Report of the
Error and Emittance Task Force
on the
Superconducting Super Collider:
Part I – Resistive Machines

October 1993

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David E. Johnson
Chair

EXECUTIVE SUMMARY

A review of the design and specifications of the resistive accelerators in the SSC complex was conducted during the past year. This review was initiated in response to a request from the SSC Project Manager.

The Error and Emittance Task Force was created October 30, 1992, and charged with reviewing issues associated with the specification of errors and tolerances throughout the injector chain and in the Collider, and to optimize the global error budget. Effects which directly impact the emittance budget were of prime importance. The Task Force responded to three charges:

1. Examination of the resistive accelerators and their injection and extraction systems;
2. Examination of the connecting beamlines and the overall approach taken in their design; and,
3. Global filling, timing, and synchronization issues.

The High Energy Booster and the Collider were deemed to be sufficiently different from the resistive accelerators that it was decided to treat them as a separate group. They will be the subject of a second part to this report.

Charge 1

The Task Force concluded that the designs and specifications for each of the accelerators were consistent with each other and with the overall emittance budget and the SSC Laboratory specifications. The Committee could see no areas of overriding concern with respect to the individual accelerators and could find no areas which were either too loosely or too tightly specified. In general, the Committee felt that the analysis done on each machine as a system was of high quality and complete enough to ensure that the machine could be built and operated within design requirements. In the specific case of transverse beam emit-

tance, the Committee could find no reason to expect that the emittance budget of approximately 10% per machine could not be met within the machine. There was some concern with space charge in the Low Energy Booster and transition crossing in the Medium Energy Booster, but the Committee felt that these items were either under control or that adequate plans for future work had been made to assure that the expected performance would not be compromised. The Committee felt that the major accelerator systems needed for good operation of the accelerators had been specified and that the tolerances placed on the major components, notably the magnets, were consistent with those needed to guarantee performance. No reason was found by the Committee to change the assignment of the total emittance budget to the individual machines.

Charge 2

The Committee felt that the design analysis of the beam transfer lines between machines was done in considerably less detail than the analyses of the accelerators. The Committee felt that the basic designs of the beamlines were quite good, as were the element specifications. The first-order details, the steering of the beam through the line and correction of beam centroid errors, were handled adequately. The correction of position and angle errors at the injection point of a machine could be accomplished through the use of damper systems. In all cases, these damper systems were not yet designed, but were at the 'existence proof' level. The machine leaders were aware that these systems needed to be fully developed and intended to do so in the future. This was deemed an adequate approach.

The matching of lattice functions at a machine injection point was next examined. The overall beamline designs are robust on paper and more than adequate to match from one machine to another. Tuning scenarios, however, were limited in their development, and, in this Committee's opinion, inadequate. Mismatching of machines through beam transfer lines can occur due to three main causes:

(a) errors resulting in non-design optics of the extracting or injecting machines; (b) errors in the beamline elements at the level of the individual element specifications; and, (c) limitations in the ability of an operator to adequately know the transfer function of a given element or set of elements in the beamline. The first of these areas was examined in detail. The ability of the beamlines to match from one machine to the next over a very large range of possible optics conditions was demonstrated. That is, one could cause the computer to adjust element strengths to match from a given set of machine functions to another, over a large range of functions. It was also demonstrated that errors due to the individual beamline element specifications would lead to a small or inconsequential mismatch and an inconsequential increase in the beam transverse emittance. An examination of the ability of an operator to correctly diagnose and correct realistic errors in beam tuning from a specified set of instrumentation, however, has not been carried out.

The lack of detailed operational scenarios for tuning beamlines is seen as the most serious problem facing the emittance budget. Analyses presented to the Committee have not demonstrated to the Committee's satisfaction that the emittance increase in a machine due to an injection mismatch caused by an incorrectly tuned beam transfer line can be controlled to within the total allowed budget of approximately 10% per machine.

Charge 3

While each beam transfer operation has the potential for beam degradation due to injection errors, the transfers must also be looked at from a more global perspective. Beam steering errors, and beam loss in some instances, can be caused by inappropriate kicker magnet rise and fall times. While each accelerator and associated transfer lines have certain requirements, the entire set of kicker magnet requirements needs to be looked at across the accelerators to understand how best to fill the Collider with beam. In addition, timing and synchronization errors can

have an effect if the kicker rise and fall times are pushing limits imposed by beam gaps in the accelerators.

The Committee looked at the global filling operation of the SSC chain of accelerators, looking particularly at kicker magnet requirements. Several options to the filling scenario were presented to the committee which can provide more leeway in the kicker designs, while sacrificing only a few percent in the total Collider filling fraction. The committee believes that this approach to determining the kicker requirements should be continued in a more vigorous manner in order to firm up these requirements and pin down the future operating scenarios.

In addition, the Committee reviewed the issue of circumference errors in the accelerators, especially in the Collider. Here, the requirement is that the Collider circumference be within 5 cm of its design value of 87120 m. Circumference errors can lead to longitudinal phase space dilution at injection due to the mismatch of the beam with respect to the buckets, and mis-synchronization of the collision points in the detectors. The Committee heard presentations which indicated that the 5 cm tolerance on the circumference is possible with the present surveying techniques, especially if sight pipes located at the service areas are used.

Recommendations

The Committee recommends that:

1. A much more detailed examination of the tunability of the beamlines be undertaken. The diagnostics to be used must be specified and beamline tuning must be demonstrated using only the output of the specified diagnostics.
2. Damper systems are required in all of the circular accelerators for control of injection errors, and, in the case of the superconducting machines, for control of resistive-wall instabilities and vibration. In these latter cases, the damper systems are required to operate over the entire machine cycle. In previous accelerator experience, continual damper operation has led to beam growth due to electronic noise. A program of R&D into low-noise damper systems should be initiated as soon as possible.

1. CONTENTS

Executive Summary	i
1. Table of Contents	1
2. Introduction	2-1
3. Linac	3-1
4. Low Energy Booster	4-1
5. Medium Energy Booster	5-1
6. Beam Transfer Lines	6-1
7. Global Issues	7-1
8. Issues Remaining	8-1
9. Status of First International Workshop on Emittance Preservation in Proton Accelerators	9-1
Appendix A	A-1

2. INTRODUCTION

The Error and Emittance Task Force was created October 30, 1992 and charged with reviewing issues associated with the specification of errors and tolerances throughout the injector chain and in the Collider, and to optimize the global the error budget. Effects which directly impact the emittance budget were of prime importance. The Task Force was composed as follows:

David Johnson, Chair

George Bourianoff

Samir Dutt

Gennady Stupakov

Mike Syphers

The Committee was charged with reviewing existing error specifications of all the accelerators, working with appropriate individuals in the machine groups. The results of this review were to be a report containing specific recommendations for review by the Project Manager.

The first meeting of the Committee was held Nov. 25, 1992, and the charter was discussed and detailed. It was decided that each element of the booster chain be treated independently. The emittance it delivers to its successor was identified as the criterion for declaring the unit acceptable. The following issues of general interest or concern were identified:

- The emittance budget presently allocated to each element of the booster chain may need modification.
 - ▷ Tolerances may be too tight in some places, with no advantage downstream.
 - ▷ Emittance dilution in established proton synchrotrons at Fermilab, CERN and HERA needs to be studied.
 - ▷ Examine the adequacy of the diagnostic capabilities for detecting and

correcting deviations from nominal machine performance.

- ▷ Examine simulations of the effect of space charge taking into account emittance dilution in:
 - the transfer line from the Linac to the LEB;
 - the stripping and injection process in the LEB;
 - the LEB ramp cycle;
 - the transfer line from the LEB to the MEB; and,
 - transition crossing in the MEB.
- ▷ Identify an appropriate scheme for transition crossing in the MEB, on the basis of studies either conducted heretofore, or to be recommended for this purpose.
- ▷ In light of the need for blowing up the longitudinal emittance, the Task Force should:
 - look into possible mechanisms to bring this about; and,
 - determine the longitudinal emittance appropriate for each machine.
- The following issues were identified to be of importance in determining the emittance performance of the booster chain:
 - ▷ Injection & Extraction:
 - β matching
 - Steering schemes
 - Diagnostics
 - Damping
 - Kickers:
 - Overshoot
 - Ripple
 - Timing

Jitter

— RF Matching:

Cogging

Bunch Rotation

▷ Vacuum Requirements in Injectors:

— Beam-Gas Scattering

— Pressure-bump instability in Collider to be studied by Liner Group.

▷ Magnets:

— Multipoles, with attention to multipole components in the Collider and HEB corrector magnets.

— End Effects

— Alignment Errors

— Field strength and gradient errors in the dipoles and quadrupoles respectively.

— Aperture requirements for the warm machines.

— The effect of ground vibrations on magnets.

— The effect of power supply ripple on magnets.

▷ RF System:

— Noise

— Higher Order Modes

— Landau Damping

— Feedback & Feedforward

The Committee decided that the immediate task was to identify the studies already performed on the above subjects, and that, with due consideration, additional studies be recommended in consultation with the Machine Leaders.

During the following year, weekly meetings were held at which representatives of the various machines were invited to present studies, specifications, and other information about each machine. Copies of these presentations can be found in the Proceedings of the Error & Emittance Task Force. A summary of the presentations is given in the following chapters of this report.

In the spring of 1993, it was decided to hold a workshop on emittance preservation with participation from all of the major accelerator laboratories, in order to review and discuss beam studies and operational methods of emittance preservation. The workshop was scheduled for October, 1993, and subsequently postponed until the spring of 1994. The workshop will be further discussed in Chapter 9.

3. LINAC

Much effort has gone into the study of error tolerances for the SSCL Linac. A summary of these studies can be found in a separate report.^[1] In this work, which was presented to the Committee by D. Raparia, three types of errors were examined: beam-related errors (mismatch, energy shift, *etc.*), time independent effects (manufacturing errors, cell length errors, quad gradient errors, *etc.*), and time dependent errors (rf phase and amplitude errors, mechanical vibrations, *etc.*). The Low Energy Beam Transport system (LEBT), Radio Frequency Quadrupole (RFQ), Drift Tube Linac (DTL) and the Coupled Cavity Linac (CCL) were each looked at independently. The analyses allowed one to produce a consistent picture with realistic error tolerances which could produce a final emittance less than 0.3π mm-mrad at 600 MeV. Tolerances of tank and quadrupole relative displacements for the DTL and CCL are typically 0.1-0.25 mm, which should be easily achievable for these components (see Tables 1 and 2).

Table 1: Output Normalized Emittance (rms) (π mm-mrad).

Average of 50 runs. M is the total magnet error.

M(%)	Quadrupole rotation								
	0.00 Deg			0.25 Deg			0.50 Deg		
	ϵ_x	ϵ_y	ϵ_z	ϵ_x	ϵ_y	ϵ_z	ϵ_x	ϵ_y	ϵ_z
0.0	0.21	0.20	0.28	0.22	0.21	0.28	0.23	0.22	0.28
1.0	0.21	0.20	0.28	0.22	0.21	0.28	0.23	0.22	0.28
1.5	0.21	0.20	0.28	0.22	0.21	0.28	0.23	0.22	0.28
2.0	0.21	0.20	0.28	0.22	0.21	0.28	0.23	0.22	0.28

Table 2: Tolerance Budget for the SSC DTL

Time Independent	
Error	Tolerance Limit
Tank Displacement	± 0.25 mm
Quad Displacement	± 0.1 mm
Quad Pitch & Yaw	± 1.0 deg
Quad Roll	± 0.5 deg
Quad Strength	0 - 5%
Multipoles, n=3,4,5,6	1.5% @ 6mm
Tank Field Tilt	$\pm 3\%$
Cell-to-Cell Field	$\pm 3\%$
Cell-to-Cell Phase	± 0.5 deg
Time Dependent	
Tank Field	$\pm 3\%$
Tank Phase	± 0.5 deg
DT Vibration Amplitude (rms)	6 μ

The most sensitive error for emittance growth is quadrupole rotation errors. The specified value for quad roll is $\pm 0.5^\circ$ (9 mrad), also within reason.

The final output emittance from the linac which will be transferred into the Low Energy Booster can be well below the allowed budget of 0.5π mm-mrad. This is represented by the table on the following page. In actual operation, it is expected that the transverse emittance will be made to be larger than this value in order to minimize the effects of space charge in the LEB.

The one area of concern in this first transfer is the tuning of the linac to LEB transfer line. The tuning ability may cause the emittance in the LEB to be larger than the results shown. This is a general problem with the beam transfer lines and will be covered in more detail in Chapter 6.

Emittance Growth in the Transferline

	mm mrad, rms, nor
D2 (dipole)	0.001
($\beta_x = 44.3$ m, PS Stability 0.01%)	
Septum Magnet	0.009
($\beta_x = 8.4$ m, PS Stability 0.04 %)	
Bump Magnet	0.016
($\beta_x = 13.3$ m, PS Stability 0.1 %)	
Multiple Scattering in the foil	0.060
Total	0.086
Emittance From Transfer line	0.25
Emittance after injection	0.336
β Mismatch in LEB	0.0336
Final emittance (x) of injected beam in LEB	0.3696

In a joint session with the SSCL Impedance Committee, Yuriy Senichev presented results of his calculations which indicated a possible source of longitudinal instability which would lead to increase longitudinal emittance upon entrance to the LEB.^[2] The parametric resonance could occur at nominal bunch intensities in the Coupled Cavity Linac due to transient beam loading. Senichev reported that the Linac group is considering feeding power to the tanks at the 1/4 and 3/4 points, rather than at their midpoints. This would suppress the most damaging mode to the beam. The Committee felt that this problem was well understood and under control.

References

1. D. Raparia, *et al.*, "Error and Tolerance Studies for the SSC Linac", **SSCL-Preprint-92**, presented at the 1993 IEEE Part. Accel. Conf., Washington, D.C.
2. Y. Senichev, "Beam Loading Effects in the SSCL Coupled Cavity Linac," presented at 1993 IEEE Part. Accel. Conf., Washington, D.C.

4. LOW ENERGY BOOSTER

4.1 Transverse Emittance

The issue of the transverse emittance in the LEB was described in a talk by S. Machida. Several physical mechanisms which can cause transverse emittance growth in the LEB were studied. These include space charge effects, synchro-betatron coupling and crossing of resonances. Using computer simulation with a code that models space charge effects it was shown that with a proper choice of the tune one can keep the emittance increase within the required limits. Higher order resonances could be corrected with special correctors that are designed to suppress the driving terms of those resonances.

4.2 Longitudinal Emittance

The issue of the longitudinal emittance was covered in a presentation made by N. Mahale. The nominal longitudinal emittance ϵ_L for the LEB is specified as 0.012 eV-sec at injection and 0.038 eV-sec at extraction. In contrast to the transverse emittance, there is no concern about an uncontrolled growth of the longitudinal emittance. Computer simulations show that after the beam is trapped in the bucket the longitudinal emittance is well conserved throughout the acceleration cycle, reaching the final value of about 0.025 eV-sec at the end of the cycle. To match the nominal value of ϵ_L at extraction, special measures must be taken in order to blow up the emittance. One of the options studied is based on the use of a parametric resonance at the second harmonic of the synchrotron oscillations in the later half of the cycle. Another option under consideration is to make the bunch length larger using a phase-jump technique. Computer simulations show that with a proper choice of the injection parameters and timing sequence, the particle losses during the trapping of the beam in the LEB in the optimal regime can be made small, less than 1%. Additional study is needed to examine the sensitivity of the optimal regime to errors in beam injection energy, beam current, *etc.* Experimental verification of the trapping technique on one of the existing machines (such as Fermilab booster) is desirable.

Several issues of concern were raised by the Committee with regard to the acceleration cycle in the LEB. The current specifications call for operation at a very high synchronous phase angle of 61° . This is required partially in order to obtain a sufficiently large bucket with the amount of rf voltage available. This large phase angle may be too high for practical realization. The same concern also pertains to the low ratio of the bunch area to the bucket area (0.65% at extraction). Both issues impose additional requirements on the quality of the feedback system in order to minimize possible errors in RF voltage and phase. For example, the phase stability of the rf system must be controlled to within one degree. The Committee expressed concern over this situation. Subsequently, members had discussions with U. Wienands, R. York, and J. Griffin. These discussions led to the general conclusion that the approach taken did not pose a threat to the operation of the LEB, and that, in any event, the situation could be alleviated by adding more rf cavities, should that prove necessary. The Committee recommends that this situation be reexamined when more information becomes available on the output voltage of the rf cavities.

5. MEDIUM ENERGY BOOSTER

Emittance issues in the MEB are of a relatively benign character. Transverse and longitudinal emittance growth issues have been studied by Y.X. Huang and J. Palkovic respectively. We present a critical summary of their findings.

5.1 Transverse Emittance

The transverse emittance budget for the MEB is between 0.6 to 0.7π mm-mrad. Major sources of emittance growth can be grouped into four categories:

1. The effect of magnetic multipoles and power supply ripple;
2. Space charge tune spread at (a) injection and (b) transition crossing;
3. Decoherence arising from injection errors; and,
4. Collective instabilities.

Nonlinearities are found to induce a small amount of coupling between the horizontal and vertical emittance, causing them to beat together. This has been further confirmed by fourier analyzing single particle motion. The effect is, however, well under one percent, and can be ignored. Power supply ripple is not expected to be a significant factor in MEB emittance growth, due to its very high rotation frequency.

The space charge tune spread at injection (-0.08) was found to cause 10% emittance dilution on account of resonance crossing. The problem has been solved by choosing a new operating point at $\nu_x = 25.43$, and $\nu_y = 25.46$.

Decoherence effects arising from injection errors can lead to significant emittance growth (20% horizontal and 85% vertical). An injection damper system with a BPM resolution of 0.1 mm has been studied and found to reduce emittance dilution to under 1%.

Coherent instabilities important for the MEB are:

- single bunch instability:
 - This can be cured by minimizing the broad band impedance. In view of the longitudinal emittance and impedance specifications for the MEB, this is not expected to be an issue.
- coupled bunch instability:
 - HOM damping increases growth times to more than 20 seconds.
- resistive wall instability:
 - A second damper system controls emittance dilution to under 1%.
- head-tail instability at transition crossing:
 - A chromaticity jump of $\Delta\xi = \pm 4$ is planned for.

5.2 Longitudinal Emittance

Detailed simulations show that the longitudinal emittance will increase by a factor of two in the MEB. This is within the baseline design. In view of the relatively long cycle time of the MEB (8 sec), it may be desirable to identify a mechanism for diluting the longitudinal emittance even more, so as to avoid the microwave instability in the HEB.

6. BEAM TRANSFER LINES

The Committee reviewed the designs and analysis of the two low energy transfer lines (Linac to LEB and LEB to MEB). The goal was to examine specified tolerances of the various components to determine if they were unnecessarily strict, beyond current state of the art or too loosely defined to allow proper functioning of the accelerator chain. A secondary goal was to examine the specified instrumentation to determine if it was sufficient to allow correction of the beamlines to within specified tolerances. The correction algorithms were also examined.

The errors that lead to emittance dilution in beam transfers derive from a mismatch of beam characteristics at the interface between the accelerator lattice functions and the transfer line lattice functions. Three types of mismatches are considered: mismatch of beam centroids; mismatch of beam focusing (beta and alpha functions); and dispersion mismatches. The centroids are easy to adjust and should not pose a problem. A similar statement applies to the dispersion functions.

This Committee feels, however, that insufficient attention has been paid to matching the focusing functions between transfer line and accelerator lattice. This is based on several specific observations. First, the gradient errors that have been utilized in existing analyses are too low. The values used are 0.1% which are the specified values for gradient error of the quadrupoles. However, this error must be combined with the power supply error and magnetic hysteresis effects to predict the accuracy of the magnetic field actually seen by the beam. This is especially true of the magnets in the L-M transfer line which will be manufactured from solid iron blocks as opposed to laminated construction techniques. Solid core magnets are well known to have unpredictable B-I characteristics. The Committee feels that the final figure for gradient errors could easily be as high as 1-2% and the correction systems should be able to correct this level of error.

A second area of concern is the placement of profile monitors in the L-M

transfer line. These are placed in the center of the line and cannot be used for tuning the entire line. It would be desirable to have beam profile monitors located closer to the MEB injection point for use in beam line tuning, as well as to use monitors installed in the MEB itself.

Some preliminary analyses of correction procedures have been carried out for the L-M transfer line. These calculations generally assume that the beamline is close to its design configurations and that the effect of errors can be analyzed by taking linear expansions of optics functions about their nominal operating point. The Committee feels that the situation will likely be much more complicated than that with the beamline being very far from its nominal operating point and that correction procedures will not be independent but strongly coupled. In such a condition, the simple analyses will serve to give some understanding but cannot be trusted to give quantitative predictions of the residual errors after correction.

An interactive simulator tool was developed by the Machine Simulation and Correction group to allow an operator or machine physicist to carry out the fully coupled analyses alluded to in the previous paragraph. The simulator allows the operator to specify errors on all the components and then attempt to compensate for these errors by manually adjusting correction elements while monitoring the actual information that would be available to an operator. The program, TRANS is more fully described in Appendix A.

The TRANS code has been used to calculate the effect of larger gradient errors on the beta function at the injection point into the MEB. A set of 150 cases with quadrupole errors having an rms sigma of 1% gives an average beta mismatch of $\delta\beta/\beta = 0.52$. This leads to an emittance dilution of approximately 5% at injection into the MEB. This constitutes half of the emittance budget for the L-M transfer line and MEB combined.

The 5% dilution factor can and will be reduced through appropriate correction and adjustment procedures. However, the importance of these corrections should not be underestimated.

7. GLOBAL ISSUES

The Committee reviewed the filling scenario for Collider operation, with particular attention to kicker magnet requirements. The scenario described in the SCDR required partial fills of the MEB. Since that time, the circumferences of the LEB and HEB have changed and now the Collider can be filled to the same level of bucket population (90%) without the need for partial fills in any booster accelerators. However, kicker rise/fall times are still pushed to extremes in some cases.

Four options were presented to the Committee by Mike Wilson of the Pulsed Power Group (ASD/EE Dept.) which addressed the kicker requirements. These options lowered the Collider fill fraction from 90% to about 85-88%. One option, with 86% fill, relaxes the kicker rise/fall time requirements for all systems (by 14% at MEB injection, to as much as 98% for HEB injection). (See the following figures.) The kicker parameters for the present design and the four options presented are shown in the following table.

The Committee also examined the question of circumference errors, especially in the Collider. The requirement for the Collider circumference is 87120 ± 0.05 m. This requirement is driven mostly by a) cogging time for HEB/Collider transfers; b) longitudinal phase space dilution upon injection; and c) synchronization of collision points in detectors at opposite sides of the ring. Presentations were made to the Committee by N. K. Mahale and T. Garavaglia,^{[3] [4]} which indicated that the 5 cm tolerance on the Collider circumference should be possible with the present surveying techniques. The use of sight pipes located at the service areas would greatly enhance the ability to preserve the circumference.

Option 4. COLLIDER FILLING SCENARIO (Discard Ten LEB Bunches/Transfer)

$$\eta = 14976/17424 = 86.0 \%$$

KICKER PARAMETERS

	Present Scenario			Option 1			Option 2			Option 3			Option 4		
	Rise	Flat	Fall	Rise	Flat	Fall	Rise	Flat	Fall	Rise	Flat	Fall	Rise	Flat	Fall
LEB Extraction	0.08	2.5	∞	-	-	-	-	-	-	-	-	-	-	-	-
MEB Injection	0.07	1.82	2	-	-	-	-	-	-	-	-	-	0.08	-	-
MEB Abort	2	14	∞	-	-	-	-	-	-	2.2	-	-	2.5	-	-
MEB Extraction	2	14	∞	-	-	-	-	-	-	2.2	-	-	2.5	-	-
HEB Injection	0.42	11.2	1.7	-	-	-	0.83	9,11	3,1	0.53	-	2.1	0.83	-	2.1
HEB Abort	1.7	36	∞	-	-	-	2.8	-	-	2.1	-	-	2.1	-	-
HEB Extraction	1.7	36	∞	-	-	-	2.8	-	-	2.1	-	-	2.1	-	-
SSC Injection	1.7	34.3	4.2	2.5	-	10.2	2.5	-	6.9	2	-	5.4	2	-	5.5
SSC Abort	4.2	290	∞	10.2	-	-	6.9	-	-	5.4	-	-	5.5	-	-
FILLING FRACTION	0.90			0.86			0.85			0.88			0.86		
COMMENTS				Only helps collider kickers.			Requires variable pulsewidth or short falltime.			Helps all systems, except LEB Xfer.			Helps all systems substantially.		

References

3. Garavaglia, T., J. Peterson, and N. Mahale, "The Effect of Global Alignment Survey Errors on the Performance of the Super Collider," SSCL-N-803, December, 1992.
4. Garavaglia, T., N. Mahale, and J. Peterson, "The Effect of Global Survey Misalignment on the SSC," SSCL-Preprint-370, presented at 1993 IEEE Part. Accel. Conf., Washington, D.C.

8. ISSUES REMAINING

A partial list of issues which should be studied in more detail and resolved by the appropriate machine groups are listed below:

- Transition crossing in the MEB;
- Synchronous phase angle in the LEB;
- Design of transverse beam damper systems;
- Examination of the need for longitudinal beam damper systems;
- Detailed scenarios for longitudinal emittance increase;
- Examination of transverse and longitudinal impedance;
- Examination of transverse and longitudinal instabilities.
- Examination of beam profile measurement techniques.

9. FIRST INTERNATIONAL EMITTANCE WORKSHOP

A workshop to review and discuss beam studies and operational techniques for observation and preservation of transverse and longitudinal emittance in proton synchrotrons around the world was proposed. This workshop was scheduled for October, 1993, and has been subsequently postponed until the spring of 1994. The intent was to have papers presented which would:

- Describe established results;
- Bring out practical difficulties and real and potential problems; and,
- Identify issues which are either only partially or not well understood.

A brief description of the workshop is given below, and an announcement and draft schedule are given on the following pages.

The workshop is expected to aid the SSC staff in identifying existing facilities which closely resemble elements in the SSC booster chain. This would provide invaluable in anticipating problems and pitfalls which may arise in the injector chain elements, and in assimilating the operational experience presently available. Joint projects involving the SSC staff and other facilities could be taken up as a useful outcome of this workshop. The workshop could also assist in drafting plans for future studies of interest to existing facilities. The emphasis of this workshop is to be on the experimental aspects of accelerator physics.

Participation will be limited to 75 people, with approximately half coming from outside the SSC. Attendance will be solicited from BNL, CERN, DESY, Fermilab, KEK, LANL, Rutherford, and Russian Laboratories, as well as from several universities. Working groups will be formed to study the following topics:

- Space-charge Effects
- Transition Crossing, both Observation and Control
- Controlled Dilution of Longitudinal Emittance
- Beam Profile Measurement techniques

- Long-term Emittance Growth
- Beam Transfers.

**International Workshop on
Emittance Preservation in Proton Synchrotrons**

October 11 - 15, 1993

South Padre Island, Texas

Purpose

The workshop will review and discuss beam studies and daily operational efforts for emittance preservation (both transverse and longitudinal) in proton synchrotrons all over the world. Papers to be presented will not only describe the established results but also bring up difficulties, problems, and issues which are either partially understood or not understood. It will be a quite unique workshop focusing on *Experimental Accelerator Physics*.

The format of the meeting will be a workshop consisting of invited talks followed by small group working sessions. The emphasis will be on developing practical emittance preservation techniques which can be incorporated into the design and operation of the SSC accelerators.

The number of attendees will be between 50 and 75 people, with participation from all of the major accelerator labs. Participation is by invitation only.

**First International Workshop on
Emittance Preservation in Proton Synchrotrons**
October 11 - 15, 1993
South Padre Island, Texas

Preliminary Program

	<i>Monday</i>	<i>Tuesday</i>	<i>Wednesday</i>	<i>Thursday</i>	<i>Friday</i>
<i>08:30 - 09:00</i>	Welcome				
<i>09:00 - 09:45</i>	Low Energy Booster	DESY	Rutherford	TRIUMF	Working Group Reports
<i>09:45 - 10:30</i>	Medium Energy Booster	Protvino	BNL	KEK	
<i>10:30 - 11:00</i>	<i>Coffee Break</i>	<i>Coffee Break</i>	<i>Coffee Break</i>	<i>Coffee Break</i>	<i>Coffee Break</i>
<i>11:00 - 11:45</i>	High Energy Booster	Working Groups meet	Working Groups meet	Working Groups meet	Wrapup Talks
<i>11:45 - 12:30</i>	Collider				
<i>12:30 - 14:00</i>	<i>Lunch</i>	<i>Lunch</i>	<i>Lunch</i>	<i>Lunch</i>	
<i>14:00 - 14:45</i>	Fermilab	Working Groups continue	Working Groups continue	Working Groups continue	
<i>14:45 - 15:30</i>	CERN				
<i>15:30 - 16:00</i>	<i>Coffee Break</i>	<i>Coffee Break</i>	<i>Coffee Break</i>	<i>Coffee Break</i>	
<i>16:00 - 17:00</i>	Working Groups organize	Working Groups continue	as needed	as needed	

APPENDIX A

A.1 Description of Program TRANS

The TRANS program is designed to graphically simulate the beam dynamics in beam transfer lines. The main purpose of the program is to enhance the study of beam emittance growth caused by transfer lines mismatch and ways to correct them. The program simulates transfer line operation by displaying beam profile at various location and accept correction commands from the user.

The present version of the program uses MAGIC format input data. Traditional two by three matrix formalism is used to calculate ideal beam envelope functions. Beam profile and centroid calculation for lattices with errors are performed using a seven by seven matrix formalism. Thus X-Y coupling and initial beam tilt may be handled readily. Beam distribution is assumed to be Gaussian in six dimensional space. Beam profiles are obtained by integration of the transformed Gaussian distribution over latitudinal and momentum coordinates.

Lattice configuration of the beam transfer line and input beam parameters are read in from a data file and then graphically displayed on the console. Modification of the lattice configuration can be done easily through the program's graphic editing feature which includes add, delete, cut, copy, paste and change element parameter values.

Once the lattice configuration is confirmed, the user may define the simulation environment by selecting a beamline element for profile display, knob assignment and error range specifications for different errors of beam transfer line.

Every time the error generation button is pressed the program will generate a set of errors (either misalignment error or magnet strength error), apply the errors to specified elements, calculate beam profiles and beam centroid curves and display them to the user.

Knobs are used to enable user to do manual correction. Certain global and local correction schemes may also be implemented in the future. The program

will also display ideal beam envelope and dispersion functions along the beamline.

A.2 Source and Executable Files

The source code of TRANS program contains several FORTRAN and C files that reside in the directory: `~yao/transfer`

The name of executable file is TRANS also in the above directory. There are some pixmap files in the directory which are needed for the element display and should not be deleted.

A.3 Input and Output Files

Input file is in MAGIC format. Any valid UNIX file name is acceptable. The default file name is `fort.4`. A file named `fort.1` output file is always generated every time a new input file is read. Users may save the data file in any name.

A.4 Lattice Editing Mode

A menu button labeled "Edit/Run" allows the user to select either editing or running mode. In the "Edit" mode, the lattice can be created, modified by Cut, Delete, Paste, *etc.*, or expanded with new lattice data. In the "Run" mode some editing functions are disabled to avoid confusion.

A single click selects or deselects element for editing. Single click + `< shift >` does group selection. Selected elements are highlighted.

A.5 Run Mode

Configuration of display selection and controls are needed before running the simulation:

a. Display selection

First select the element where you want to display beam profile, then use the "Ctrl Select" pull down menu to select the desired display window. The selected element will be shown on the label above the displays.

b. Control Selection

The first parameter of an element may be assigned as a control variable associated with one of six slide knobs. Controls are selected the same way as the display selection. Selected element and the current variable values are displayed on the slide label.

c. Group Selection

Group selection is not implemented yet.

d. Open Element

Element parameters and names can be modified and displayed by "Open" button. A click on OK will set the input value to lattice.

e. Generating Errors

A menu button labeled "Err" is used to define and activate random error generation routing. The maximum percentage change is set by "Set Max" button. The following equation is used to set variable value:

$$\text{New value} = \text{Old value} * (1 + \text{random}(i) * \text{Max})$$

f. Trace Menu

This menu provides the following display selection for the drawing window:

- beam allows one to read new beam input parameters
- envelope displays beam envelope and dispersion functions
- xy-plot displays profiles in curve format
- profile displays profiles in 2D picture
- centroid displays the beam centroid along the beam line.

Sep 24, 1993

Beam Transfer Line Simulation

11:06:13