Summary of the Working Group for Operations, Reliability, Injection, and Instrumentation

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When a particle accelerator achieves the status of a particle production factory or super-factory (luminosities in the range of 10^{33} to 10^{36} cm^{-2}-sec^{-1}), the expectation is that it will be capable of operating at high luminosities reliably. To achieve this goal, those in accelerator operations must concern themselves with the disposition of personnel, the efficiency of day-to-day operations, the reliability of the accelerator hardware and software, and reproducibility of accelerator luminosity conditions. In order to achieve high integrated luminosity performance, it imperative that the injection and preparation of the beams be handled as rapidly and efficiently as possible. When the accelerator encounters a fault condition, it is critical to detect the nature of the fault, to undertake repairs and to recover operations in the most expeditious manner. To accomplish the fault detection and repairs effectively, necessitates a suite of diagnostic instrumentation and supporting analysis software. The efforts of this working group have focused on these issues.

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1. INTRODUCTION

This paper focuses on the operational aspects of high luminosity colliders, which are expected to achieve high average performance levels. It is a brief summary of the discussions held between members of the operations staff of the electron positron colliders at CESR-C, KEKB and PEP-II. Although this not a complete sampling of all high luminosity colliders in operation, the experiences of the members of this working group is expected to be a reasonable representation of those of other high luminosity colliders.

1.1. Charge to the Working Group

Explore and document the operational experiences, fault detection and recovery, the determination of causes for poor performance and the overall reliability of operating electron-positron colliders. Also explore and document experiences with instrumentation and injection at these colliders, which is relevant to the electron-positron collider community at large.

2. OVERVIEW OF OPERATIONS

2.1. Personnel Involved with Operations

The first place to begin the discussion of the operational aspects of high luminosity colliders is with an examination of the personnel required by different laboratories to maintain the day-to-day operation. It is convenient to separate the function of the personnel into two distinct groups, those who have largely administrative functions and those who are responsible for the implementation of the program in the control room. Table 1 shows the distribution of personnel at KEKB, PEP-II and CESR-C. This description of personnel functions is somewhat generalized, since each laboratory configures its workload to be compatible with its own requirements and choice for operational style.

The upper half of Table 1 contains the personnel with the administrative functions. All three laboratories have a Director of Operations position, which has the overall responsibility for the operation of the accelerators: implementing the High Energy Physics program, and a Synchrotron light program (if it exists), and overseeing the particle accelerators for these programs and any accelerator research and development programs. This responsibility is usually shared with one or more deputies (Program Deputy or Operations Deputy), who typically oversee the scheduling of the accelerator's time between the various projects or the configuration of the particle accelerators' conditions, the time spent on repairs, and the strategies to be employed to achieve stated performance goals. At the different laboratories, these oversight functions may be shared among the administrative staff in slightly different ways. As an example, at CESR-C only the responsibility for detailed scheduling of machine studies projects is shifted to a different person.

The second half of Table 1 shows the personnel, who have control room shift responsibilities, i.e. positions that are filled for the twenty-one 8-hour shifts per week. The Accelerator Physicist provides support for tasks that require detailed knowledge of beam physics or specialized techniques for measuring accelerator parameters. On site to supervise the Accelerator Operators and to make time critical decisions about the implementation of the accelerator program, the sequence of tasks or repairs is the Shift Leader. The Accelerator Operators have the front line responsibility for controlling the accelerators and detecting accelerator faults and failures. In the case of KEKB the operators are personnel provided under contract to a firm, which trains and oversees their work. Again the exact set of responsibilities for a given position varies between the laboratories. These duties, listed above, are generally covered by the 1 to 5 persons at the different laboratories.

Table 1: Functional Distribution of Personnel

	KEKB	**PEP-II**	**CESR-C**
Director of Operations	1	1	1
Program Deputy	1	1	1
Operations Deputy	1	1	
Personnel in the Control Room			
Accelerator Physicist	1-2	1	
Shift Leader	1	1	
Operators	2	2	1

2.2. Communications

Communications between the operating staff members is quite critical for efficient operations. This begins with the annotation into some form of electronic or paper logbook of relevant details of observations, procedures, faults, and error conditions, which affect the accelerator complex. The routine communications continues with the passing along of detailed operational information in the control room as one shift arrives and overlaps with the persons going "off shift."

Each laboratory has established a schedule for meetings to exchange information between members of the operations staff, technical staff and experimenters. PEP-II has this structured as two meetings per day. The first is a program meeting among the operations staff and experimenters to discuss conditions affecting the accelerator's performance, strategies for repairs and the scheduling of the accelerators. A second meeting, which involves operational and technical staff, deals with the performance of all the accelerator systems, fault reporting, repairs, maintenance, and the relevant schedules. KEK-B has one daily meeting, which covers both the program and technical system aspects. CESR-C generally has one weekly meeting covering both program and technical details, although during down periods or start up periods this is changed into a daily meeting.

2.3 Optimum HEP Run Length

Coupled with the goal of producing high luminosities is the requirement that the accelerator produce the greatest possible integrated luminosity. Accomplishing this places constraints on the accelerator schedule at several levels. These encompass choices, which determine the high energy physics (HEP) data taking run length relative to the filling time of the accelerator, the fraction of the scheduled operating time that is devoted to machine research and development and the scheduled down time.

During periods of steady HEP operations, the HEP data taking time is defined here to be the time from when the HEP detector has begun collecting data until it has stopped and is preparing for a refill of the beams. The filling time is defined as simply the time beginning when the HEP detector turns off, the beams are refilled and up until the detector has just commenced collecting data. The object is to select the optimum HEP data taking time given the known average filling time and the known or projected luminosity profile vs. time. The different laboratories have employed a few strategies for arriving at this optimum. One of these is to keep a running average of the luminosity over both the HEP data taking time and the filling time and to end the HEP data collection when the luminosity in the fill equals the average luminosity. Another strategy is to assume or to fit a given a luminosity profile vs. time. From this function it is possible to either find the optimum numerically or if it is a simple function (e.g. linear or exponential) solve analytically or numerically for the optimum. As a simple example consider a luminosity function which decreases exponentially vs. time. If T_r is the HEP data taking time divided by the luminosity lifetime and T_f is the filling time also divided by the luminosity lifetime, then the optimum value for T_r satisfies the equation,

$$\exp(T_r) - T_r = 1 - T_f$$

This is satisfied approximately by

$$T_r \approx \sqrt{2T_f} - \tfrac{1}{3}T_f \ ,$$

which gives the optimum integrated luminosity within a few percent for $0 \le T_f \le 1$. If the exponential function was approximated by a line, which has the same slope and luminosity at the beginning of HEP data taking, then the optimum value of T_r would be just the first term of the last expression. After examining numerical results for the fraction of the maximum integrated luminosity vs. different choices for T_r, it will become apparent that the actual integrated luminosity varies rather slowly away from the optimum choice for T_r. This agrees well with the observations from the different laboratories that all the above choices yield essentially the same optimum for the integrated luminosity. Carrying this one step further, the ratio of the time averaged luminosity divided by the peak luminosity gives the luminosity efficiency, η_L, for the collider. Again taking the example of a luminosity, which decreases exponentially with time, the efficiency may be written as

$$\eta_L = \frac{1 - \exp(-T_r)}{T_r + T_f} \approx \frac{1 - \exp\left(-\sqrt{2T_f} + \frac{1}{3}T_f\right)}{\sqrt{2T_f} + \frac{2}{3}T_f}$$

for the same range of T_f. Notice that as T_f approaches zero (short filling times), the efficiency approaches 1 – 3/2 T_f, suggesting that with many short filling periods, the luminosity efficiency could approach one.

2.4 Scheduling

Times for maintenance and repairs are required during long periods of operations at every accelerator. The different laboratories have found somewhat different schedules for these times for accelerator access. At CESR-C one shift of access is scheduled per week, while at KEK-B one to four shifts of access are scheduled for every other week. PEP-II has chosen to schedule accesses, only when needed for repairs or required maintenance. All laboratories attempt to use the access times efficiently, by judiciously scheduling additional projects, chosen from the repair and maintenance lists.

Machine studies or development periods are needed at all of the laboratories to diagnose beam-related problems, make improvements to the operations, and study the effects of changes in operating parameters. These are generally are not appropriate during HEP operations. Longer periods of dedicated machine development are scheduled after major shutdowns, but all laboratories have some number of eight-hour shifts set aside for machine studies periods within their weekly or biweekly operating schedules. Often the amount of time scheduled for machine development is greater during the occasions when major changes have been made to the operating conditions of the accelerator. KEK_B schedules 2 shifts on a bi-weekly basis. On the average CESR-C schedules 4 to 6 shifts per week, while PEP-II schedules 0.5 shifts per week.

3. INTERRUPTIONS TO OPERATIONS

3.1. Introduction

The next three sections will deal with various aspects of interruptions to smooth accelerator operations. The topics will be treated in the order that may seem to be reversed from the normal chronological order: fault recovery, fault prevention and then fault detection. Although this order of presentation may seem counter-intuitive, it will more naturally lead into the subsequent sections on accelerator instrumentation, which plays a critical role at the stage of diagnosing faults, especially the more subtle variety.

3.2. Fault Recovery

The approach taken for the recovery from some fault in one of the accelerator systems, which has halted the accelerator operation, is very similar for PEP-II, KEK-B and CESR-C. When a fault condition is detected by the operators in the control room, they or their supervisors initiate a process to isolate the cause of the failure and to contact responsible personnel. They also will either initiate the repairs themselves or provide support to the personnel diagnosing the component (or sub-system), which has failed. Failures that occur outside of normal working hours and require technical support are handled differently by the laboratories. PEP-II has some number of technical support staff on the site at all time, while CESR-C and KEK-B do not. At all laboratories, system specialists are on call at all hours for advice to the operating staff, in some cases to run diagnostics on systems remotely, and to provide on-site support for repairs.

Another policy common to all the accelerator facilities is one that is termed the “escalation policy” at PEP-II. After a failure, which stops operations for some length of time (typically a couple of hours), this policy requires a higher level administrative person be informed. This is to provide some assurance that diagnostics and repairs are being implemented expeditiously. At KEK-B the Hardware Coordinator is person that is notified, while at PEP-II it is the Operations Deputy and at CESR-C, the Director of Operations.

All laboratories use some form of an electronic logbook for the dissemination of information among accelerator personnel, the documentation of faults or systems failures, as well as all other observations and measurements. Some laboratories also continue to use a paper logbook. After a repair has been completed, a brief description of the problem, its consequences and its repairs is inserted into the logbook. For systems that require a longer period of diagnostics and repairs, entries in the logbook describe the progress on the task.

Today's electronic logbooks provide very important capabilities for the operational and maintenance and repair staff. For example at CESR-C, the logbook permits automatic mail distribution of logged fault entries to maintenance and repair staff. It also permits semi-automatic logging of beam loss information. This includes FFT's of horizontal, vertical and longitudinal position signals, the recording of which element tripped initially, the designations of automatically recorded fault transient files and other comments by the operator.

Another very useful feature found in the logbooks at KEK-B and CESR-C is the ability to semi-automatically characterize operating conditions of the accelerator. Taking approximately one hour per week, the process records the tunes, orbits, dispersions, betatron phase advance, local coupling, chromaticities, status of various hardware components, et al under various conditions. These records are incredibly useful when recovering from faults or during periods of accelerator start up.

A critical consideration, which can have a major impact on the recovery time from a fault is the question of spare parts. Clearly it is necessary to have spare parts on hand especially for repairs, which can occur at any hour of the day. The general consensus among the laboratories is that accelerator personnel must assure parts are available on site to accomplish needed repairs. Depending on the nature of the spare parts it may be necessary to be sure that there is a "lifetime" supply of spare parts on hand. An example of this case is the number of specialized integrated circuits in use today. It is quite common for the production period of these components to be limited to only a few years, making the parts obsolete while the accelerator may contain sub-systems with a great number of the parts. It will also be necessary to have extra spare parts on hand for items, which have long delivery times or are difficult to find. The general consensus is that all of the laboratories need to focus more attention on making sure that long lead time spare parts and parts likely to become obsolete are readily available for repairs.

Although seemingly out of place in the discussion of accelerator fault recovery is the important issue of the personnel safety protection systems. These systems can be grouped into two basic categories, equipment safety and radiation safety. The safety systems are critical for protection of personnel. Care should be taken, however, to efficiently reinstate the protection levels of these systems in a manner so as to avoid needlessly adding time to the recovery from a failure. These systems also require some level of maintenance; it is important to be cognizant of the efforts required and to try to streamline implementation of these procedures, whenever possible. A specific example is the radiation safety protection systems for the accelerators. By regulation these systems require calibration and testing a number of times (typically twice) per year. There is a large variation in the checkout time required for the different laboratories for this task. At KEK-B this procedure requires about 4 hours. At CESR-C the tasks is broken into two parts, testing CESR-C and CHESS (the synchrotron light facility) interlocks, requiring about 2 and 4 hours, respectively. Due the large number of separate areas this task takes from 6 to 8 shifts at PEP-II.

3.3. Fault Prevention

To be successful with the efficient production of integrated luminosity an accelerator complex must take a very active role in the prevention of accelerator system faults. One important tool employed by all laboratories for this is the accurate accounting of time usage for the accelerators, especially unscheduled downtime. This accounts system by system, allowing the tracking of system lost time, the mean time to a failure (MTTF) and the mean time to repair (MTTR) and indicates which systems need further attention. Typically laboratories account for time usage with about a 0.1 hour resolution. By studying lost time records, improvements may be undertaken to improve system performance and repair times.

The obvious method to reduce accelerator failures is to improve system and sub-system reliability. This implies that obvious, reoccurring problems need to be dealt with. This is clear for major system and sub-system failures, which will shut down the facility. However, there is a general consensus that it is important to complete the repair or upgrade even of items, which provide monitoring, backup indications and diagnostic capabilities, and will not generally cause the shutting down of the facility. These are generally considered to be low priority items, since their operational impact is often small. However, the consensus is that, when repairs are not made, the reduction of monitoring and diagnostics will eventually compromise the overall reliability of the facility.

A question that needs to be considered when deciding about reliability improvements for systems is when do we upgrade older systems? These older systems can be a major cause of headaches, such as intermittent failures, and substantial repair efforts. To help determine, which systems or sub-systems would benefit from a major upgrade, it is important to document MTTF, MTTR, the cost of repairs and downtime. From these considerations, it is possible to evaluate the impact on the operations of an upgrade to an older system.

3.4 Fault Detection

When an accelerator system has failed during operations, detecting the nature of the failure is important in order to concentrate efforts on the detailed diagnostics and ultimate repairs. When the failure occurs, it is of paramount importance to not overload the operators with too much information. This often happens when a number of monitors have been left unrepaired and their indications provide a large display of information, unrelated to the most recent failure. These constitute distractions and can account for a significant time in the recovery from a failure. It is important that the operational staff make prudent choices to temporarily veto false indicators, or to raise trip or warning threshold levels, or to fix even the low priority problems during access periods.

Training operators to detect the cause of faults and aid in the diagnosing of problems can yield big savings in unscheduled down time. It is still the case that specialists may need to analyze complex failure records, but any initial narrowing of the scope of possible failures will save time. Often, when there is failure in one system, e.g. causing the beam to abort, a number of other systems will also indicate fault conditions. Determining from the failure records, which system failed, is the first step toward diagnosing the problem and initiating the repairs. However, these failure records, which often contain signal waveforms from a large number of monitoring points, can take some time to analyze. Helping specialists and, perhaps, operators to analyze this data quickly could also yield important reductions in the repair time.

4. INSTRUMENTATION

4.1. Transient Fault Detection

The discussion of accelerator fault detection leads naturally to the consideration of possible instrumentation for this purpose. Since failures of accelerator systems can occur on many different time scales, it is necessary to have a set of fault detection tools. Examples of tools, used by today's laboratories, will be categorized by the time scale, on which they functions.

Since faults in beam feedback systems, RF accelerator systems and electrostatic beam separators can occur on a time scale short compared to the period of the accelerator, different types of fast recoding instruments have been developed. One type (in use at CESR-C and KEK-B) employs multiple monitor signals, connected to threshold detectors, which in turn trigger timing counters. In one implementation (at CESR-C), when a transient condition occurs, causing one or many signals to cross their thresholds, the first signal disables its counter and causes the counters for all the other signals to begin to count[1]. When other signals cross their thresholds later on, the counter for each signal halts, recording the delay between the first trip and the trip of each particular signal. After some initial study of typical fault scenarios with beam, the signal propagation delays can be determined. It is then possible to identify accurately the source of the failure in the vast majority of cases. The resolution typical for this type of system is 100 nsec.

All laboratories make use of some form of a transient recorder for accelerator signals. These generally utilize ADC's with sampling rates of up to 10 Msamples/sec and memory storage for 1 to several thousands samples per waveform. Signals that are digitized for this purpose include the horizontal and vertical beam positions and the beam currents, RF waveforms (e.g. the forward, and reflected powers, the RF phases and tuning angles), abort kicker current, electrostatic separator voltages and feedback system output power. The recorders are configured to trigger on some signal(s), e.g. a beam loss indicator, which then initiates a dump of the recorder's memory into disk files. These files must be analyzed to determine the sub-system failure and specific nature of the fault.

Experience at CESR-C has shown at times there is a need to record signals for longer time periods.[1] This is clear for failures in magnet systems or vacuum systems where the characteristic times for signals is in the range of a fraction of a second. One way that this can be accomplished is with very long memory buffers on the transient recorders. This solution can be expensive, as there are often many more "slow" signals than "fast" ones and the analysis of many signals for long times can require significant computational times. At CESR-C a control system program runs at all times reading into memory the values of from 100 to 200 signals at a 10 Hz rate. These are signals that routinely monitored and logged at a much lower rate. When one of the signals satisfies a transient criterion or an operator triggers the system manually, the data recording continues for some length of time (a few tens of seconds) and then the data is written out into a file. By scanning these records, it is possible to quickly determine which signal is at fault and something of the nature of the failure. As a very simple example, it is often possible to detect the location of a vacuum leak by the propagation of the initial pressure burst within the accelerator.

Generally the interpretation of signals recorded during transient conditions can be difficult. Simple observations of the absence of a signal may suffice, but arriving at the correct interpretation will often require the analysis of a specialist, knowledgeable in the detailed behavior of the system from which the signal is derived. As different types of faults are analyzed and suitably interpreted, an easily accessible set of records needs to be available for operations staff to aid their diagnosing of one of these more complicated accelerator faults.[2] The training of operating staff in the interpretation of these signals has been undertaken to some degree at all of the laboratories with very positive benefits.

Future, even more complex accelerators will find many subtle ways to fail. The accelerator community, as a whole, must find effective methods for the automatic analysis of recorded waveforms from system faults, to allow accurate, rapid assessment of the system or sub-system responsible for the failure. This is important at least for the common failure modes. It is interesting to consider, whether techniques, in use in HEP for handling large data sets and extracting information, might be adaptable to this application.

4.2. Diagnostics for Operating Conditions

A fairly conventional set of accelerator tools is used at all of the laboratories for standardizing conditions. These include the measurement of orbits, tunes, dispersions, beta-functions (via changes in quadrupoles or phase advance measurements) and global coupling (by the minimum approach of the two normal mode dipole tunes and local coupling again via phase advance measurements. These techniques are fairly well established and provide a basic set of benchmark parameters for single bunches, permitting the diagnosing of problems and the recovery of operating conditions.

As mentioned above, there are two basic techniques for characterizing the betatron functions. In accelerators such as CESR-C that have the capability of independently powering the ring quadrupoles, the quadrupole strengths can be varied one-by-one and the betas inferred from the changes in the tunes. The second technique is faster and utilizes the beam position monitoring system in the ring.[3,4] This approach excites the beam on one or both of the dipole normal modes and measures the change in phase from one beam position monitor (BPM) to the next. The phase measurement may either be accomplished by fitting of multi-turn BPM data or a phase locked loop system. The phase advance data is complementary to the direct beta measurements, but from either a reasonably accurate comparison may be made between the measured and design values. The strengths of individual quadrupoles or families of quadrupoles may be varied to reduce the accelerator beta errors to acceptable values. By measuring the “out of plane” component of the motion, using essentially the same technique, the local coupling of the ring may be determined. Again, it is possible to determine changes to accelerator transverse coupling elements to reduce the local coupling to reasonable levels.[4,5] These techniques provide powerful tools for the maintenance and repair of accelerator conditions over time.

In addition to the standard complement of diagnostics, beam stabilizing feedback systems can also provide diagnostics capable of diagnosing bunch-by-bunch behavior.[6] The digital signal processing in these systems provides position measurements bunch-by-bunch and turn-by-turn, and from these, bunch-by-bunch currents, tunes and damping rates. One example of the added capabilities for multiple-bunch beams is a technique known as grow-damp measurements. In these measurements the beam stabilizing feedback gain is either set to zero or reversed for a short time allowing the growth of an unstable oscillation of the beam. The feedback gain is then reset to again stabilize the beam. During the period of time, when the instability grows, the position signals may be analyzed with an FFT to give the time dependent frequency spectrum. From the growth rates of the modes in the betatron or synchrotron oscillation, some aspects of the impedance of the accelerator may be inferred.[7] This is particularly useful when changes in the spectral characteristics may be correlated with accelerator component changes.

4.3. Diagnostics During Collisions

When beams are in collision and HEP data taking has commenced, a different set of measurements is desired. Special care must be taken not to perturb the beams too much during the measurements or the luminosity performance may be adversely affected. The discussion in this section will be limited to relatively new diagnostics in use with beams in collision.

Of course, one of the most important instruments during collisions is the luminosity monitor. In order to tune the beams in collision, it is necessary to make accurate luminosity measurements. In this context, accurate luminosity measurements implies two criteria, a large enough statistical sample for high relative accurate and a sensitivity only to parameters, which change the luminosity. Recent developments with high statistics monitors have utilized the single photon bhabba scattering process allowing bunch-by-bunch measurements. KEKB, PEP-II and DAΦNE make use of this new class of monitors, which have of the order of 0.1% relative accuracy per second for maximum luminosities in the range of $3x10^{30}$ to $1x10^{33}$ cm^{-2} sec^{-1}. [8,9]

A parameter, important for maintaining good beam-beam lifetimes, is the location of the beams’ tunes. Small changes in each beam’s tunes can reduce the lifetime of one beam and quickly cause the relative beam current ratio to drift outside of the optimum for the highest luminosity. Maintaining the tunes within acceptable limits often requires vigilance by the operator. One instrument, under study at PEP-II, uses a shaker to excite the normal dipole modes of a non-colliding bunch and a lock-in amplifier to determine the tune from the phase characteristics of BPM’s positional response. A signal from the lock-in generates feedback to stabilize the beam’s tunes.[10]

4.4. Instruments: A Philosophical View

Substantial progress has been made toward automating machine controls and adding feedback systems for critical parameters. The consensus among the laboratories is that this long-term effort has improved the operational behavior of the accelerators. Continued development has improved the observational and analytic tools available for the operation of high luminosity colliders.

These tools allow the more accurate measurement and correction of accelerator errors and the ability to discover or confirm intensity dependent behavior. They also permit the determination and maintenance of injection conditions and they aid in the measurement and improvement of luminosity performance. This progress with instrumentation has yielded many benefits to the collider programs. However, as is true for any other tool in the workshop, these tools need maintenance; the cost is time and effort. For example, resources are needed to calibrate BPM offsets, to test software controls, which operate groups of control elements. To better understand the accelerators it is necessary to generate test cases for analysis tools and to ultimately test accelerator model itself. All of the instrumentation and diagnostics are important for the performance of colliders, but resources continue to be needed for maintenance of the tools and for future improvements.

5. INJECTION

5.1 General Considerations

All of the discussion thus far has centered on the operations of the accelerator in HEP conditions, recovery from interruptions and supporting instrumentation. One important aspect of the operations has not yet been considered, the injection process. The routine injection mode at all of the laboratories is to top-off the beams, i.e. after HEP collisions are halted, particles are injected on top of the remaining stored beam.

A number of observations are common to all of the laboratories. It is important to maintain a good beam in the injector accelerators. During injection, keeping detector backgrounds low is critical. Often collimators are employed to reduce any initial errors in the injected beam's horizontal and vertical trajectories and energy. Another common problem is that the orbits tend to drift over time. One solution would be to exercise the magnets in their standardizing magnetic cycles more frequently, but this tends to take time. The magnet standardization cycle time is approximately 45 minutes for PEP-II, 12 minutes for KEB, and 4 minutes for CESR-C. CESR-C solves the injected vs. colliding orbit differences by saving different conditions for the two states.

When the injection performance is below the acceptable range, tuning is required. A critical issue during injection tuning is the protection of the HEP detectors against high radiation levels. One technique is to reduce injection repetition rate, while tuning is underway, paying close attention to radiation loss monitoring around the HEP detector. The most drastic method for ultimately protecting the HEP detector has the beam being aborted when radiation levels exceed some value.

Two other issues for accelerators, having a large number of bunches, is how to avoid over filling and how to avoid filling bunches into RF buckets, which are intended to remain empty. One technique employed for the over filling problem is to finish leveling off bunches at a lower repetition rate to allow for any latency in the process of reading the bunch currents and controlling the topping off. If the beam is over filled, it can always be partially dumped by reducing the stored beam's lifetime. With the very high operating beam currents in this generation of accelerators, significantly overfilling bunches can be destructive to vacuum chamber components due to the large wakefields and synchrotron radiation deposition. At PEP-II the over filling protection requires that the beam be dumped if a bunch is significantly overfilled. At CESR-C the filling software stops the filling process, if the ring's DC current transformer, which measures the total ring current, differs significantly from the sum of the bunch current monitors.

5.2. Injection Fill Pattern Generation

The highest luminosity in today's B-factories has been achieved not with a uniform fill of bunches, but with fill patterns that leave ion clearing gaps. It is important to have sufficient injection control functions so that bunches may be easily filled into RF buckets using pattern generator for the set of bunch spacings. Such controls are in use at CESR-C, KEK-B[11] and PEP-II. They include the necessary intercommunication between processors that provide a good human interface for the operator's input, the pattern generation and the injector bunch control. Operating modes for these injection controls includes uniform filling and topping off modes.

5.3 Continuous Injection

As stated earlier, the goal for high luminosity colliders requires not only high peak luminosities, but also high average luminosities. Following the argument made above, the luminosity efficiency approaches one as the filling time divided by the luminosity lifetime approaches zero. This argues for a method of continuously "topping off" the beam at a low repetition rate and with small amounts of charge per injection cycle. This method has been tested successfully at both KEK-B and PEP-II. The implementation at PEP-II makes use of beam loss diagnostics provided by BABAR.[12] The beam loss is measured as a counting rate for particles above threshold in the electromagnetic calorimeter. From measurements from this diagnostic, it has been found that disabling the detector in a window +/- 300 nsec around the injection time of a bunch is sufficient to reject lost particles from injection. Preliminary tests indicate about a 12% increase in the integrated luminosity. Similar results have been observed at KEK-B. This has not yet been used in operations due to heating related to the higher average beam currents.

5.4 Injector Upgrades

At this time only KEK is considering any major upgrades to their injector. Studies are underway for a Linac upgrade for the proposed future Super KEK-B.[13] A number of upgrade paths are being examined, including raising the positron injection energy to 8 GeV, adding damping rings for lower emittance, increasing the accelerated charge and accelerating positrons and electron simultaneously. This study has produced a 5.7 GHz RF structure, procured an RF source and modulator for tests. The structure has successfully accelerated a beam with a gradient of 41 MeV/m.

6. CONCLUSIONS

This working group had a reasonable amount of time for both presentations and discussions. A fair amount of information about operational details was shared among the members of this working group. It is this author's opinion that a number of useful conclusions have arisen from the discussions and these are summarized as follows:

- Further study of methods to analyze and detect faults visible in digitized signals from operating accelerator systems.
- Advanced accelerator diagnostics systems require maintenance time with the beams. How is this to be accommodated in the present and future accelerators?

There were also some areas where further discussion in the future may be of some interest:

- How the different laboratories use electronic logbooks?
- How machine studies time is scheduled and utilized?
- What are the accelerator diagnostic measurements needed to characterize a set of conditions and what limits the repeatability of the accelerator conditions?
- What are the possible types of accelerator instrumentation and diagnostics and what is a reasonable set of them for the future?

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[11] E. Kikutani, "Fill Pattern Control System of KEKB", working group talk given at this workshop.
[12] U. Wienands, "Trickle (Continuous) Injection Issues with PEP-II", working group talk given at this workshop.
[13] S. Fukuda, "KEKB-Linac Upgrade Plan Using C-Band System for SuperKEKB", working group talk given at this workshop.

APPENDIX: LIST OF TALKS

Table A contains a list of talks given by members of this working group.

Table A: Working Group Talks

Presenter	**Talk**
M. Billing	Operating Experience with CESR
R. Erickson	Operational Reliability of PEP-II
A. Fisher	Developing the Tune Tracker for PEP-II
S. Fukuda	KEKB-Linac Upgrade Plan Using C-Band System for SuperKEKB
E. Kikutani	Fill Pattern Control System of KEKB
D. Teytelman	Fault Analysis for PEP-II RF
U. Wienands	Trickle (Continuous) Injection Issues with PEP-II
U. Wienands / J. Turner	Online Lattice Models and Beam Measurements