Summary of the Optics, IR, Injection, Operations, Reliability and Instrumentation Working Group *

U. Wienands, SLAC, Stanford, CA94309, USA;
Y. Funakoshi, KEK, Ibaraki-Ken, 305-0801 Japan

Attendees

M. Boscolo (INFN); J. Crittenden, M. Forster, R. Helms, D. Rice, D. Sagan (Cornell); I. Koop (BINP); R. Erickson, Y. Nosochkov, Y. Yan (SLAC); Y. Funakoshi (KEK, co-chair); U. Wienands (SLAC, co-chair)

1 INTRODUCTION

The facilities reported on are all in a fairly mature state of operation, as evidenced by the very detailed studies and correction schemes that all groups are working on. First- and higher-order aberrations are diagnosed and planned to be corrected. Very detailed beam measurements are done to get a global picture of the beam dynamics. More than other facilities the high-luminosity colliders are struggling with experimental background issues, mitigation of which is a permanent challenge.

We heard several prepared talks, taking up about half the time. The other half was taken up by discussions, guided by two working lists. One is the charge to the working groups, which we reproduce here:

- Review present designs and operational status of working group topics.
- How well have parameters measured up to expectations in existing machines?
- What are the problems and operational difficulties common to multiple machines?
- How much further can parameters be pushed to improve machine performance?
- What are the critical steps in doing this?

The other list, made by one of the chair persons (Y.F.), treats some issues in more detail:

- What are performance limiting issues at each machine?
- Method of optics parameter measurement (beta function, x-y coupling, dispersion)
- Method of correction
- Dynamic aperture: Method of measurement
- What limit dynamic aperture
- Detector beam background situation
- Minimum β_y^*
- Other issues?

Based on the lists above, we made four tables (Table 1,2,3 and 4) guiding our discussions. Since I. Koop from BINP could not take part in all discussions, unfortunately the tables do not contain data of VEPP-4M or VEPP-2M.

2 PREPARED TALKS

M. Boscolo presented the experiments leading to understanding the effect of the wigglers at DAΦNE. Very good agreement between experiment and numeric studies using the measured wiggler field parameters has been found for chromaticity (nonlinear), tune shift with orbit and betatron oscillation decoherence. Tune shift with (amplitude)^2 should be small but negative for Landau damping. As a consequence, correction octupoles will be installed which are expected to significantly increase the dynamic aperture and reduce backgrounds. Beam lifetime in DAΦNE is limited by Touschek scattering to about 1/2 hour and the resulting beam-loss rate leads to significant background in the detectors. The group has reduced the background rate by a factor of 25 by changing the ring optics, thus reducing $\mathcal{H}$, and by optimizing the setting of the beam collimators. Numeric studies with GEANT and STAR has led to optimized beam scrapers that further reduce the background. Further benefit is expected from the compensation octupoles because of reduction of multi-turn background.

Y. Nosochkov showed the lattices he has developed for the PEP rings for a horizontal tune near 0.5. Lattice parameters and dynamic aperture appear to be acceptable, although maintaining good chromatic behavior is challenging. Beta beating is observed in the LER lattice after misalignment and magnet errors have been added, but can be compensated (in the code) using the existing magnet families.

D. Sagan explained the lattice-diagnostic and correction technique successfully employed at CESR to track down coupling and focusing errors. It is based on turn-by-turn BPM data, 16k samples of which are summed and used to extract optics data: coupling data from the BPM amplitudes and phases, and beta functions from the BPM phases. Using the model these measurements are then used to trim optical elements to correct beta-function and coupling errors. By piece-wise fitting of the model to measurement

* Work supported in part by US DOE under contract DE-AC03-76SF00515.

data the group has been able to identify skew fields originating from displaced backleg windings and focusing errors due to bad quadrupole supply controllers.

U. Wienands showed recent measurements of the LER beta functions using a new algorithm designed to determine the lattice functions also in the 90^o arcs of the ring by forward and backward propagation of the measured lattice parameters through sections with 90^o cells. Using this technique the large beta beating encountered at $\nu_x \approx 0.53$ was uncovered. The PEP-II LER beam life time was measured vs. rf voltage. The result confirmed earlier suspicions of the LER beam life time being strongly influenced by Touschek effect. As a side-benefit the analysis indicates that momentum spread of the beam and momentum acceptance of the lattice are consistent with the design values.

Y. Yan presented analysis of turn-by-turn BPM data from the PEP-II LER using MIA techniques. Lattice functions demonstrating some beta beating are extracted from the data as well as an estimate for the gain of the BPMs. A first attempt to correct the measured beta beating indicates that good correction should be achievable varying 13 quadrupoles and skew quads.

I. Koop has derived a simple expression for the minimum β^* achievable in a machine from optics and hardware considerations. Applying it to the VLLC he concludes that values down to 1 mm are conceivable. While this may be aggressive, the 1 cm β_y^* actually proposed are significantly relaxed from this number.

Y. Funakoshi showed methods of optics measurements and corrections used at KEKB. Although KEKB is not equipped with many turn-by-turn BPMs, the beta beating and x–y coupling measurements are successfully done based on COD measurements with single kicks by usual corrector magnets. The measurements and corrections can be done on line using the SAD code. At KEKB, this kind of optics corrections are very important to keep the luminosity high and are done typically every 2 weeks.

3 DISCUSSIONS

3.1 Machine status and operational issues

Machine status Except for future *B* Factories in planning, we compared 4 colliders, *i.e.* CESR, DAΦNE, PEP-II and KEKB. Of these machines, CESR is an exceptional machine in the sense that it has a very long history and is a very mature machine, having essentially met its major expectations. The other machines are relatively young and still growing, although they produce physics at a significant fraction of their design goals after only a short (approx. one year) commissioning time.

For example, only CESR is said to be operating at the beam-beam limit, while the other machines have probably not reached the ultimate tune shift yet, leaving room for luminosity increases. The history of CESR teaches us that the beam-beam parameter can be increased gradually by incremental improvements.

DAΦNE, PEP-II and KEKB are double ring colliders. This enables "high current-multibunch" running (like synchrotron light sources) which is vital to get to the high luminosity. Only at CESR are parasitic crossings a major performance limit since it is difficult to get enough separation of the two beams around the IP with the pretzel scheme.

Collective effects The "high current, multibunch" feature has brought some new issues which were not encountered in single-ring colliders; *i.e.* the electron cloud instability, heavy loading to the rf system and so on.

For the *B* Factories, the electron-cloud instability is the major hurdle to overcome, although significant progress has been made in this regard using solenoidal fields on the vacuum chamber and, in case of PEP-II, with gaps in the bunch pattern. The effect seems to be global and is shared by high current proton machines. On the other hand, fast ion instability and dust trapping have been less serious than expected so far. In DAΦNE, electron cloud instability has not been observed, somewhat surprisingly considering the experience in the *B* Factories.

Coupled bunch instability induced by the fundamental mode of the rf cavities was considered in the design phase to be one of the most serious problems of the B factories. The two *B* Factories have solved this problem (at least for now) in different ways—using high-Q cavities in KEKB, while using rf feedback loops in PEP-II. On the technological front, however, reliability of the rf systems under very heavy loading is one of the prime concerns.

Beam-beam effect poses the ultimate limit for colliders, and it is interesting to note that both *B* Factories claim the vertical tune-shift parameter of the high energy (electron) ring, ξ_y^- , to be lower than the other three by almost a factor of two. The straight-forward explanation would be a blowup of the positron beam (*e.g.* due to the electron cloud), although the detailed picture may well be more complicated.

Operational issues The machines have reached their performance not necessary at the design point in parameter space, e.g. the *B* Factories run significantly higher bunch currents but also larger beam sizes than foreseen in the designs.

At KEKB, bunch currents higher than design is a consequence of the bunch spacing problem. It has been observed that the specific luminosity significantly decreases with shorter bunch spacing even below the threshold beam current for single-beam blowup in LER from the electron cloud instability. The mechanism of this phenomenon has not been well understood, and it is one of the major performance limits. A similar bunch spacing issue is also found at DAΦNE, while PEP II has not yet experienced this issue. CESR-B is the exception also here quite possibly since it is the most mature machine.

The high beam currents also cause heating problems in particularly at the *B* Factories, although this issue was not stressed in the working group.

Most machines have had to struggle with less-than-perfect reproducibility, esp. during recovery from periods with no beam.

A common thread operationally is the difficulty in understanding and correcting the x–y coupling caused by the experiment's solenoid. PEP-II appears to be particularly difficult in this regard, probably due to the absence of anti-solenoids.

Beam lifetime, on the other hand, appears to be reasonably well understood. For the lower energy rings—esp. for DAΦNE—it is dominated by Touschek scattering, while the high energy rings of the *B* Factories are more affected by residual gas and by radiative Bhabha scattering at the IP.

The detector beam background is also a potential performance limit. At DAΦNE, the background originating from Touschek scattering has been a serious issue,esp. since its energy is relatively low and the beam currents are relatively high compared with the other colliders.

3.2 Optics measurements and corrections

We reviewed the techniques used to assess β functions, x–y coupling and the dynamic aperture, Table 3 and 4. Different techniques for optics measurement are used depending on the type of BPM available. While the BPMs at CESR and PEP-II detect turn-by-turn beam positions, those of DAΦNE and KEKB measure only closed-orbit distortions (COD). Using turn-by-turn BPMs, the optics parameters are obtained by measuring the phase advance of forced betatron oscillations. With COD BPMs, the optics parameters are obtained by fitting spatial orbit waves induced by dc correctors. The former method has a principal advantage over the latter in that phase information is free from calibration errors of the BPMs. Also for x–y coupling measurements the former is superior because pure eigenmodes can be excited.

The work done at CESR on betatron and coupling measurements using phase-advance data appears to be most advanced, although KEKB is also having very good results using the orbit-wave technique. At DAΦNE, very small x–y coupling of 0.3 or 0.5 % has been achieved after correction. At PEP-II the 90° phase advance in the LER makes β function extraction difficult although progress has been made in this regard.

The wigglers employed in many low energy rings to control the beam emittance present challenges arising from their potentially strong effect on the linear beam optics and from difficulties in properly assessing their nonlinearities about the beam orbit. Octupole corrections are being implemented at DAΦNE to combat this problem. These issues are shared by the synchrotron light sources, and collaboration with the various light-source groups may be of benefit to the colliders.

3.3 Zero-current emittance

The importance of the zero-current beam size on the maximum luminosity achievable was discussed, the question being raised by D. Rice. In most machines, after a long shutdown, optics corrections are done first, with x–y coupling correction generally felt to be most important. This would imply that the zero-current beam size *is* important for the luminosity.

The KEKB experience corroborates the importance of x–y coupling correction, in the sense that non-zero x–y coupling at the IP possibly induces an additional beam-beam blowup which simulations show can arise from x–y coupling at the IP combined with the crossing angle. However, matching the beam sizes at the IP is more important for the luminosity than the zero-current beam size itself. This may arise from the energy asymmetry. Since the HER beam is usually stronger, its size is enlarged intentionally by controlling the vertical dispersion around the ring, depending on the beam current.

At PEP-II, the machine is tuned up at high (operational) beam current to reach maximum performance, which will typically lead to (vertical) beam sizes at the IP somewhat larger than the minimum achievable.

3.4 Operating point

In Table 2, the present working points of each machine are summarized. All machines except for DAΦNE employ tunes above the half integer resonance. One of the merits of these tunes is less orbit drift, but most facilities attempt to maximize the dynamic β reduction at the IP achievable by running with a tune just above the half-integer resonance.

At KEKB, the dynamic beta and emittance effect due to the horizontal tune very close to the half integer resonance was found to be important in raising luminosity. Due to these effects, the horizontal emittance becomes larger while keeping the horizontal beam size small at the IP; This is helpful in achieving high luminosity with high bunch current.

The tunes of KEKB and CESR seem very similar, although they were surveyed independently. The tunes of VEPP-4M (not included in the table) at 6 GeV are 8.54 and 7.58 in the horizontal and vertical directions, respectively. PEP-II is trying to move the horizontal tune of the LER closer to the half integer resonance based on beam-beam simulations. At DAΦNE, it is not easy to change tunes to a large extent due to its small ring size.

3.5 Parameter improvements planned

We reviewed the prospects for further improvements in machine parameters related to luminosity performance (Table 2). All facilities are planning to push β^* lower, albeit by different amounts. The KEKB plans are most aggressive for β^* as well as for the luminosity ultimately hoped for. To increase the luminosity by lowering β_y^*, shorter bunch lengths will be needed. For the future, it is contemplated to change the beam polarities so the positrons would have the higher energy and not be as much affected by the electron cloud.

At PEP-II, two new rf stations will be installed in the HER to raise the beam-current limit, with more rf for both rings planned as the need arises. Several heating problems will be solved by replacing relevant hardware components.

At DAΦNE, the main emphasis is on increasing the bunch-current and number of bunches; to this end, octupoles are being installed and a change in working point is being considered.

CESR is a special case in that it is proposed to change the energy down to about 2 GeV, for a $\tau-$Charm Factory conversion.

4 CONCLUSION

The working group dealt with a very wide rage of practical issues which limit performance of the machines and compared their techniques of operations and their performance. We anticipate this to be a first attempt. In a future workshop in this series, we propose to attempt more fundamental comparisons of each machine, including design parameters. For example, DAΦNE and KEKB employ a finite crossing angle. The minimum value of β_y^* attainable at KEKB seems to relate to this scheme. Effectiveness of compensation solenoids and turn-by-turn BPMs etc. should be examined in more detail.

In the near future, CESR-C and VEPP-2000 will start their operation. We expect to hear important new experiences from these machines; in particular VEPP-2000 will be the first machine to have adopted round beams. At SLAC and KEK, next generation *B* Factories are being considered. It will be worthwhile to discuss the design issues of these machines based on the experiences of the existing factory machines.

5 ACKNOWLEDGMENTS

The working-group chairmen would like to thank all the group attendees for their contributions and the lively discussions we had. In particular, we would also like to thank D. Rice, Cornell and ICFA for their invitation and support.

Table 1: Summary Table

	Present Design and Operation Status (performance limiting issues)	**Parameter vs. Expectations**	**Problem and Operational Difficulties**
CESR-B	Running (parasitic x-ing)	Expectations have been met.	Solenoid compensation, reproducibility, rf trips
KEKB	Running @ 1/2 of design Lum. (e$^-$ cloud, bunch spacing, beam-beam)	ϵ blowup larger, ξ_{y-} smaller, # of bunches smaller (I_b higher)	change of ring circumference, Luminosity instability, aborts (rf trips, Belle), x–y coupling @ IP, lifetime decrease (need β change)
PEP II	Running, 133% of design Lum. (beam current (heat, rf), beam-beam, e$^-$ cloud)	Vertical beam size bigger, ξ_{y-} smaller	machine drift, reproducibility, feedback loops, rf loops, rf trips, background, injection, x–y coupling
DAΦNE	Running below design Lum. Lum/bunch 25% (beam-beam, background, ion trapping)	ξ_y smaller (1/2), lifetime smaller (<1/2)	injection after downtime, background, # of bunches smaller, I_b 15 mA, x–y coupling
Super KEKB	in design		
Super *B* Factory	parameter search		

Table 2: Parameter improvements considered

	How far can parameters be pushed?	Critical steps in doing so	Working point (present)
CESR-C	$\beta_y^* \to 1$ cm Lum. $\to 3 \times 10^{32}$ (design@1.9GeV) $E \to 1.5 \ldots 2.5$ GeV	Wigglers (14)	(.53, .58)
KEKB	$\beta_y^* \to 0.5$ cm overcome e^- cloud instab. $\xi_y^- \to 0.05$ Design beam current, Lum.$\to 2 \times 10^{34}$	e^+ in HER, e^- in LER (Linac upgrade) Installation of ante-chamber, Crab cavities	(.51, .58) (LER) (.53, .59) (HER)
PEP II	$\beta^* \to 35$ cm, < 1 cm HER $I \to 1.5$ A LER $I \to 3.8$ A Lum $\to 10^{34}$	HER rf (2 new stations) Replace Q2 chamber, Q1 bellows, FB kickers; may need wiggler on again	(.64,.57) (LER) (.57,.63) (HER)
DAΦNE	$\beta_y^* \to$? $\xi \to 0.04$, $I_b \to 25 \ldots 30$ mA # of bunches Lum.$\to 10^{32}$	Tune change Octupole, shim wiggler 3^{rd} harmonic rf ? (cavity prototype exists)	(.15, .21) (electron) (.12, .17) (positron)

Table 3: Beam-Diagnostics Methods used

	β **Measurement**	$x - y$ **coupling measurement**	**Dispersion measurement**
CESR-B	phase advance from turn-by-turn BPM	Forced betatron oscillation.	
KEKB	Orbit kick by correctors	Orbit kick by correctors	RF frequency change
PEP II	phase advance from turn-by-turn BPM	Orbit coupling using global wave	RF frequency change closed orbit wave
DAΦNE	Quadrupole variation	Vert. beam size by SLM	Rf frequency change

Table 4: Dynamic Aperture Measurement Methods

	Correction of optical errors	**Dynamic aperture Method of measurement**	**Dynamic aperture Measurement, What limit?**
CESR-B			Transverse: consistent with physical aperture
KEK-B	Online using SAD	Transverse: pulse kicker magnet Longitudinal: RF phase kick	Transverse: consistent with physical aperture (H) poor data (V) Longitudinal: typically 1% chromaticity correction
PEP-II	Offline using Lego, MAD Online using beta-function measurement voltage	Transverse: offset injection, orbit wave Longitudinal: Beam lifetime *vs.* rf Touschek analysis	Transverse: very few data, not significant issue. Longitudinal: ≈0.7%
DAΦNE		no measurement	