a few turns become rather sensitive to tune changes. As suggested it may therefore be wise to provide two pick-up front ends about one quarter of a betatron wavelength apart and use a linear combination of the two signals for phase control. [DESY uses a 3-tap filter, a single pick-up, and control the 3 coefficients to adapt to varying betatron phase advance. This require however a substantial amount of digital hardware at 508 MHz and two pick-up front ends seems to be a much simpler solution at high bunch frequencies].

The required power, which is determined by required gain (required damping rate) and the magnitude of the injection oscillations, is reasonably small. Simulations done at SLAC confirms that as only a single bunch has large oscillations, a substantial amount of *controlled* saturation can be tolerated without any adverse effects. This means that an injected bunch will initially be damped by bang-bang damping, such that oscillation amplitude decays initially linearly followed by exponential decay in the linear regime.

Such controlled saturation could be included digitally in the ALU (shift of 9-bit result plus overflow control) before the result is sent to the multiplexer. This allows for faster damping rates for a given power limit.

Instabilities induced by captured neutralizing particles (ions in HER and electrons in LER) may have fast growth rates. But even if the gain of the feedback systems were increased to damp the *dipole* modes, theory predicts that higher order modes like *quadrupole* modes do not have much higher thresholds. Active damping of quadrupole modes is extremely difficult to damp by feedback as it is very difficult to provide sufficient RF quadrupole fields by wall electrodes 20 sigma's or more away from the beam. This was experienced in the CERN antiproton accumulator, which in 1988 was intensity limited by a coherent ion-antiproton instability. The transverse feedback damper gain was increased to stablilise the dipole mode, but the emittance blow-up and coherent instability remained. After installation of a quadrupole pick-up, the coherent instability was identified as a quadrupolar instability. The threshold was subsequently raised by moving the transverse tunes closer to the quarter integer in agreement with theory.

Summary and Suggestions

Of the two RF systems proposed, ARES seems the obvious choice for the LER and also appears to be the best solution for the HER, The possibility of operation without impedance-reducing RF feedback is an operational advantage since the high-power klystrons can be in saturation. However since ARES includes many new features it is recommended that the superconducting option be kept open until the full-size test of a complete ARES prototype is successfully completed.

Parameter lists for operating either of the two rings with one klystron station down should be worked out, as this raises substantially the operational availability of the collider. This requires a correct cavity tuning of the idling cavities, which must be taken into account in the design of the tuning and cavity protection interlock system. A tune too close to the RF frequency could result in substantial damage to loads and cavities, while a tune too close to a revolution harmonic will result in a fatal coupled bunch instability.

The committee fully supports the proposed beam tests of working prototypes of both ARES and superconducting cavities, multibunch feedback and RF feedback in the AR ring during 1996.

We recommend that a detail plan and test objectives be prepared as soon as possible for these tests. This would allow adequate preparations for any baseline machine studies that need to be conducted with the AR, as well as time to prepare for any special tests, as for example to bump the beam, or to prepare any special optics that may be needed to run the new cavities with the customary AR cavities removed.

F. Impedance Budget

Operation of high beam intensities is one of the most challenging issues facing the KEKB. The design of KEKB has thus made serious efforts in minimizing the impedance and in establishing a detailed impedance budget. These efforts are necessary precautions and have so far been properly done in the KEKB design.

Single bunch instabilities are not a serious problem in the KEKB because the single bunch current is not higher than the existing electron storage rings. As a measure of impedance budgeting, a specification has been set that all vacuum chamber discontinuities must not exceed 0.5 mm. The value of Z/n has been estimated to be 0.015 Ω, which is quite reasonable for a machine this size. By adding up the calculated impedances of all identified vacuum chamber components, the longitudinal mode coupling instability threshold is calculated for the LER and is found to be a factor of 2-4 (depending on how radiation damping is taken into account) higher than the design specification. This safety margin is regarded reasonable as this stage. The only identified significant single-bunch collective effect is a 10% increase in bunch length due to potential well distortion and that is acceptable.

It is noted that the estimate of Z/n has not included contributions from the RF cavities. As the engineering design progresses, it is envisioned that more detailed impedance items will be added to the impedance budget list. The expected Z/n will then increase somewhat. In particular, the kicker impedance should be included as a design concept becomes available. To be done also is a calculation of the transverse microwave instability threshold given the detailed total transverse impedance of the ring. It is suggested that these be completed soon. The longitudinal and transverse microwave instabilities are not expected to be serious for the HER.

Elimination of tapers around the cavities substantially reduces the loss factor of the cavities. This change is encouraged by the committee. The committee wishes also to caution the possible failure modes of the bellows fingers which, if happens, will undoubtedly cause impedance (and other) problems. An evaluation of such possible failure modes is encouraged by the committee.

Multi-bunch effects are of more serious concern. This concern has led to the inclusion of HOM dampers in the RF cavities and the fact that the vacuum chamber is to be made of copper with a large pipe aperture. Feedback systems are included in KEKB to deal with these coupled-bunch instabilities. Impedance of the BPMs has been carefully evaluated; the relatively high-Q impedance peak at 8 GHz and Q=40 is found to be acceptable.

More discussions on the longitudinal coupled-bunch instability due to the fundamental mode of the RF cavities, and discussion of the feedback systems are given elsewhere in this report.

Recognizing the importance of a good estimate of high-Q modes in order to give a reliable estimate of the coupled-bunch instability growth rates, it is suggested that more efforts be dedicated to identify and quantify the possible high-Q mode sources in addition to those associated with the RF cavities. These sources include the vacuum chamber distortions in the IR region, and the possible nearly-trapped modes by the pumping slots.

The parasitic heating due to trapped modes in the region of the beryllium pipe has been estimated to be about 4 W, while the tolerable level is 200 W. However, the neighboring IR region contains other impedance sources whose total heating power is about 20 kW. An estimate should be made as to how much of this neighboring heating is propagated to the beryllium pipe region in the form of microwaves.

G. Ion and Photoelectron Instabilities

Fast Ion Instability in HER

Ions have been a known problem in many electron accelerators. A gap in the bunch train is usually sufficient to deal with this problem. In the KEKB however, the beam intensity is high enough that a new fast instability may occur. A theoretical study including analysis and simulation has been carried out to study this effect. It is found the growth rate of the 500-th bunch in a 500-bunch train is about 70 turns with a vacuum of 10^{-9} torr of CO. To cure this instability, one possibility is to apply a fast feedback system. This, however, is a concern because (a) it adds to the burden of the already-busy feedback systems, and (b) the feedback system will not be effective to cure any higher instability modes such as quadrupole modes, while these modes are likely to occur when the driving force is direct space charge. Another possible cure is to introduce a gap with much shorter bunch trains, while fighting the remaining smaller growth rate with the feedback system. However, at present, the needed gap size is not clear.

The fast ion instability issue is as yet unresolved. The committee is concerned and strongly recommends that experiments be carried out (at AR or ESRF) to compare with the theoretical calculations and/or proposed cures. In particular, the same analysis should be applied to ESRF and compare with ESRF observations. In parallel, the theoretical study should be extended to find out the optimal bunch filling scenario (pattern of filled bunches and gaps). Effects of feedback should be included in the simulations.

Photoelectron Instability in LER

In the LER, the positron beam generates a large number of photoelectrons. Although these electrons disappear in a short time, their effects on the positron beam may not be negligible. There are indications that a similar effect was observed at the PF. A theoretical study has been made on this effect, yielding an estimated growth rate of 2500/s of coupled-bunch instability. This estimate is regarded preliminary as the photoproduction rate assumed in the calculation is somewhat arbitrary, and the effects of magnetic field or secondary emissions have not been included. To cure this instability, one possibility is to apply feedbacks (see cautionary note in the section on fast ion instability). Another is to apply a vertical or a solenoidal magnet field to guide the electrons away from the beam.

The committee recommends that more theoretical studies be carried out, particularly to consolidate the assumptions made in the theoretical study so far. It is also suggested that experiments be carried out either at the PF or the Argonne APS to study this effect, even though it is recognized that neither PF nor APS are available in the very near term.

H. Interaction Region Design and Background

By necessity, the design of the interaction region is very involved given the convergence of the two rings and surrounded by the physics detector. The overall layout as presented looks quite efficient and well planned for this stage of the project. The superconducting magnets, cryostats, and cryogenics designs are well advanced. The choice of a finite crossing angle allowing the beams to enter the detector centered in the accelerator magnets will, in the end, pay good dividends.

Studies indicated that with the nTorr pressures near the detector the backgrounds are not a severe problem.

However, several concerns did surface during the committee discussions, although most are already being addressed by the KEKB staff:

1) The effect of the misalignment of the quadrupoles, solenoid, and detector has to be studied, especially when the detector solenoid is energized. A realisitic error analysis, especially of the superconducting IR magnets, should be done soon. A method to measure the position of and align the IR SC magnets should be developed.

2) There was some concern about the long cantilever support of the IR quadrupoles and compensation solenoids. Do the resonant modes avoid the prominent ground motion frequencies?

3) The experimenters should be asked to specify a (reasonable) maximum range of operational energies required of the two rings.

4) The plan for the installation of the IR components and the detector interact with the layout of the IR and need further study. We recommend a very early full scale test of the vacuum flange connection inside the bore of the cryostat. Also, the water and He connections for this vacuum joint should be specified.

5) The field quality of the warm magnets near the IR may not be sufficient and the required tolerances should be obtained from lattice studies .

6) Given the sensitivity of the silicon vertex chamber to radiation, injection losses in the region should be rechecked.

7) To keep the beams in collision, there are tolerances on, for example, the RF phases and IR steering. The committee suggests further study of these tolerances and tuning procedures.

8) Beam position monitors common to the two beams near the IR are highly recommended to study beam drifts during collisions and during beam setup.

9) The Be beam pipe can likely handle the locally generated heat from the beam but there was a concern that the high HOM power from the nearby beam separation crotches may propagate to the Be pipe and cause overheating.

10) The crab crossing system is quite complicated and has specific tolerances. This system and the resulting tolerances should be specified.

11) Finally, continued studies of the backgrounds from particle loss and synchrotron radiation are important given continuing design changes near the detector, realistic pressure profiles, and from new effects (e.g. Touschek lifetime).

I. Linac Upgrade and Transport Lines

The design and implementation of the linac upgrade is well advanced and great progress has been made. The new layout of the linac is a good match to the KEK site.

The linac energy overhead seems reasonable but care must be taken that the accumulation of construction errors will not reduce that overhead.

The committee believes that the positron accumulation rate in the LER has little margin given the presented injection time of about 15 minutes from scratch assuming a 100% capture efficiency. The contributions to the injection rate of positrons should be studied further looking for improvements. Several new possibilities may make this task easier: 1) accelerating several simultaneous bunches [This may affect the bunch by bunch feedback system.], 2) accelerating both e^+ and e^- simultaneously in the linac, or 3) to leave open the option to use the Accumulator Ring as a positron damping ring to minimize the beam emittance, thus, reducing injection losses and detector backgrounds.

The committee asks what the tolerance is on the bunch to bunch current variation in each ring after injection considering the beam-beam interaction.

Studies to reduce the R_{56} of the transport lines may yield an optics solution allowing relaxed longitudinal injection tolerances.

The planned tests of positron production with the newly located target are very important.

J. Instrumentation

The committee heard reports on three different beam instrumentation projects - Beam Position Monitor, Synchrotron Radiation Monitor and Laser Wire Monitor.

Beam Position Monitors

Work on the Beam Position Monitor is proceeding very well, and the concept, in the words of the committee, appears "excellent." Encouraging excitation spectra were shown, as well as a design for front-end signal processing. The intention (for cash flow reasons) is to multiplex (X4) the BPM electronics at first, and the committee felt that further evaluation of the time to collect complete orbit data is required. In addition, no scheme was presented for collecting global orbit data, and this has to be worked out. (See comment in Section K) If possible, a (lower resolution) scheme to thread the first term should be developed.

Synchrotron Radiation Monitor

The committee was concerned that the synchrotron radiation monitor system for measuring the beam profile described has only marginal resolution, and recommends consideration of investigating the far UV or x-ray region, or use of a pin-hole camera for improved resolution. It might also be useful to have more than the single intended SRM/ring in order to help decouple horizontal emittance and energy spread.

Laser Wire Scanner

A creative, though speculative "laser wire monitor" system for measurement of individual bunch sizes was also described. Such a system could also provide an absolute beam height determination. The committee found the concept to be very interesting, and encourages further investigation of this idea; however is concerned about the time required to take a single scan. Statistics in the tails will be poor, and counting times long. (An estimate was given of a "few minutes" to get statistics below 1%. It was not clear what assumptions were made about the tails in this estimate.)

Other Instrumentation

The committee noted that no mention was made of any other type of beam instrumentation. It is assumed that most or all of the list below are already taken care of, however the following list is offered for completeness.

* Beam Loss Monitors. These will be vital because of the high circulating currents. In this connection, the committee noted the need to evaluate the requirements for a beam abort system, not mentioned at any time during the presentations.
* Beam Current Monitor. One per ring.
* Tune Monitor.
* Streak Camera.
* Movable scrapers for tail measurements (and removal).
* Emittance Measurement. There was no discussion of emittance measurement procedures, and whether any equipment beyond already described position monitors would be required.
* Optical Transition Radiation Monitors. The successful scheme used at CEBAF should be investigated.
* Screens. The committee discussed the value of screens for the first turns. Concern was expressed about potential impedance of insertable screen systems, however assurance was given, based upon DESY experience, that screens (and other insertable monitors) having

nearly zero impedance are possible.

* Luminosity Monitor. This necessary monitor may be a part of the BELLE data acquisition system. In any case it clearly interacts closely with BELLE. Communication between BELLE data and the KEKB control system needs to be specified. (See Section K)

* Background Monitor. Same comments as for luminosity detection.

* Collision Feedback. Some collision feedback system may be required, also possibly requiring a close interface with BELLE. A strategy for exciting one beam bunch and picking up the signal on the other beam for luminosity optimization may be required. Such a system must be integrated with the fast feedback system commented upon elsewhere, and could, in fact, be that system.

K. Control System

The controls group has made a good beginning with identifying requirements for the KEKB supervisory control system, and relating these to constaints imposed by the need to reuse as much TRISTAN front-end control equipment as possible. Now it is time to get on with a more detailed design.

EPICS Decision

A decision has been taken to base the KEKB supervisory control system on the EPICS software toolkit. This should prove more than adequate to meet all the requirements as currently understood and reported. The choice of EPICS will facilitate the reuse of TRISTAN CAMAC front end hardware. The group should learn as quickly as possible to take maximum advantage of the collaboration - using electronic mail and collaboration meetings to share problems and solutions. Look first for drivers and applications already developed within the collaboration. In addition, we recommend that members of the controls group visit CEBAF and the APS as soon as possible, as experience in these laboratories building comparably-sized systems using EPICS should be very helpful. Other laboratories have found it valuable to send a controls group member to LANL for 6-12 months to become familiar with EPICS in detail. It is also encouraging to hear that the controls group intends to use the CEBAF-developed Application Program Interface "cdev," recently proposed as a world standard within the accelerator community for the sharing of application programs.

It is important to appreciate that EPICS is a toolkit, not a control system. The amount of work required to build a complete control system for a machine as complex as KEKB should not be underestimated, EPICS notwithstanding.

Manpower

Limited manpower resources was identified as a problem for the controls group.

(4 physicists, 8 engineers and 11 part-time "linkmen" from the equipment groups.) The intention is to address this problem in a manner familiar at KEK - some amount of the work will be contracted to a commercial company. The situation for KEKB is different from earlier experience, however, because of the choice of EPICS. The successful company will have to be trained in EPICS, and some legal arrangement will have to be made to protect the commercial EPICS lisencees. It becomes especially important to carefully specify, and then cast into the form of a contract, the work to be performed commercially. This is a non-trivial problem. Candidate tasks include EPICS hardware and software installation, database construction (preferably using the CAPFAST tool), and the addition of features to EPICS itself. It is recommended that EPICS system administration and database design be done "in-house." Database design should be done by equipment group "linkmen."

Data Flow Analysis

While a very general system diagram was presented, the committee strongly recommends that a more detailed reference system layout be developed as soon as possible, followed by a data flow analysis based upon that design. This will allow determination of the required number and distribution of IOCs, as well as identification of potential bottlenecks and the necessary information to develope a believable cost estimate.

Platforms and Buses

Although it was correctly pointed out that EPICS runs on a large number of different platforms, and has drivers for many different hardware buses, every effort should be made to minimize the number of different platforms and buses actually used in the KEKB control systems. The more variety, the greater the maintenance cost.

New Developments

Maximum advantage can be made of EPICS by selecting hardware that is already supported. A special bus is being developed to support magnet power supplies. Every effort should be made to find a standard bus (such as CANbus) or a commercially available bus that can do this job. The controls group should avoid any work that is not strictly required to meet KEKB specifications. The suggestion of porting EPICS to LynxOS does not appear to be a requirement.

Development System

It is important to plan to have a development system separate from the operational system. This allows continued development, debugging, etc without interfering with operations. At the same time, a procedure for version control needs to be implemented as soon as possible.

LINAC Control System

The committee is pleased to see that it is the intention to control the LINAC injector from the same control room as the storage rings. These two control systems should be integrated to the extent possible. Although there are clearly both technical and logistical difficulties, maximum benefit - in particular long-term operational cost savings - would be realized if the two control systems could be made the same. The LINAC control system already makes use of VME, and EPICS is well suited to an incremental upgrade program.

Use of EPICS in Test Systems

It is recommended that every effort be made to encourage the various equipment groups to do equipment tests and commissioning using EPICS. EPICS is well suited to small, stand-alone test set-ups, and using EPICS for testing will provide experience to the "linkmen" and within the groups. Moreover, equipment databases can be prepared during the development stage, and tests conducted using EPICS will be more complete (as they will have tested both the hardware and the operational software). Diagnostics developed during subsystem testing will be available for incorporation into the operational system.

Archiving

The intention to collect and archive "everything that can be collected" is both important and laudable. A more quantitative specification is required, however, as to data rates for various parameter types, strategies for data reduction over time, accessability rates, and duration of saving various data. Archiving, to be useful, implies sophisticated strategies for data storage and retrieval. Nothing was said of these.

BPMs

It was somewhat unclear how many IOCs will be dedicated to the BPM system. Whatever the case, BPMs for each ring are distributed over a large number of IOCs, between 20 and 60, and present plans call for data to be shared over the control system FDDI backbone. Although this does not represent a great deal of data, it does imply both time and computer cycles to assemble a global position data set. Consideration should be given to the use of a reflective memory system for distribution of BPM data, similar to what was done for the APS. Such a system has the advantage of providing a global data set at each local BPM station in an elegant, software-free, deterministic (but possibly expensive) manner.

Databases

Notwithstanding a comment to the effect that object-oriented techniques would be used, only Relational Databases were mentioned as potential repositories for both configuration and archived data. The work at CEBAF using Objectstore for the configuration database should be examined. It is consistent with the proposed use of cdev. Performance of any and all proposed database technologies should be carefully examined.

Availability

No control system availability requirements have been given. A specification is required, so that the possible need for redundancy can be determined.

Timing

It is noted that the TRISTAN timing system will be used for KEKB. This system should be examined for its adequacy for KEKB requirements. A new interface and driver for EPICS will be needed.

BELLE

Necessary communication to/from the BELLE data acquisition system should be identified, and a strategy developed. Several large HEP detectors have adopted EPICS for their slow control systems. There would be advantages to both KEKB controls and BELLE if EPICS were used by both. This possibility should be examined by BELLE.

Appendix A

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Appendix B

Agenda of KEKB Accelerator Review June 7-10, 1995

June 7(Wed)	9:00-9:45	Executive Session	
	10:00-10:30	Accelerator Overview	S. Kurokawa
	10:30-11:00	Parameters and Lattice	H. Koiso
	11:00-11:30	Beam-Beam Issues	K. Hirata
	11:30-12:00	Error Analysis	M. Kikuchi
	13:30-14:00	Magnet System	R. Sugahara
	14:00-14:30	Vacuum System	K. Kanazawa
	14:30-15:00	Impedance Budget	Y. Chin
	15:30-16:00	Fast Beam-Ion Instability	K. Yokoya
	16:00-16:30	Fast Beam-Electron Instability	K. Ohmi
	16:30-17:00	Beam Feedback System	E. Kikutani
	17:15-18:00	Executive Session	
	19:00-21:00	Reception	

June 8(Thu)	9:00- 9:30	Overview of RF System	K. Akai
	9:30-10:15	ARES	T. Kageyama
	10:35-11:00	Superconducting Cavity	S. Mitsunobu
	11:00-11:20	Crab Cavity	K. Hosoyama
	11:20-11:40	RF Feedback	E. Ezura
	13:30-14:00	IR Overview	N. Toge
	14:00-14:50	IR Hardware	K. Tsuchiya, K. Kanazawa, H. Nakayama
	14:50-15:20	Background Issues	S. Uno
	15:40-16:10	Linac Upgrade	A. Enomoto
	16:10-16:30	Beam Transport	M. Kikuchi
	16:30-17:00	Instrumentation System	S. Hiramatsu
	17:00-17:30	Control System	T. Katoh
	17:50-19:00	Executive Session	
June 9(Fri)	9:00-12:00	Executive Session	
	13:30-17:00	Report Writing	
June 10(Sat)	9:00-12:00	Executive Session	