SSC-2

SSC Aperture Workshop Summary

November 1984

Foreword

The SSC Aperture Workshop was held November 5-9, 1984 at Lawrence Berkeley Laboratory. Attended by 60 accelerator physicists and engineers from 13 accelerator laboratories, the workshop focused on issues related to the selection of an optimum aperture for the SSC. Aperture is a critical issue at this early stage of design, because it strongly affects both the construction cost and the satisfactory commissioning and operation of the collider.

The workshop had a double purpose:

- To design a course of action for determining the needed physical and dynamic aperture and commensurate magnetic field specifications for a high luminosity proton collider with a beam energy of 20 TeV.
- To prepare a proposal for carrying out the recommended R&D program in two steps -- a four-month intensive phase to provide knowledge essential for conceptual design and magnet selection, and a longer term effort to supply details and ultimately to support the construction, commissioning, and operation of the new collider.

To accomplish these objectives, the participants met in seven working groups, each led by a coordinator:

A. Test Lattices (A. Chao)

B. Aperture Requirements (D. Edwards)

C. Magnet Errors (E. Fisk)

D. Formats, Data Bases, Networks and Lattice Codes (S. Peggs)

E. Tracking Codes (A. Dragt)

F. Analytical Screening (C. Leemann)

G. Experiments on Existing Machines (H. Edwards/G. Lambertson)

Many individuals contributed to several groups, and there was a significant amount of collaboration among groups. After reviewing the status of their topic, each group identified a plan of action. Pursuit of these plans started at the workshop, with participants working on urgent tasks during their available time.

This workshop report includes a summary integrating the findings of all working groups. If the recommendations produce action, the SSC aperture specification should proceed effectively.

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SUMMARY RECOMMENDATIONS

The SSC Aperture Workshop was held November 5-9, 1984 at Lawrence Berkeley Laboratory. The participants met in seven closely collaborating working groups to identify technical issues related to defining the SSC aperture requirement and to recommend a coordinated research strategy for addressing those issues. The working groups focused respectively on

- o Test Lattices needed for aperture determination
- o Aperture Requirements to achieve desired performance and to define the algorithm for magnet evaluation
- o Measurement and understanding of Magnet Errors
- o Data Bases, Networks, Lattice Codes, and I/O Format
- o Improvements to Tracking Codes
- o Analytical Screening of lattice designs
- o Experiments on Existing Machines

As is apparent from the summary reports of the working groups, there was considerable overlap of participation and interest among the groups and significant interconnection between the groups' recommendations. Perhaps one of the most significant general conclusions is that communication among the groups working on the problem during the early months of the SSC R&D effort must be as effective as the inter-group exchanges at the Workshop.

Test Lattices

Magnet quality and lattice design together control the dynamic aperture. Thus an optimal lattice design can relax magnet tolerances significantly and make it both easier and more cost effective to achieve a given aperture. The working group proposed a five-step

program to define benchmark lattices for testing and comparing analytical techniques, tracking codes, and magnet styles, and this report describes in some detail the desirable features of these lattices.

The five-step development entails

1) Strings of FODO cells
2) FODO cells with simple IR
3) Inclusion of errors and correction schemes
4) Inclusion of sophisticated sextupole schemes
5) "Real" SSC lattices

These lattices are to be standardized test lattices, rather than real lattices. The first three steps of the process should be accomplished over the next two months and the lattices should be made available on the SSC Data Base.

Aperture Requirements

This working group considered development of a performance-oriented aperture specification and the incorporation of this specification into an algorithm for magnet evaluation. The group agreed that the optimum aperture for the SSC is one that results in a reasonable construction cost and high operational reliability.

After considering many SSC systems and operating states, the group concluded that injection, first-turn behavior, and beam measurement requirements control the aperture requirement. Thus analysis of these aspects of the SSC will provide the critical specifications for aperture and misalignment tolerances. In the group's opinion it is essential to monitor closely the Tevatron's startup in 1985 to obtain

measurements of dynamic aperture and thorough documentation of machine pathologies, particularly those related to aperture.

Magnet evaluation in light of the performance requirements should proceed via test lattices, analytical screening, tracking, and comparing the results with the performance specifications.

Magnet Errors

This working group discussed the data available characterizing magnet field quality and the types of measurements needed soon to allow magnet errors to be included in tracking and lattice codes.

For cosine magnets random errors due to imperfect construction have been measured on 700 Tevatron dipoles and on 10 field-quality CBA dipole. These measurements are quite consistent, with the CBA magnets having lower magnet errors than the Tevatron magnets. The group recommended, therefore, that a conservative approach would assume errors in SSC dipoles comparable to those found in the Tevatron magnets. However, field-error calculations based on a realistic appraisal of construction errors in SSC Models A and B are underway, and should produce an improved set of multipole errors.

For superferric magnets, existing data are sparse and those cited in the Reference Design Report are not up to date. Random multipole errors will be estimated and available in December. Measurements on 3-foot model superferric magnets are expected in three months.

Studies of the effects of persistent currents in both types of magnets are underway and the first results should be available by January 1985. The practicality and cost penalty of using finer

superconducting filaments to minimize persistent currents will be investigated as well.

The working group recommended that up to date data on magnet errors be maintained in the SSC data base, and agreed to meet in early December to finalize this first phase of its work.

Data Bases, Networks, Lattice Codes and I/O Format

For coordination, ease of communication, and R&D efficiency, lattice characterization and I/O format for lattice and tracking programs should be standardized. The working group recommends a modified Carey-Iselin format as described in Appendix 8 of this workshop report.

The group also agreed that an SSC Data Base should be established by the CDG on a VAX-780 at Lawrence Berkeley Laboratory. The Data Base should be accessible via existing networks to all SSC R&D participants. The data base should include standard sets of magnet errors, standard lattices, current versions of lattice design and tracking programs, and other data and codes of general interest. The Data Base should be available by December 1 for testing. The working group strongly recommends that adequate staff to establish and maintain the data base, convert and standardize programs, and provide assistance to users should be available as soon as possible.

Tracking Codes

This working group concluded that lattice and tracking codes need to be upgraded quickly to serve the SSC effort. The key challenge for kick codes is to be symplectic, handle six-dimensional phase space, and include synchrotron oscillations. Lie algebraic codes need to be

extended to higher order and adapted to include magnet misplacement, misalignment, and mispowering. All codes need to be documented better, have standardized input format, and be adapted to parallel processors and Class VI computers. To support this effort, programming support is essential.

Analytical Screening

Analytical methods allow cost-effective estimates to be made of tune shifts, resonance widths, and invariant curves. Thus, they could be used for preliminary screening of lattice designs with minimal investment of computer time and manpower. In addition, analytical technique could form the basis of design tools and provide the understanding essential for the extrapolation of long-term stability from limited tracking runs.

The working group concluded that it is important to provide improved analytical capability for the SSC design effort. In particular, work should begin immediately to strengthen or implement analytical procedures in the front ends of existing tracking codes to allow for rapid screening of proposed lattices.

Experiments on Existing Machines

A major purpose of machine experiments to address the aperture issue is to supplement and check tracking codes and their computation. Existing machines also could provide analog models for studying SSC behavior and aid understanding. The working group placed the highest priority on experiments at the Tevatron during the next run to

- o measure dynamic aperture,
- o validate aperture analysis and predictions,
- o reveal and study phenomena not predicted with numerical simulations,
- o measure the effects of controlled sextupole perturbation, and
- o observe distorted phase motion of large-amplitude particles.

Additionally, experiments at SPEAR could compare dynamic aperture measurements with values calculated from tracking programs. Later in the R&D program experiments should be done at Tevatron to establish a firm basis for extrapolating to the Tevatron scale.

The first step in the experimental effort is the generation and submission of proposals. This needs to be done quite soon, and the working group sketched out a couple of example proposals, included in this report.

Conclusions

The workshop concluded that aperture-related issues are important ones that must be resolved early during the SSC R&D phase. Magnet specifications and lattice design cannot be finalized until the aperture is optimized. In light of the schedule for SSC R&D, the next few months are critical ones for selecting the appropriate aperture and putting the tools (computational and experimental) in place that will be essential for the development of an optimal, cost-effective SSC design.

REPORT FROM WORKING GROUP A*

ON

TEST LATTICES

*A. Chao (Coordinator), T. Collins, E. Courant, F. Dell, D. Douglas, A. Garren, D. Johnson, E. Keil, S. Lee, M. Month, D. Neuffer, R. Talman, S. Heifets, A. Ruggiero, A. Wrulich

Goals

Group A of the workshop performs two functions:

1) define the linear and the nonlinear test lattices that are needed to feed into the magnet aperture evaluation algorithm.
2) propose a plan and time table to produce the defined test lattices.

It is worth emphasizing that the test lattices are not meant to be the final SSC lattices. They will have to contain the necessary ingredients for dynamic aperture evaluations, but otherwise do not have to contain many of the practical considerations envisioned for the final SSC design. Drastic simplifications are thus allowed, even encouraged, as long as they do not significantly influence the dynamic aperture determination for the various magnet styles.

One difficulty in making comparisons among the various study groups has been that the existing test lattices have covered a wide range in parameter space and in their levels of sophistication. In order to make comparisons as effectively as possible, the idea is to produce a small number of "bench mark" test lattices which are to be stored and maintained in the data base at the SSC central design group. Users from various local groups obtain these lattices from the data base and if necessary they can study minor variations of them. The bench mark lattices, however, remain to be the ones for which to evaluate

1) the various analytical techniques,
2) the various tracking codes, and
3) the dynamic aperture of the various magnet styles.

As work proceeds, the bench mark lattices will evolve.

The Test Lattices

The group has recommended to produce the test lattices in five steps.

1) A string of FODO cells
2) FODO cells interrupted by "simple interaction regions (IR)"
3) Inclusion of errors and corrections
4) Inclusion of sophisticated sextupole schemes
5) "Real" SSC lattices

Step 1. FODO String

The most primitive representation of the SSC is simply a string of FODO cells. See Appendix 2.

One question on the FODO cell is the choice of half cell length L. Various considerations affecting L have been discussed in Appendix 2. The group has come to the concensus that the following choices of L are probably not too far away from the optimum and will be adopted in the test lattices:

$$L = \begin{cases} 100\text{m for magnet design A} \\ 115\text{m for magnet design B} \\ 150\text{m for magnet design C} \end{cases}$$

Another question concerns the betatron phase advance per cell ϕ. Clearly the linear optics can handle any value of ϕ between 0 and 180°. In order to have well defined sextupole solutions (see later), however, the group has suggested to study the $\phi = 60°$ and 90° cases only.

The choice of L and ϕ determines the rough values of the betatron tunes for the three magnet designs. The rough tunes are shown in the following table.

	A	B	C
$\phi = 60^\circ$	66	75	97
$\phi = 90^\circ$	99	113	146

It is worth mentioning that, for given ϕ, longer cells require weaker chromaticity sextupoles but shorter cells are less sensitive to error effects.

It is also suggested that the FODO cells be equipped with two families of chromaticity sextupoles. The locations of the sextupoles are not to perturb the symmetry of the locations of the quadrupoles and the dipoles in the cell geometry.

We should make sure the FODO cell lattices yield ample apertures for all three magnet styles. When errors are included at a later stage, some variations of the lattices need to be made in order, for example, to make tune scans to study the resonance effects.

Step 2. FODO Strings + "Simple IRs"

A simple string of FODO cells allows essential information on dynamic apertures to be extracted but some essential features (such as the chromatic effects of the IR's) will be lacking. To eliminate such ambiguities as much as possible, the group suggested to have "simple IR's" inserted in the FODO strings as the second step.

The "simple IR" will have to have the essential features of a realistic IR as far as the dynamic aperture is concerned, while it also has to be well defined and simple for various study purposes. Given the FODO cells, the IR will need to match the linear optics to a desired optics at the interaction point (IP).

The group suggested the lattice with simple IR's to look like Fig. A1. The whole lattice has superperiodicity of 6 with mirror antisymmetries with respect to the IP and also with respect to the midpoints of the arcs.** The rf cavities are located in the phase-trombones.

The group suggested to use the "2-cell-reduced-bending" scheme for the dispersion suppressors. For the IR, it suggested to adopt $\beta_x^* = \beta_y^* = 1$ m at the IP. See Fig. A1. We will not worry too much about the maximum allowed quadrupole strength in the IR.

A complication is that there needs to be a way to adjust the tunes of the lattices. The question arises whether to do it in the cells or in the IR's. The group suggested to do it in the IR's, which will be performed in the phase trombone section, which is basically a continuation of the normal cells but with variable quadrupole strengths to allow tune variations (details to be worked out soon). The reason of this choice is to allow that the cell optics can be frozen for the sextupole schemes. It was felt that allowing the sextupole schemes to be violated, even by the "small" amounts needed for tune variations, could potentially lead to ambiguities which we are trying to avoid in the test lattices.

The global values of the betatron tunes are determined by the cell length and phase advance per cell as described above. To decide on the test lattices, one still needs to decide on the fractional part

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**Modified from the oral report on November 9, 1984.

(modulus 6) of the tunes. Appendix 3 is a list of issues that need to be considered for a detailed tune search. The concensus is that one should avoid "low" order resonances in the tune spread range of the beam. The tune spreads come from nonlinear magnetic fields as well as the beam-beam perturbation. This means we should choose the working region carefully to fit into a resonance free area in the (NUx,NUy) diagram. In addition, one might refer to the Sp$\bar{p}$S tunes, which are close to NUx = 26.69 and NUy = 27.68. The nonintegral parts are approximately 0.7. Since the beam-beam tune shifts in Sp$\bar{p}$S is opposite to that in SSC, it is suggested (Courant) that the nonintegral part of SSC be close to 0.3.

Another consideration in the choice of fractional part of the tunes is given in Appendix 4. In Appendix 4, it is shown that $d^2\nu/d\delta^2$ and $d\beta^*/d\delta$ are approximately the smallest when the tune per superperiod is 0.25 or 0.75 ± 0.02. If these chromatic effects turn out to be important limiting factors in dynamic aperture, this consideration would guide the subsequent tune choices.

Step 3. Errors and Corrections

There are basically two types of errors that need to be considered: the magnet multipole field errors and the magnet misalignment errors. The magnet multipole field errors are being specified by Group C. The part that concerns the test lattice group is the correction scheme for these multipole field errors. In particular, the random sextupole component, residual from local corrections made on magnets, may still need to be corrected by lumped correction elements. If so, we need to

design a correction scheme in collaboration with the analytic screening group (F).

As to the magnet alignment errors, the first task is to determine the magnitude of these errors to be used in the test lattices. The same set of misalignment errors are to be used for all magnet styles for comparison purposes. A review of the reference design report suffices.

When errors are included, corrections must follow in order for a fair evaluation of the aperture. In particular, the closed orbit needs to be corrected. A simplified correction scheme will be needed to simulate these effects. The orbit after correction will probably have a rms value of the order of 1mm or 2mm to simulate the needed room for practical operations.

Once step 2 is finished, simulating the simplified orbit error and correction in the test lattices should not take more than 2 or 3 weeks. A more difficult job is to simulate the errors and corrections of the tilted quadrupoles, which cause x-y coupling in the particle motions. This work, however, will be initiated only when need arises.

Step 4. Sextupole Schemes

Test lattices up to now contain only two families of sextupoles for chromaticity corrections. For large storage rings, more sophisticated sextupole schemes are necessary. The group recommended that three sextupole schemes be studied in the test lattices:

1) the non-interleaved scheme,
2) the interleaved scheme, and
3) Collins scheme and its derivatives.

The same three schemes are being studied by HERA and LEP designers. Without doing the actual studies, the group did not feel comfortable to make judgments on preferences among the three schemes and therefore they will all be included.

All schemes require specific values of betatron phase advance per cell. As mentioned before, to ensure the sextupole schemes are not violated, the cells are frozen and tunes are varied not in cells but in the trombones in the IR's. Since the IR's are dispersion free, there will not be sextupoles in IR's.

When comparing different magnet styles, the same sextupole scheme will be used. The comparison process is then repeated using other sextupole schemes.

Step 5. "Real" Lattices

To determine the dynamic aperture of the magnet styles, it is not necessary to include all the practical details in the lattice. Indeed, he search for the final SSC lattice is a continuous effort; attempt to find a "real" lattice to be used as test lattice at this stage would not be beneficial and, in fact to the contrary, would be harmful in that it distracts us from our main goal. It was therefore recommended at the workshop that work on "real" lattices be carried out by the various working groups at a lower priority with a longer time scale. Items that can be studied in this step then includes:

- crossing angle geometry
- utility sections
- combining phase trombones with utility sections
- side-by-side vs under-over geometries

- clustered IR's
- beam-beam interaction
- noise and feedback
- terrain following
- 20 TeV storage lattice

Clearly the list does not end here. The hope is that the test lattice will not have to include these features in order to be able to make the magnet style choice. When and if some of these features are found (for example by Group B of the workshop) to be essential in terms of dipole magnet aperture, they will be included in the test lattices accordingly.

Summary of Test Lattices

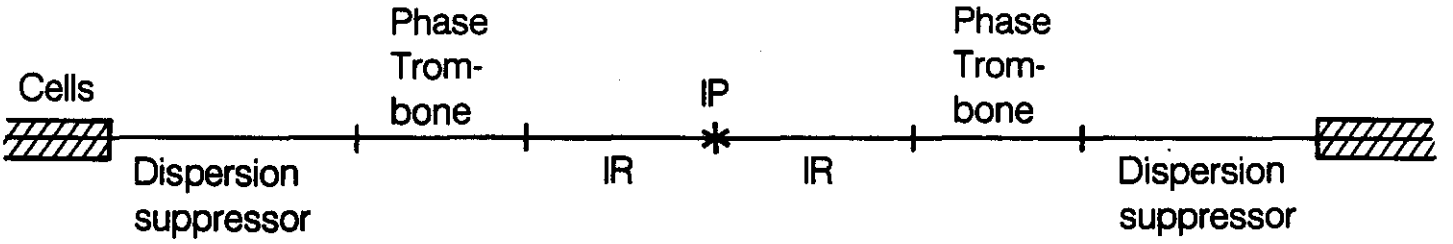
The group has suggested that there should be six linear test lattices to be studied, two for each magnet style. As a first step, the test lattice can be just a string of FODO cells. Studies of these simple lattices should not last for too long until the second step takes place. The test lattices to be used in the second step would contain simple IR's in the FODO cell string. The two linear test lattices for each magnet style correspond to betatron phase advance per cell $\phi = 60^\circ$ and 90°, respectively.

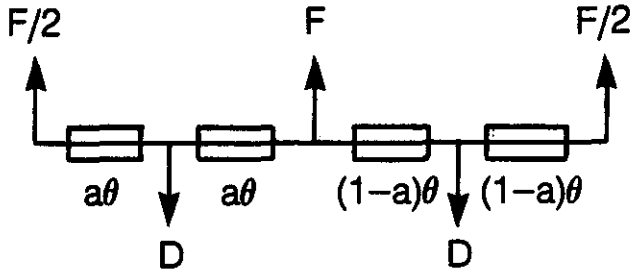
Magnet errors are then added as the third step. Studies of error effects would occupy a longer time than studies of the bare test lattices in steps 1 and 2. At about the same time, sophisticated sextupole schemes are being designed as the fourth step. The group has suggested three sextupole schemes for each of the six linear lattices,

yielding a total of 18 nonlinear lattices. It is conceivable that some of these 18 lattices can be eliminated on general grounds before extensive studies begin. Studies of the nonlinear lattices would take approximately two months time. Studies of lattices with magnet errors and sophisticated sextupole schemes combined would take place soon after that.

In the background, design of "real" lattices would be going on. These lattices are not to be used as the bench mark test lattices for dynamic aperture evaluation and therefore are not high priorities as far as magnet style choice is concerned.

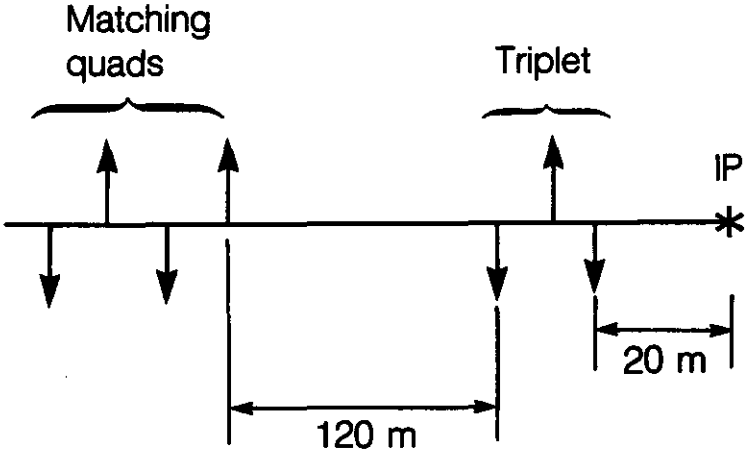
Figure A2 is a rough sketch of the test lattice work to be done for the next three months. The dotted lines represent estimates on how long the analytical and tracking (especially tracking) studies by other groups would perhaps take. Some names are identified for the work to be done; they are represented by the abbreviations on the chart.





Dispersion suppressor

$$a = \begin{cases} 0 \text{ if } \phi = 60° \\ 1/2 \text{ if } \phi = 90° \end{cases}$$



$\beta_x^* = \beta_y^* = 1$ m

Fig. A1

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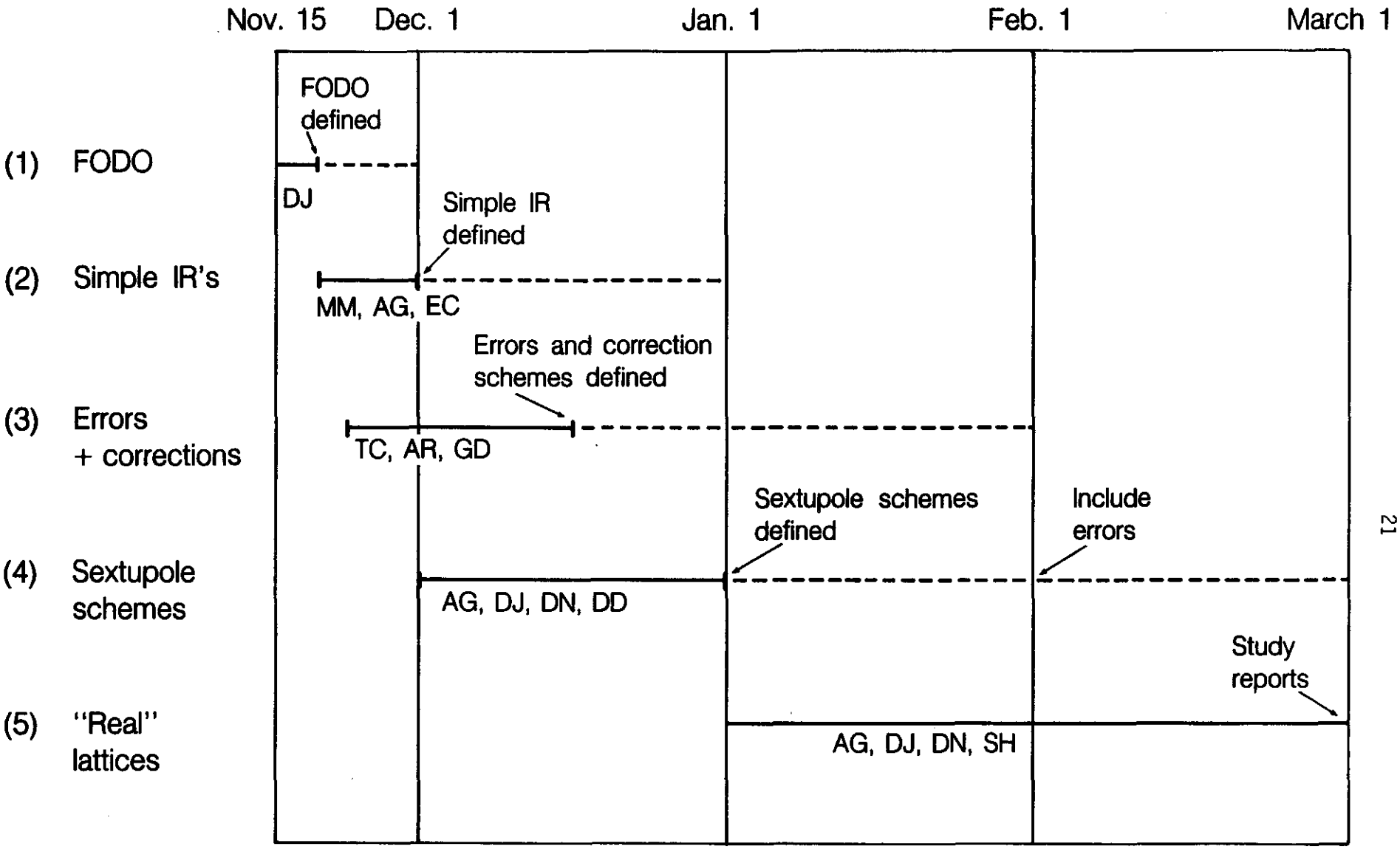

Fig. A2

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REPORT FROM WORKING GROUP B*

ON

APERTURE REQUIREMENTS AND MAGNET EVALUATION ALGORITHM

*D. Edwards (Coordinator), J. Bisognano, E. Courant, M. Harrison
E. Keil, G. Lambertson, C. Leemann, M. Month, P. Morton, D. Neuffer
J. Schonfeld

Introduction

The charge to this group is stated in the announcement and need not be repeated in full here. Briefly it contains two stages:

1) Develop a performance specification and translate to aperture requirements.
2) Propose an algorithm for magnet evaluation in "light" of the above.

The material in this summary was assembled from material provided either in writing or in conversation by Joe Bisognano, Mike Harrison, Eberhard Keil, Chris Leemann, Mel Month, Dave Neuffer, and Jonathan Schonfeld. In some cases, the authors haven't had a chance to review this summary; if there are errors of interpretation, the fault is the assembler's.

Performance Specification

Here, one is supposed to examine the requirements of the various operational modes, such as

- initial operation and basic measurements
- single beam injection
- diagnostics and studies
- second beam injection
- acceleration
- storage
- etc.

We note two particular difficulties common to elements of the above.

1) Quantification of allowance for non-ideal ("sick) operation. This is not to be confused with any design safety factor applied by the management.
2) Definition of rational accelerator behavior.

Brief commentary on some of these modes follows.

Abort

The fundamental problem with an abort system is the inherent uncertainty in the characteristics that one can associate with the beam during the abort process. The decision to abort the beam presumably reflects some pathology which may manifest itself as a much larger beam spot or a position which is far removed from the nominal closed orbit. The only real assumption that one is allowed to make in terms of beam dynamics when considering the abort system is that the beam is still circulating inside the machine in some fashion. Whether or not this

aspect of the machine performance has any ramifications on the aperture question is (not surprisingly) related to the choice of design of the abort region. If one embeds the abort channel and kicker system within the regular lattice then the lattice must possess sufficient physical aperture above and beyond that in which the beam can circulate to allow a clean abort. This aperture requirement can be avoided by constraining the beam dynamics implicit in the abort system to be a local effect removed from the main arcs. A detailed discussion of the aperture needed for an abort system is outside the scope of this report but the reference design gives a good feeling for the approximate scale of things. Based on these numbers it is apparent that imposing the needs of the abort system on the aperture of the main bending magnets is not a rational design choice. We therefore conclude that the choice of magnet aperture is not influenced in any way by the abort system but rather that the abort system reflects the available magnet aperture.

Acceleration

Operational experience with the Tevatron has shown that the onset of acceleration is a point in the machine cycle where beam loss does indeed occur on a relatively frequent basis. (The use of the word relative here is important. The Tevatron by definition is a clean machine and beam loss is essentially zero during regular operation. When losses do occur however, this is one of the places where they manifest themselves.) The question of whether this is related to the magnet aperture of the main dipoles in the direct fashion (beam loss can always be associated indirectly with magnet aperture) is the one

that must be answered. Acceleration cycle beam loss exhibits a strong correlation with synchrotron oscillations during injection. A beam injected "off-axis" into the RF buckets will filament and eventually occupy a longitudinal phase space area within the bucket much larger than the inherent phase space area of the beam. The bucket area shrinks at the onset of acceleration and beam falls out of the stable area and is lost. Increasing the momentum aperture of the machine would have little if any effect on this process as the momentum acceptance of the machine is much greater than the bucket area in any case. This problem is really one of injection.

During normal operational of the SSC the high injection energy (relative to γ_t) will ensure a very stable beam during acceleration (similar to the Tevatron) and as such no defining aperture requirements from this aspect of machine performance are envisaged.

Operational Tolerances

In an operational environment an accelerator must be expected to function reasonably effectively under less than optimum circumstances. Tolerances associated with performance criteria will obviously not define the machine aperture directly but can be regarded as a kind of contingency requirement which must be added on to aperture estimates arrived at from other considerations. Data from the Tevatron shows that while it is possible to smooth the orbit at any given energy to within 0.1 mm of any desired position, closed orbit residuals of ±2 mm are accepted as an operational norm. Orbit positions during acceleration are presumably less important than those when the beams are

colliding. Local closed orbit excursions are used frequently in the Tevatron but exclusively in the context of positioning the beam across the straight sections to accommodate the various beam manipulations (injection, abort, extraction). In the Tevatron design this does indeed place aperture demands on the main dipoles. This need not be the case in the SSC where a greater flexibility in design is possible. Medium term closed orbit stability can be expected to be good in the SSC; without operator intervention Tevatron beam positions appear to be constant to within 1 mm over periods of several weeks. Problems associated with RF stability will not pose significant aperture demands.

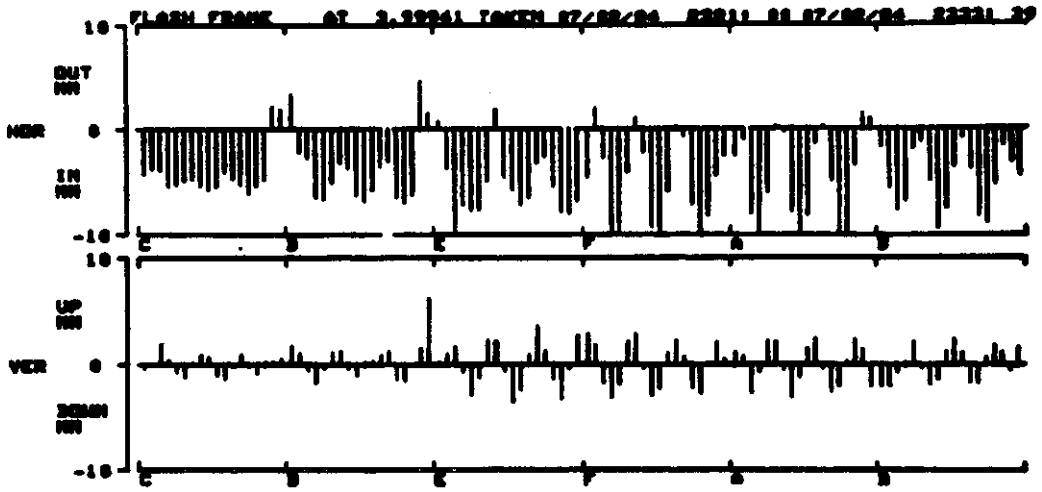
We conclude that operation tolerances must be factored into the final aperture assessment but the effects on the dipole aperture can be minimized in the machine design. Careful monitoring of the Tevatron operation should provide good information for the SSC design.

Injection

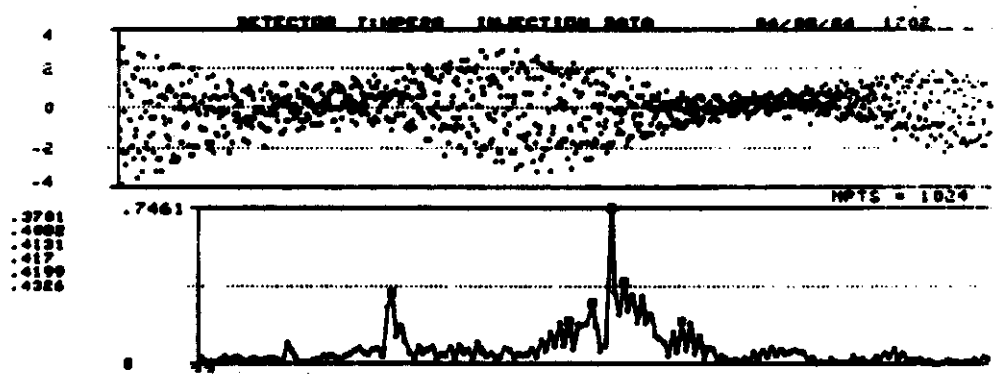
The problems inherent to the injection process may well prove to be the most demanding in terms of magnetic aperture. Several factors are working against you at low energy (larger beam size, persistent currents) and the beam must survive for a relatively long time (~20 minutes) while the machine is being filled with beam. Some factors are relatively easy to estimate in terms of beam behaviour (kicker magnet waveform, power supply ripple, dipole field matching). Unfortunately these effects are small and would lead to an unrealistic assessment if these were the only criteria considered. Naively one

may imagine that once the injection system is tuned up and the beam placed directly onto the closed orbit then the residual betatron oscillations should remain small. Operational experience on the CERN $S\bar{p}pS$ (where great care is taken) and Fermilab (less so) shows that achieving injection oscillations below the ±2 mm level is difficult in a practical environment. The production of beams of injection energy requires a sophisticated system of pre-accelerators and beam manipulations; an accurate projection of the end product must be made.

The situation does not end here, however. In a device as complex as an SSC it is not realistic to expect everything to function correctly all the time. Gross malfunctions are easily detected in a variety of ways, more subtle effects can only be revealed by the beam itself. This class of problem which is really one of machine functionality rather than injection is invariably manifested at injection as this is the first time the beam is in the machine. The situation that we must be careful to avoid is one where the machine either functions perfectly or we quench at injection. There appears to be a correlation between available machine aperture, the number of turns needed to provide a signature as to what the problem is, and the potential consequences of the problem.



The data above is the first turn in the Tevatron in a situation which produced a magnet quench. An energy mismatch between the two rings is obvious.



This data shows the first 1000 turns as a single position detector. The machine was not running correctly and several subtle things were wrong. The machine, however, was capable of accelerating

(and extracting) at a reduced intensity. It is interesting to speculate on how long it would have taken to trace a problem in an RF cavity beam loading compensation circuit without the benefit of the beam. No systematic data has been taken with a view to attempting to quantify these effects (until recently no accelerator quenched); we proposed to closely monitor the first few months of the upcoming Tevatron fixed target physics run.

Beam Measurements

Commissioning of an accelerator involves an extensive series of measurements to determine the optical properties of the machine. Of necessity these measurements will place aperture demands on the magnets and together with the injection process will in all likelihood define the magnet aperture. It is therefore crucial to obtain an accurate picture of the commissioning scheme. Basic machine operation will involve measurements of tune, x-y coupling, chromaticity, resonance widths and tune versus amplitude behavior. This information is necessary to establish accelerated beams. Further measurements must then be made to commission low-beta regions and beam collisions. Fortunately we have a recent example of the start-up of a superconducting accelerator together with a low-beta region. We propose to analyze the Fermilab experience in some detail. This information together with the projected magnetic field harmonics can then be used to scale to the SSC. The results of this exercise ought to be relatively insensitive to the detailed lattice structure in the arcs. This problem is one where computer simulations can be used effectively to

predict the beam behavior and we would anticipate a substantial input from this type of approach.

The other topic we must address is that of measurement technique and accuracy. For first turn behavior counting oscillations is a perfectly good tune measuring system but not terribly precise. High precision in measuring systems can ensure that no more machine aperture than necessary is devoted to a measurement of chromaticity, say.

This subject is an important one and will be addressed in detail in the next several months.

Second Beam Injection

The problem of whether the presence of beam in one ring affects the aperture requirements of injection into the other one basically reduces to questions of do we need to separate the beams at the crossing points and if so, would this have any effect on the arcs.

The interaction between the beams at low energy and the possible consequences on the beam lifetime must be looked into in some detail. The aperture requirements at injection are likely to be severe enough that any additional beam manipulations at the crossing points must be defined to be local and confined to the interaction regions themselves. This problem is one of design and not aperture.

Instabilities

The SSC machine parameters given in the design report indicate that beam instability thresholds are not approached during the standard running modes. Nevertheless it would seem prudent to examine whether beam instabilities can be expected to make direct demands on dipole aperture.

Beam instabilities are created in conditions where controllable beam parameters (phase space densities) interact in a pathological way with fixed design features. The problem becomes one of identifying the cause of the effect in a situation where beam loss (quench) is likely. Fortunately, thresholds are well defined and can be approached in a controlled way so that problems associated with persistent beam losses can generally be avoided with an effective abort sytem. The dynamics of the beam losses are such that very little is gained by enlarging magnet apertures - particles getting lost in a 15 mm radius would presumably exit a 20 mm radius machine also a few turns later.

Beam measurements needed to identify instabilities are not the type which impose aperture requirements. Thus we conclude that beam instabilities should not directly influence the choice of magnet aperture.

First Turn

The first task in commissioning the SSC is obtaining beam transport around a single full turn of the ring. This task is opposed by magnet misalignment, which deflects the beam from the magnet centers toward the beam pipes. Iterative correction of the beam path is necessary.

During the SSC reference designs study P. Myers studied this problem[1] and simulated this iterative process with the correction procedure used in Tevatron commissioning. In the Tevatron each focusing quad has a position sensor and a steering magnet. (F quads correct horizontally, D quads vertically.) Positions are measured in each attempted turn, and a "three-bump" calculation at each quad

obtains steering corrections for the next attempt. Further attempts progress further around the ring until a full turn is obtained.

In Ref. 1 an rms displacement error of 1 mm was generated randomly about a set of lattice cells and single turn transport within an aperture of 15 mm (radius) was attempted. In the simulations an average lattice progressed about 7.5 cells/iteration. However, ~35 of randomly generated 100 cell lattices failed to obtain a full turn. Failures occurred where nearest neighbor quads had particularly large relative displacements (2σ). Failure was reduced to 5 if correction in both x and y was attempted or if nearest neighbor alignment was within less than 2 mm. This may be acceptable since occasional failures may be recovered by human intervention.

The study indicated that obtaining a single turn with these parameters is possible but somewhat difficult. Further studies which explore the parameters of the alignment process are strongly indicated for the SSC. Questions to be explored include:

1) What rms error in magnet placement is reasonable Some observers[2] indicate σ_{RMS} = 0.1 mm is possible. Alignment of nearest neighbors should be much smaller than the RMS value, and the effects of realistically obtained errors should be investigated.

2) Dependence on aperture limit as well as σ_{RMS} should be explored.

3) After a more accurate determination of error magnitudes, the question of whether constructing both F and D correction systems (x and y) is desirable should be decided.

4) Practical limitations should be considered. Beam loss during first turn determination may lead to magnet quench and subsequent delays in the iteration process. How often will that occur at SSC parameters? 500 cells/turn with 7.5 cells gained per iteration implies ~70 iterations. Is this impractically large? If not, what number is practical?

Storage

No additional requirements peculiar to storage were identified, particularly when the short time available to this study is taken into account. The control of background arising from beam halo should be studied, but this is not the sort of thing that can be treated in a few months.

References

1. "SSC Magnet Alignment and Aperture," P.D. Meyers, SSC Note-27 (1984).
2. Anonymous, unpublished communications (A.D.).

Algorithm for Magnet Evaluation

Simplified flow charts are easily sketched such as the version drawn at the end of this report. In reality, there are many closed loops and branches; if one tried to take all the variants into account at the outset, it would be next to impossible to get started. For "next week" a simple version - any simple version - is likely to be the best one can do.

The determination of whether a lattice/magnet design satisfies basic aperture requirements involves the interaction of a large number of workers in a variety of roles. One possible itemization of the roles would be:

1) Determination of operation requirements from performance goals, analysis, and experiments on existing machines.
2) Measurement and modelling of magnet state-of-the-art.
3) Construction of test lattices for various magnet specifications in light of performance goals.
4) Analytic screening of lattices for unacceptable nonlinear behaviour.
5) Tracking studies to determine if test lattices that pass (4) satisfy goals as set by (1).

This list can be viewed as a simple flow chart of the decision-making process. Items (1) and (2) provide input, item (3) determines a test configuration, and items (4) and (5) determine if the test case satisfies requirements of item (1). If either step (4) or (5) rejects a lattice, then one loops back to (3).

Execution of role (1) presupposes that work has been done to translate operating goals into unambiguous figures of merit that can be addressed clearly by lattice evaluators. Both (4) and (5) presuppose that real-machine experiments have been done to justify the theoretical tools in question. (5) presupposes development of well-defined statistical criteria as well as inter-code checks.

Several other patterns can be envisioned for the decision process, but the basic question is not so much this structure, but its implementation in practice. A number of issues, some technical and some managerial, come to mind. Among the technical issues are:

1) "Operation requirements" refers not only to aperture per se, but also to conditions that, for example, will make the storage ring relatively easy to tune, and make at least certain common problems relatively easy to diagnose. Thus, the requirements should include not only numerical aperture specifications, but also, for example, a numerical specification of how the machine should respond to certain common malfunctions (e.g. misfiring of an injection kicker). Such malfunctions should then be routinely simulated by analytical screeners, and by trackers.

2) The people responsible for analytical and numerical evaluation of a proposed lattice ought to be able to tell a designer more than "start again" if the lattice in question does not meet requirements. The available analytical tools - low-order perturbation theory, resonant stop-band

calculations - are simple enough that one can hope to use them to pinpoint the source of a problem and to suggest a correction. Tracking is not yet up to this. We consider this the weakest single link in the design process. In our view, the goal of theoretical research in the near future should be the development of analytical aids that can permit one to extract more useful information (e.g. correction schemes) from tracking outputs. This might in time lead to diagnostic tools for extracting useful information from real orbit characteristics once the machine is actually turned on, and once the corresponding measurement capabilities are in hand.

3) A corollary of (2) is this: We cannot say at present when enough iterations of subloop 3-4-5 has produced the best lattice possible for the magnets available, let alone whether it has produced a global as opposed to a local optimization. We cannot even say at this time if 3-4-5 can be made convergent in a systematic way.

4) If issue (3) could be settled, one would like to know if the results of 3-4-5 could be fed back to (2) to provoke improvements in magnet technology. Will time permit such "secondary" R and D?

In connection with (1), we wish to stress that it is <u>not</u> clear that a smaller aperture means a less expensive machine, if smoothness of operation is sufficiently compromised (even if the compromise is

not fatal). In such a case, one must reckon with the cost of correction systems. Experience with the Fermilab Main Ring during its first three years leads us to caution that one must also reckon with the cost of delay in the startup of experimental programs; with the cost of a sacrifice of experimental beam time to machine studies time; and with the cost of an extended period of low intensity.

As for the managerial issues: In view of constraints on time and on available manpower, we are not confident about making much progress on (2) and (3), nor on receiving more than the coarsest guidance from specific machine experiments. How does one then manage rationally in the absence of really helpful quantitative tools, or at best while such tools are evolving precisely as the design is being worked out? We have here a number of activities which ideally should be performed sequentially, but which in reality our community is attempting to perform in parallel. How will it be determined when a given lattice passes a given decision point? How will one know when the appropriate response to a tracking veto is or is not to start over?

In summary, on the technical side, we feel that the operational requirements commonly discussed by analysts and trackers are incomplete at present; and that the use to which analysis and tracking are to be put has been only incompletely thought out. Without more progress in these areas, we believe that designers and project managers will be frustrated by a lack of quantitative guidance on which to base design modifications, and on the basis of which to formulate project timetables.

On the managerial side, we recommend that there be a group entirely and specifically responsible for communication, coordination, and facilitation in an environment dominated by several groups at best proceeding peacefully in different directions, and at worst frustrating one another's efforts.

Next Steps

1) Improvement of operational aperture usage

When the Tevatron resumes operation next month, there will be greater attention than in the past given to documenting the operational pathologies and the aperture used to diagnose and correct them under "routine" operating conditions. The intent here is to firm up, within two to four months, one of the least understood parts of the aperture requirement.

2) First turn and coasting beam simulation

The work done by Raja and Russell for the Tevatron and by Meyers for the SSC will be resumed. Although this will probably extend beyond the four month period, monthly progress reports will be made to factor into the developing performance specification.

3) Background simulation

Work will be initiated to study the development of beam halo and detector background arising as a result of p-p interactions at crossing points. We will review by 14 December the likelihood that this (potentially long term) effort can have any useful output within the four month period.

4) Magnet aperture algorithm

Using Group C report and a typical standard cell we will attempt a cycle through the algorithm in the coming two weeks. This may be useful, even though we will not have input from other groups.

5) Check experiment proposed by Group G

We will use short term tracking to see if we can verify the Group G prediction that the excitation of four sextupoles will significantly reduce the dynamic aperture of the Tevatron. Initial results are expected by 16 November.

6) Install Tevatron lattice in data base

We will put the Tevatron fixed target lattice in MAD format onto node DEVL:: on DECNET. Though this is a short term activity, conflicts for personnel time may defer completion until 1 January 1985.

REPORT FROM WORKING GROUP C*

ON

MAGNET ERRORS

*E. Fisk (Coordinator), K. Halbach, W. Hassenzahl, B. Meuser,
J. Peterson, S. Pissanetzky, C. Taylor, P. Wanderer, W. Wenzel

Random Errors Due to Construction Errors

Present Data, Cosine Magnets

The existing data on random magnetic errors show great consistency. The rms variation of each multipole strength is about the same (within a factor of 2) for the Tevatron, CBA, HERA, and Saclay superconducting magnets when normalized at 2/3 of the inner coil radius.

Therefore, for the immediate future our conservative recommendation is to use the results from the more than 700 Tevatron magnets. Scaled to a 1.0 cm normalizing radius for a 2.0 cm inner coil radius (SSC Reference Design A) these coefficients are:

n	b_n(norm)	a_n(skew)
1 (quadrupole)	$1.4 \times 10^{-4} cm^{-2n}$	$2.2 \times 10^{-4} cm^{-2n}$
2 (sextupole)	1.7	0.7
3 (octupole)	.3	.6
4	.4	.16
5	.07	.14

A more optimistic recommendation would be to use the 1.0 cm coefficients scaled from the data from 10 "field quality" CBA dipoles:

n	b_n(norm)	a_n(skew)
1	$.69 \times 10^{-4} cm^{-2n}$	$1.98 \times 10^{-4} cm^{-2n}$
2	1.06	0.26
3	0.10	.30
4	.37	.057
6	.039	.020
8*	.013	-
10*	.0068	-
12*	.0143	-

*Sample of four out of ten.

Future Data, Cosine Magnets

The Magnetic-Errors Working Group plans to reconvene at LBL in one month to intercompare several field-error calculations based on realistic appraisals of construction errors of SSC Models A and B. The calculations will be done by Meuser at LBL, Fisk at FNAL, and Herrera and Wanderer at BNL. The result should be an improved set of multipole errors.

New measurements on magnet models will not be available for at least six months.

Present Data, Superferric Magnets

The sensitivity of multipole errors to various mechanical, electrical, and magnetic perturbations have been calculated and measured, and were reported by Pissanetsky. These will be used to produce an estimated set of random multipole errors for the superferric dipole magnet, and will be available in about two weeks. The multipole error data listed in the Reference Design Report are no longer up to date.

Future Data, Superferric Magnets

Measurements on six 3-foot superferric magnets are expected in about three months.

Persistent Currents

Variations in the magnetic perturbations produced by persistent currents in the superconducting filaments in cosine magnets will be estimated and reported in one month. W. Hassenzahl at LBL will consider the effects of temperature variations among the magnets in a refrigeration string and compare the three multipole compensation schemes in terms of cost and effectiveness. P. Wanderer and W. Sampson at BNL will consider the effects of variations of the critical current caused by metallurgical effects. The present guess is that the rms variation in the sextupole coefficient will be less than $1 \times 10^{-4} cm^{-2}$ and $0.5 \times 10^{-4} cm^{-4}$ for the decapole for the magnetization cycle 0 - 20 TeV - 0 - 1 Tev. The systematic multipoles are some thirty times larger than these expected variations.

An estimate for the variation in the multipoles produced in superferric magnets by persistent currents is expected from Pissanetsky at TAC in one month.

Finer Superconducting Filaments

The cost penalty of finer superconducting filaments (down to 2 microns) will be investigated by C. Taylor at LBL.

REPORT FROM WORKING GROUP D/E*

ON

I/O, DATA BASE, NETWORKS, LATTICE CODES

*Group D: S. Peggs (Coordinator), M. Furman, A. Garren, W. Grush, M. Harrison, C. Iselin, D. Johnson, E. Keil, S. Kramer, B. Leemann, J. Niederer, A. Russell, A. Wrulich

Group E: A. Dragt (Coordinator), G. Dell, D. Douglas, M. Furman, A. Garren, L. Healy, S. Heifets, F. Iselin, S. Kramer, J. Laslett, B. Leemann, F. Neri, A. Ruggiero, A. Russell, R. Ruth, B. Ryne, B. Warnock, A. Wrulich

D and E Summary: Data Bases, Networks, and Standard Lattice Formats

In the past there have been difficulties of communication between the various lattice design and tracking programs, especially when exchanges between more than one of the accelerator laboratories have been involved. Popular programs at one place are sometimes completely unknown at another, or, worse, a lattice developed at one place can only be evaluated at another after the format in which it is described is painstakingly transformed, often by hand. It is vital for the efficient design of the SSC that these difficulties are minimised, so that redundant effort can be avoided, so that lattices from different sources can be compared, and so that useful codes, and their improvements, can easily be disseminated. This can be achieved by the creation of a readily accessible data base, in which accelerator design software developments are available, and in which lattices are described according to an agreed standard.

What follows is a summary of the consensus which was reached amongst members of group D and E of the LBL SSC Workshop, after many discussions which placed particular emphasis on tools which can be made available in the next four months.

A Lattice Design and Tracking Data Base

It is natural and convenient that the data base should exist under the auspices of the SSC Central Design Group at LBL, where the equivalent of a VAX-780 running a VMS operating system will be available for CDG use, and where networking links are already comparatively strong.

Under the VMS operating system it makes good sense to assign a main directory to each institution, a sub-directory to each worker or project at that institution, and so on, as necessary. Divisions below the level of main directories are freely reorganizable according to the coordinated whims of a group of users at a particular institution, assuming that interactive log on is possible over the network in use. All data base files should be readable and copiable by anyone, but by default it should not be possible to write or alter files in other main directories. File protection between sub-directories is left to the joint wishes of those concerned.

However, some rules are imposed on lattice file structure, as shown below, so that one person can understand lattices submitted by another.

WRITTEN COMMENTS

NON-STANDARD DESCRIPTION, READY FOR INPUT

STANDARD DESCRIPTION, READY FOR INPUT

The written comments, which are optional but strongly encouraged, should describe unique features of the lattice, (clustered IR's? injection or luminosity lattice? two sextupole families?....), and should name the non-standard lattice design format in which it was

prepared, if this is applicable. A user can then examine the lattice directly by using the second part of the file as input to the appropriate non-standardised program. However, it is hoped that with the passage of time this second part will become obsolete.

While the second part of the file is optional but not encouraged, the third part of the file is very strongly encouraged, although it can not and should not be made compulsory. This part is ready for direct input into programs which are committed to the MAD-like lattice description standard. MAD and TRANSPORT already incorporate the standard in their most recent versions, while DIMAT and MARYLIE are in the process of conversion. A 'short run' version of MAD will be included in the data base as soon as possible, to provide a practical definition of the standard, and to confirm the validity of a particular lattice description. Run interactively, this would check the syntax of a file, and might go as far as to return the horizontal and vertical tune values.

A secondary role of the data base is to keep common information useful to the SSC design community available for distribution - there is already a commitment, for example, to keep the most current complete version of MAD on hand. Other suggestions have included standard sets of magnet multipole errors, and a standard random number generator. However, the utility of maintaining large data sets, such as current versions of lattice design and tracking programs, depends on the efficiency and speed of the networks which link user institutions to the data base.

It is essential to maintain a comprehensive index of lattices, programs, and data sets, etcetera, which are in the data base, and it is highly desirable to develop electronic mail and bulletin board facilities. In general, though, while it is possible to predict the relative merits and desirabilities of all these features, there are many lessons which will only be learnt by experience. Active participation and feedback from the users of the data base is crucial, especially in the first weeks and months, during the establishment and the development of the data base.

In the longer term, when magnet test data is pouring in, for example, there will be a need for a much more sophisticated data base. This issue is addressed in two appendices to the workshop, by Grush and Niederer. Although this need is certain, it will probably not arise for a number of years, during which time the field of data base systems will develop rapidly. These developments should be carefully followed, but with no great sense of urgency.

Networks

The LBL computer centre is already well networked to the outside world, with DECNET, MILNET, and TYMNET connections. (MILNET is not to be confused with ARPANET). All of these include error checking during file transfer, and all permit remote interactive connection to the data base host computer. A remote connection capability is necessary for short run checking of standard lattice descriptions, and makes operations such as index file reading and mail serving much more convenient. While remote CPU intensive running is a potential abuse of

the system, restrictions need only be applied as and when they become necessary.

There is currently no LBL connection to BITNET, a common IBM-based network, which to all practical purposes only permits the transmission of files to a remote host, and not their reception. There is already a constituency of high energy physicists at LBL which favors the acquisition of BITNET, a move which is also encouraged by the CDG. In the future it may be desirable to coordinate the acquisition of common networks between the laboratories, or even to centralise data base operation around a single network. For the present, however, it is most efficient for the onus of responsibility for broad networking capabilities to rest on the data base site, so that access is possible for a user at any institution which has already acquired even a single network connection.

The active participation and feedback of the following contact people is vital to the installation and success of the data base.

CDG	D. Douglas, M. Furman, S. Peggs
ANL	S. Kramer
BNL	G. Dell
CERN	C. Iselin
CESR	D. Rubin
DESY	A. Wrulich
FNAL	A. Russell
INEL	W. Grush
SLAC	R. Servranckx
TAC	A. Dragt
Univ. of Maryland	A. Dragt

These contacts are expected to investigate and establish the network links between the data base and the home institutions as soon as possible, so that problems can be found, analysed, and solved. Although

they are people with an intrinsic interest in the data base, who will probably be working with it, their only responsibility after the establishment phase (with the exception of the CDG contacts) is to be available to introduce new users to the connection procedures, and to notify the CDG of problems which arise.

Connection between LBL and CERN may be possible through the strong satellite link that already exists between SLAC and CERN, a possibility which should be investigated. Connection from any institution to the Livermore CRAY available for SSC use is through MFENET. While improvements to the LBL/CRAY interface should be completed by January 1, substantial interface difficulties remain at to other institutions, such as Fermilab. These difficulties could rapidly become crucial, as the need for extensive tracking studies on the CRAY develops. This situation should be investigated, and should be corrected as soon as possible.

A Standard Lattice Description Format

Although the virtues of a standard format have been recognized for a long time, the first formal proposal for a standard lattice format was by Carey and Iselin in the proceedings of the Snowmass Summer Study, in an article which is reproduced here as an appendix. A working group at the LBL workshop (Douglas, Healy, Iselin and Ryne) studied the initial proposal, and made minor modifications and additions. Their report is also reproduced as an appendix.

It is hoped and presumed that the standard is already very stable. However, comments and suggestions about the standard are welcome, and

should be addressed to any of the authors of the two working papers, or to the CDG. Potential changes will be discussed and decided upon informally among the authors. The working standard will continue to be defined by the short run version of MAD in the data base.

While it is neither possible nor desirable to enforce the standard format, it is presumed that the advantages of writing new programs adhering to the standard are so clear that they need not be emphasized, at least to SSC designers. Encouragement is necessary, rather, for design code writers to follow the examples set by the authors of DIMAT and MARYLIE, and to incorporate the new standard in existing codes. One way to solve the problem of format conversion is to write a file to file translator, between standard and non standard input formats. This is less satisfactory than the direct incorporation of the standard, since it is a temporary indirect fix, but it is better and more reliable than editing the lattice files by hand, the only other alternative. The translation approaching may not even save programming time compared to incorporation if two codes have to be written, one for conversion in each direction.

The case at hand is an excellent example of a situation where a support programmer would reduce the work load of an accelerator designer - little physical intuition is necessary to perform the mundane but useful task of input format standardization. This need for programming support is a lesson which has already been learnt by physicists in the control rooms of most accelerators, and by industry at large. It is easier to hire programmers than accelerator physicists,

and the resulting increase in productivity may well be the same whether the task is designing the SSC, or is running an accelerator.

In three or four months time, when the data base has settled down and the use of the standard input format has become familiar, it will be time to organize a small workshop at the CDG of perhaps a dozen lattice designers. There it will be possible to observe the capabilities and performance characteristics of the available lattice design codes, despite the general lack of documentation, by comparing real time demonstrations of the different programs. This will be done via remote connections to home institution computers, or by installing the programs on the CDG VAX.

The idea of a standard command language practically implies the modular operation of a suite of programs in a common environment, such as MAD, with a carefully designed data structure. In this context the MAD structure should be studied and criticised as a first step towards very high level languages. However, while it is desirable to work to develop modular environments in which programs are readily inserted to react naturally with each other, there is no immediate need to press for their standard implementation.

REPORT FROM WORKING GROUP E*

ON

IMPROVING LATTICE AND TRACKING CODES

*A. Dragt (Coordinator), G. Dell, D. Douglas, M. Furman, A. Garren, L. Healy, S. Heifets, F. Ch. Iselin, S. Kramer, J. Laslett, B. Leemann, F. Neri, A. Ruggiero, A. Russell, R. Ruth, R. Ryne, R. Warnock, A. Wrulich

Introduction

The determination and understanding of the dynamic aperture for various lattice designs (with their attendant magnet placement, alignment, powering, and systematic and random multipole errors) requires long-term tracking studies and powerful analytic codes. The tracking studies should include synchrotron oscillations, and may have to be carried out for at least 100 synchrotron periods.

Present tracking programs do not simultaneously incorporate synchrotron oscillations, errors, high multipole content, good graphics, and high speed. They also do not properly exploit the parallel processing capabilities of class VI computers such as the CRAY and CYBER 205. Present lattice programs do not provide optimal analytic information. Attention should be devoted both to near-term improvements and long-term development.

The Group on Improving Lattice and Tracking Codes received as its suggested agenda the following four charges:

1) Review existing lattice and tracking codes with their various strengths and weaknesses.
2) Define attributes of 'ideal' lattice and tracking codes.
3) Determine near-term improvements to be undertaken immediately, identify persons to do the work, and establish a schedule.
4) Outline a program for continued long-term effort.

In the allotted time, it was not possible to deal completely with all these charges. However, considerable progress was made. The remaining sections of this report summarize what was accomplished.

As part of its work, the Group heard and discussed several talks. A list of these talks and their authors is given in Appendix 10. Copies of the talks may be obtained directly from the authors or from the Central Design Group at LBL.

The members of the Group on Improving Lattice and Tracking Codes are also listed in Appendix 10. The coordinator thanks them and the speakers for their hard work over many long hours.

Attributes of Ideal Lattice and Tracking Codes

A proper discussion of the attributes of 'ideal' lattice codes and 'ideal' tracking codes could fill at least two (as yet unwritten) monographs. Consequently, the two brief listings below present but the barest outline of what is desired.

IDEAL LATTICE CODES should have the following attributes and capabilities:

1) Ease of use. (Good lattice input, good fitting, good graphics, interactive, ...)
2) Ability to compute all standard linear information (including linear effects of mispowering, misplacement, and misalignment errors).
3) Ability to fit all standard linear conditions (including determination of closed orbit and settings of steering magnets to remove closed orbit distortion).
4) Ability to provide maximal nonlinear information.
    a) This information should describe high order nonlinearity. (Sextupole, octupole, and beyond.)

b) It should be representational. That is, there should be ways of describing and communicating the nonlinear aspects of a transfer map.

c) It should also be interpretive. (Provide high order chromaticities, dependence of tune on betatron amplitude, nonlinear resonance information, nonlinear lattice functions, nonlinear phase-space distortion, ...)

5) Ability to fit for various nonlinear conditions. Examples include the optimization of sextupole correction schemes, the design of high order achromats, the optimization of beams at the interaction point, the minimization of phase-space distortion, etc.

In the same spirit, IDEAL TRACKING CODES should have the following attributes and capabilities:

1) Ease of use. (Good lattice input, good graphics, interactive, ...)

2) Ability to include or interface with relevant analytic programs. For example, it may be useful to 'remove' nonlinear phase-space distortion before plotting phase-space information.

3) Symplectic. The Hamiltonian nature of the motion should be maintained exactly in order to avoid spurious long-term behavior in phase space.

4) Ability to treat high-order multipoles.

5) Ability to treat full 6-dimensional phase space. (Handle synchrotron oscillations, include synchro-betatron couplings, etc.)

6) Ability to include all magnet placement, alignment, powering, and systematic and random multipole errors.

7) High speed. To study orbits for 100 synchrotron periods requires tracking for about 3×10^5 turns. Use should be made of the vector and parallel processing features of class VI computers such as the CYBER 205 and CRAY XMP.

At present, neither lattice codes nor tracking codes have reached the ideals set out above. There is a clear need for a systematic and long-term effort. In the short term, preliminary steps should be taken to improve existing codes.

Goals for Optimal Kick and Lie Algebraic Tracking Codes

The preceding section outlined the attributes of both ideal analytic lattice codes and tracking codes. This and subsequent sections will be devoted primarily to tracking codes.

At present, there are two distinct kinds of tracking codes. First, there are what may be called 'kick' codes (such as PATRICIA, RACE TRACK, TEVLAT, ...) that treat nonlinear elements (and sometimes some linear elements) in the thin-lens kick approximation. Secondly, there are codes that handle nonlinear elements either by an extended matrix formalism (codes based on TRANSPORT such as DIMAT, DINGBAT, TURTLE ...) or by Lie algebraic methods (such as MARYLIE and the current tracking engine in MAD). Each of these approaches, and their current implementations, has special strengths and weaknesses. In what follows, particular attention will be paid to those features that the Group determined are required to improve each kind of code.

After discussion and deliberation, the Group adopted the following set of GOALS for OPTIMAL KICK CODES:

1) Good lattice specification at input.
2) Good generality. (Treat general lattice with no special symmetry; treat general charge and mass; ....)
3) Good provisions for post processing (analytical and graphical).
4) Good documentation. (User manual, description of algorithms, description of storage and data structures, description of output and its meaning, ...)
5) Should be symplectic.
6) Should use canonical variables.
7) Should handle full 6-dimensional phase space. (Use 6 x 6 matrices, or 7 x 7, etc.)
8) Exploration should be made of the dependence of 'linear' elements on momentum. (Consider what SYNCH does; examine chromatic questions.)
9) Treat synchrotron oscillations using RF cavities that kick. Maintain full possibilities for synchro-betatron couplings. Recompute matrices for 'linear' elements after each RF kick, or make sure that interpolation among prestored reference matrices does not violate symplectic condition.
10) Should handle mispowering, misplacement, and misalignment of 'linear' elements.

11) Should have good closed orbit finder. If expansions around closed orbit are used, should make sure they do not affect symplectic condition for tracking calculations.

12) Should remove orbit distortion by setting steering dipoles. (Implies ability to handle position monitors.)

13) Should handle high multipoles.

14) Should incorporate an agreed upon random number generator (machine independent) into the program as a subroutine. Put copy of subroutine code into Standard Data Base for reference. (Thanks to Tom Collins for this idea.)

15) Write a 'parallel' version of code that makes optimal use of the CRAY XMP.

Similarly, the Group adopted a set of GOALS for OPTIMAL LIE ALGEBRAIC CODES. Although sometimes stated in Lie algebraic language, many of the goals hold equally well for extended matrix codes. The goals are as follows:

1)-7) Same as for kick codes. Most of these goals have already been met by Lie algebraic codes.

8) Should go to high order. Twelve pole seems possible.

9) Same as 10 for kick codes.

10) Same as 12 for kick codes.

11) Should have fitting for both linear and nonlinear properties.

12) Should compute high-order chromaticities (beyond second order).

13) Should compute map for removing phase-space distortion, and apply it to phase-space data. Should compute nonlinear lattice functions. All such calculations should be carried out for the full six-dimensional phase space. Eventually they should be carried out to at least fourth order.

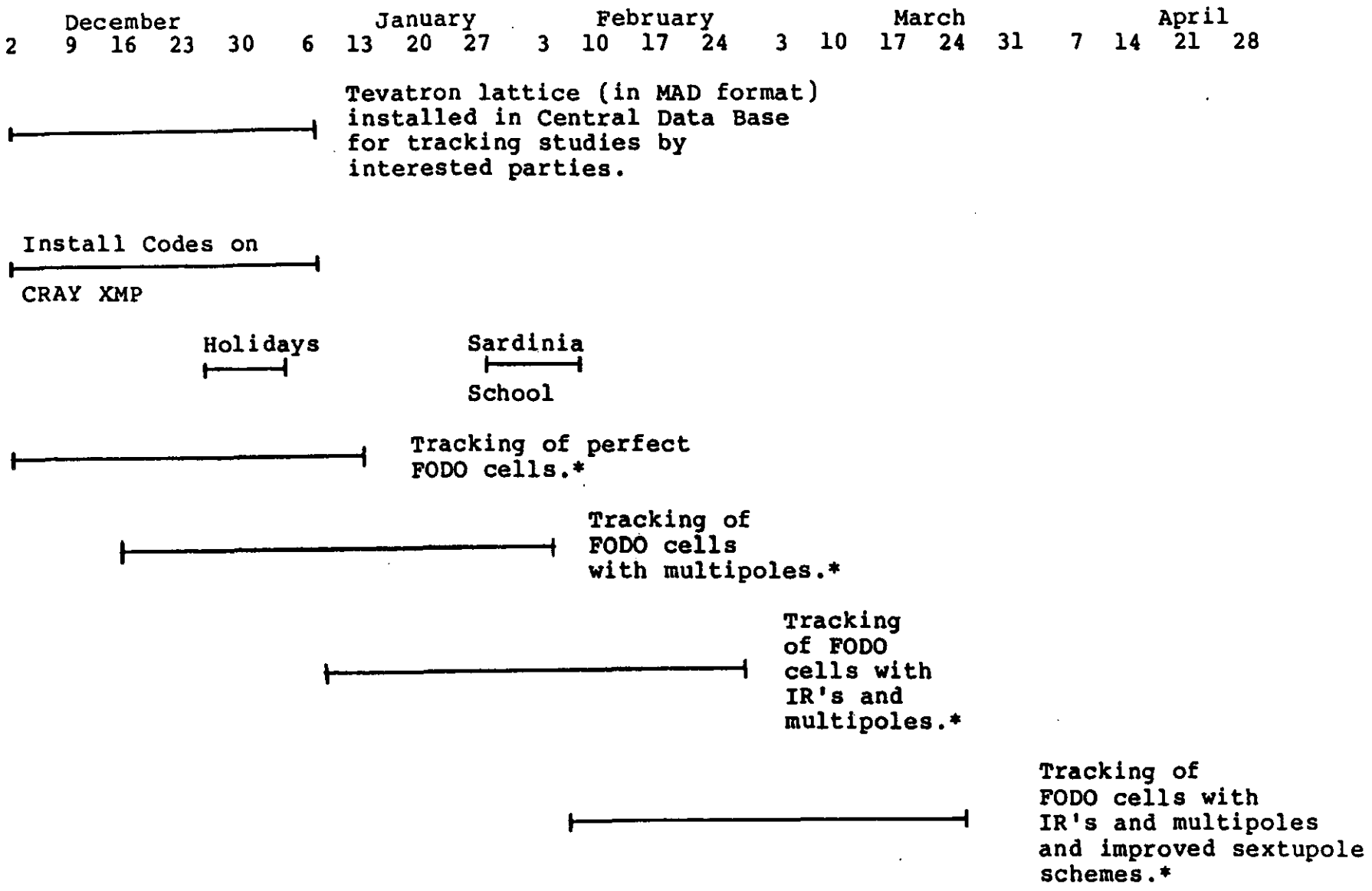
14) Effort should be devoted to an understanding of the Lie algebraic polynomials describing nonlinear effects in an attempt to correlate their magnitude with the size of the dynamic aperture.

15) Same as 14 for kick codes.

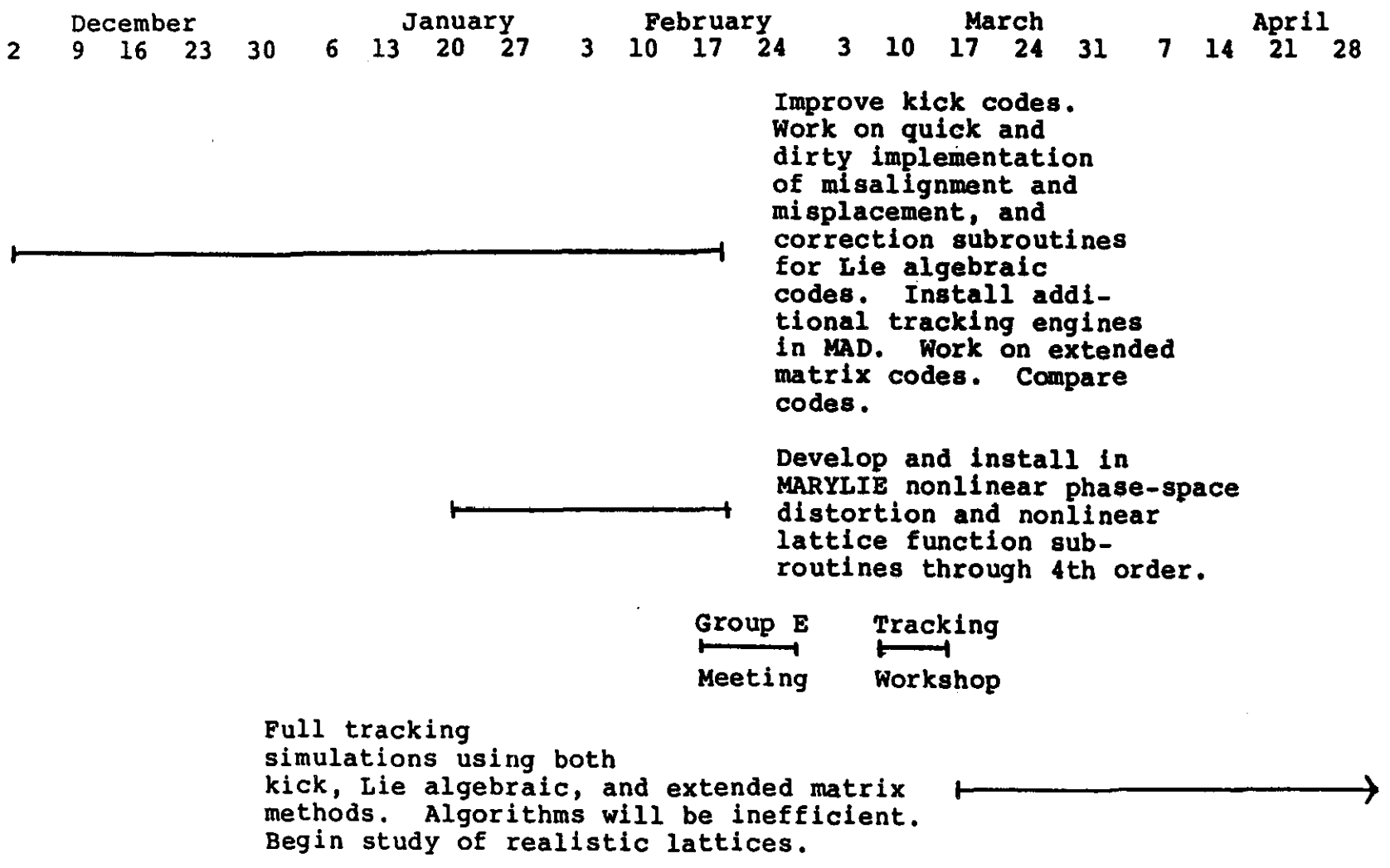
16) Same as 15 for kick codes. Already done for MARYLIE.

Near-Term and Long-Term Work Schedule

As indicated by the last two sections, in order to make definitive statements about dynamic aperture, there is much work to be done and much of this work will require considerable creative effort over a long period of time. Nevertheless, there are also near-term efforts that could give useful information. A very ambitious work schedule, which assumes the full availability of key as well as other personnel, is sketched graphically below.



* Assumes relevant lattices have been designed and placed in Central Data Base on schedule. Also assumes model for errors placed in Central Data Base. Lie Algebraic tracking will be with synchrotron oscillations, but without magnet misplacement or misalignment errors. Kick tracking will be without synchrotron oscillations, but will treat misplacement and misalignment errors.


December
January
February
March
April
2 9 16 23 30 6 13 20 27 3 10 17 24 3 10 17 24 31 7 14 21 28
Improve kick codes. Work on quick and dirty implementation of misalignment and misplacement, and correction subroutines for Lie algebraic codes. Install additional tracking engines in MAD. Work on extended matrix codes. Compare codes.
Develop and install in MARYLIE nonlinear phase-space distortion and nonlinear lattice function subroutines through 4th order.
Group E Meeting
Tracking Workshop
Full tracking simulations using both kick, Lie algebraic, and extended matrix methods. Algorithms will be inefficient. Begin study of realistic lattices.

Needed Personnel and Resources

A list of volunteers and additional needed personnel for the various projects is presented below. It should be recognized that all of the volunteers have numerous other responsibilities from which they will need to be freed for maximal effectiveness. They also should be consulted about their need for additional support.

Project	Personnel	Additional Requested Resources
Development of PATRICIA and PATRICIA like codes (PATRIS, ...)	A. Ruggiero FNAL S. Kramer ANL A. Garren LBL B. Leemann LBL H. Wiedemann STANFORD Grad. Student STANFORD F. Dell BNL	At least two more physicists. Money for programming support at the various laboratories.
Development of RACETRACK	A. Wrulich DESY A. Russell FNAL S. Kramer ANL	At least one more physicist? Programming support. See above.
Work on MARYLIE	A. Dragt MARYLAND F. Neri MARYLAND L. Healy MARYLAND R. Ryne MARYLAND D. Douglas LBL E. Forest LBL M. Furman LBL	At least two more physicists. Programming support for LBL. See above.
Work on Lie algebraic and other tracking engines in MAD	Ch. Iselin CERN	?
Work on extended matrix codes (DIMAT, DINGBAT,...)	D. Douglas to examine feasibility and to give advice.	At least one more physicist? Programming support?

REPORT FROM WORKING GROUP F*

ON

ANALYTICAL SCREENING

*Ch. Leemann (Coordinator), T. Collins, E. Courant, M. Donald, J. Kats, J. Laslett, S.Y. Lee, M. Month, P. Morton, A. Ruggiero, R. Ruth, J. Schonfeld, T. Suzuki, R. Talman, R. Warnozk

Analytical methods cannot rigorously predict long term stability in dynamical systems such as particle motion in the SSC's nonlinear guide field. They allow, however, the more or less straightforward calculation of a number of quantities such as amplitude dependent tune shifts, e.g., or distortions of invariant curves. The calculation of such quantities for any given lattice/magnet combination prior to tracking runs, formed the original idea of "analytical screening": through the early elimination of candidates with poor characteristics optimum use of precious computing resources would be made.

This particular application of analytical methods proved to be the one most easily visualized and described in terms of specific steps taken, and tasks to be executed over the next few weeks and months. Nevertheless, the consensus of the group was that the role of analytical methods and techniques in the aperture determination process should be broadened. Two major additional concerns emerged:

- The development of techniques that merit the name "design tools"; the most typical example and application of such procedures would be the design of higher order multipole correction schemes.

- The advancement of general understanding: tracking can prove stability only for a small number of discrete initial conditions, and for relatively short time intervals.

  The ultimate goal, of course, is the prediction of long term stability, and it is conjectured that analytical methods will be essential to accomplish this. The group agreed readily on a variety of topics to be pursued in such an attempt, without being able, however, to assess chances of success for this particular and most ambitious goal.

The group established the following objectives, listed below in order of decreasing priority and urgency, and agreed on the methods to achieve them.

- o Efficient Use of Computer Resources
- o Design of Higher Order Correction Schemes
- o General Studies Toward Deeper Understanding

Analytical methods lead to efficient use of computing resources in that they allow the quick calculation of approximate quantities, and identify lattice/magnet combinations with poor properties before extensive tracking studies are carried out. Quantities to be determined are driving terms of resonances, stop-band widths, and most importantly, the amplitude dependence of the tune, $Q_{x,y}(I_y,I_y)$ and the distortion of invariant curves. The latter are furthermore useful to display the results of tracking runs in "reduced form", emphasing the difference between exact calculations and approximate solutions of the equations of motion. Methods are perturbative in nature, and for the immediate application, the calculation of distortions to first order, and the tune to second order in the strength of the nonlinear perturbation seems adequate.

T. Collins' prescription to calculate distortion functions represents a solution, and the program PATRIS (A. Ruggiero), a PATRICIA "descendant", calculates the relevant quantities for systematic sextupoles and octupoles. For the present application it is important that regular and skew multipoles from quadrupoles to higher n-poles be included, and that intentional (e.g., correction), systematic and random error induced multipoles can be treated. First results are expected

by mid-December, inclusion in standard tracking codes by end of January. The Lie algebraic versions of the foregoing will be implemented starting in January. An effort of 6 man-months is expected, involving 4 to 5 physicists over the next 2 to 3 months.

The topic of corrections strongly couples group F and group A activities, particularly through the lowest order nonlinear correction, that of chromaticity. Beyond chromaticity correction there arise the questions and possibilities of various approaches to the correction of persistent current induced, and eventually also construction error caused, multipoles of increasing order. Dynamic aperture as calculated by tracking obviously depends not only on basic lattice design and main magnet errors, but also on the implied correction scheme. The group agreed that work on such correction schemes ought to be initiated although its main role and application would not be in the most critical period of the next few months.

The group was briefed on HARMON by M. Donald and concluded that it represented a powerful tool capable of handling the sextupole problem of most any SSC lattice, at least in an approach using an N-family scheme (as opposed to the "Collins scheme"). HARMON sets to zero or optimizes 31 quantities of the type $\nu_{x,y}(\delta,\delta^2,\delta^3)$, $\eta_x(\delta,\delta^2)$, $\beta_{x,y}(\delta)$, distortions, $\partial\nu_x/\partial\epsilon_x$, $\partial\nu_y/\partial\epsilon_y$, $\partial\nu_x/\partial\epsilon_y$,... under an additional constraint with respect to sextupole strength. It is maintained as module in MAD, many improvements are planned, most importantly the inclusion of skew quadupole effects, and it may well provide a model for a more general program for advanced correction schemes.

This effort might again approach half a man year, spread over approximately one year and involving 2 to 3 physicists with first results expected by end of February '85.

To broaden and deepen our understanding, at least two efforts ought to be undertaken; first, the calculation of integral mainfolds ("invariant curves") to higher orders, and second, analysis in terms of resonance widths and overlaps.

The implementation of codes to calculate higher order approximations to invariant curves is foreseen to proceed over several months. Among the group members the favorite candidate approach was "super-convergence", a perturbation approach whereby the Hamiltonian at the nth canonical transformation, $(I_{n-1},\Psi_{n-1}) \rightarrow (I_n,\Psi_n)$ takes the form $H_n = H_{0,n}(\vec{I}) + \epsilon^{2^n} F(s,\bar{\Psi},I)$, the rapid decrease (to the (2^n)th power) of the nonintegratible part of H giving rise to the name of the technique.

Finally, analysis of proposed systems in terms of their resonance structure was strongly suggested. This involves the calculations of tune shifts, resonance locations, resonance widths and resonance separations. The object is not only the avoidance of low order resonances, that could be achieved with substantially less effort, but the identification of "stochastic" regions in phase space. The actual predictive power of this approach is a matter of conjecture, if not outright faith, at this time. Comparison of predictions with tracking runs are certainly necessary as a means of calibration.

About 4 man-months, involving two physicists working over the next 6 months, are projected to program codes concerning invariant curves to higher order; first demonstrations of superconvergent in this role are expected around January 1, 1985. Resonance analysis, and other general analytical work, ought to proceed open ended at an effort level of at least one FTE.

REPORT FROM WORKING GROUP G*

ON

EXPERIMENTS ON EXISTING MACHINES

*G. Lambertson (Coordinator), M. Donald, M. Harrison, A. Hofmann,
R. Johnson, G. Lambertson, P. Morton, J. Schonfeld, R. Talman

Introduction

In this workshop, the considerations of experiments and measurements on existing machines emphasized their use specifically to supplement and check tracking computations; but we were also aware of their more complex role in the analogue modeling of SSC behavior to extend beyond computational results and to guide our understanding.

For background and realism, the group reviewed past accelerator experiments and available facilities. Examples of these experiments include the following:

At the Tevatron

1) Deceleration toward lower fields where persistent-current sextupole effects become greater.
2) Beam width and losses after increasing the betatron amplitude (~ 10-minute losses seem).

At the SPS

1) Effects of high order resonances on betatron distributions and losses.
2) Perturbation by a non-linear lens.
3) Sextupole in a low-dispersion region (in progress).

At SPEAR

1) Measurement of dynamic aperture.

Most of the experiments explore the behavior of a tuned-up accelerator and involve many unknown parameters; this complexity makes them unsuited for checking dynamic aperture predictions. The SPS

experiments that have local, known perturbations approach understandable and calculable situations.

Recommended Program

After discussing the opportunities for experiments and their role in the total SSC R&D program, the group reached the following recommendations.

1) A significant first experiment should be performed at the Tevatron. (Preliminary steps might advantageously utilize the Main Ring). It should

   a) be carried out soon (in the spring 1985 period) using largely existing facilities, and

   b) be simple, with a known non-linear perturbation dominating the expected behavior.

2) An ongoing program of documentation and experiments should be planned for the Tevatron ring for the purposes of

   a) continuing interactions with aperture analysis and predictions,

   b) revealing phenomena not predictable with tracking facilities, and

   c) use as an analogue model to provide guidance in general SSC design.

For this second sequence of experiments, the Tevatron is preferred because it is our closest real model of SSC features and because there will be a commonality of interest and of instrumentation between the SSC-related activity and its operations as a collider. This position is taken with full awareness of the pressures for operating time at the Fermilab facility.

Accelerator experiments other than the above may also be carried out, we include in this report an example experiment at SPEAR, but the major effort and continuity should attach to the above two-stage program.

A Local Sextupole Perturbation Experiment

In outline form, the elements of a proposal for the first experiment at the Tevatron are given below:

I. Abstract

A sextuple field in an arc of the Tevatron Lattice will be used to reduce the dynamic aperture. Beam lifetimes and transverse profiles will be measured for various sextupole excitations. Beam loss as a function of time and betatron amplitude can be compared with predictions made using tracking programs. Absolute comparisions can be made which will increase our confidence that these programs can be used to predict the behaviour of the SSC well enough to determine required magnet characteristics. Any beam loss at later times can be used to estimate the needed number of turns which tracking programs must achieve and/or establish empirical relationships between predictions and measured beam behaviour.

II. Concept and Physics

Sextupole effects seem to dominate in dynamic aperture calculations.

Low-order effects can be compensated. Chromaticity can be adjusted with existing systems of sextupoles. The tune can be set at a value far from third-integer resonances.

Control of low-harmonic skew quadrupole is available.

Operate at low energy, 150 GeV, to reduce the required strength of the perturbation and to reduce the sensitivity of the cryogenic magnets to beam loss.

Reduce the dynamic aperture to the reasonably linear region between the natural beam size, $\sigma = \pm 1.2$ mm and about $\pm$ 20 mm. Widen the beam as needed with a pinger or with high-frequency noise through a kicker.

Use existing (but not yet powered) sextupoles to produce a local perturbation of strength S which will reduce the stable amplitude to

$$a_{max} = \frac{1}{S} \frac{Q}{R} C_F$$

where C_F is a function of the betatron tune. To insure an effect far from resonance, use $C_F = 0.5$ for estimations. From a single sextupole, we get at one inch excursion $Bdl = 43$ kG-in, or

$$B_o b_2 L = Bdl/x^2 = 169 \text{ T/m}.$$

One sextupole then gives

$$S_1 = \frac{2c}{pc/e} \quad B_o \, b_2 \, L = 0.67 \text{ m}^{-2}$$

and a dynamic aperture

$$\alpha_1 = \frac{1}{0.67} \quad \frac{20}{1000} \quad 0.5 = 0.015 \text{ m} = 15 \text{ mm}$$

Therefore, use four sextupoles to reduce the aperture to $\pm$ 4 mm. One S_F and one S_D sextupole excited, in their normal ratio, at the centers of sectors C and F would give a periodicity-2 perturbation.

III. Tracking Calculations

For planning and checking approximate effects, a first calculation will be done soon at Fermilab.

Data on the Tevatron and experimental conditions must be prepared.

Various SSC codes should be exercised and compared with each other and the experiment.

IV. Procedure

Prepare beam - intensity, width, Δp, etc.

Monitor and adjust

Transverse profiles (with flying wire)
Beam current
Sextupole strengths
Closed Orbit
Tunes
Chromaticity
Sensitivity to skew quadrupole
Sensitivity to tune
Sensitivity to synchrotron frequency

V. Implementation

Preliminary tests might be done on the Main Ring operating parasitically. Develop diagnostics and procedures. Operate at intermediate energy where the field is good and radiation effects on the Tevatron are reduced.

Specify - Manpower
Accelerator Division Support
Scheduling, setup, etc
Coordination
Computer Needs, Time

Experiment at SPEAR

It is proposed to run the sextupoles in an electron storage ring in such a way that they introduce a dynamic aperture which is smaller

than the physical aperture. This limited acceptance is then measured and compared with tracking calculations for different conditions (different tunes, synchrotron frequency, different excitation of sextupoles and rotated quadrupoles). These experiments could provide a simple test of the predictions obtained from tracking programs.

A horizontal or vertical betatron oscillation is excited with a driving element (kicker) up to an amplitude where the life time of the beam is affected, i.e. the dynamic aperture is filled. Moving a calibrated scraper in from both sides until the life time is reduced further gives a measure of the aperture filled by the beam. This method requires betatron exciters strong enough to reach amplitudes as large as the available aperture. Operating at slightly negative chromaticity can help to reach this amplitude.

In low-energy storage rings the life time is limited by Coulomb scattering which fills the available aperture A_b (In high energy rings, losses are dominated by synchrotron radiation effects). This life time is proportional to A_b^2. Moving a scraper in will eventually reduce the life time further and can give a measure of the available aperture. This measurement gives only the aperture in the plane which is limited.

Alternative Observation Techniques

The group noted the possibility of observing distorted phase motion of large-amplitude particles by analyzing signals from pickup electrodes. In a first concept, one would kick a pencil beam into large oscillations (near the stability limit) and observe its position each successive turn on position electrodes located $\lambda/4$ apart.

Fourrier analysis of these could reveal distortions in amplitude and phase motions. In this scheme, tune spread within the beamlet may seriously limit the time of observation before it diffuses in phase. A second scheme would observe the same large-amplitude beam through a Schottky pickup where tune spread and harmonic modulations should be evident. These techniques were not adequately analyzed but deserve examination as a means of comparing beam behaviour with tracking results. Schottky pickups of adequate sensitivity for small beams in the Tevatron are being developed at LBL.

Modeling SSC Behavior

While the first experiments should be designed to complement the stability computations, understandably scaled analogue experiments can be an important part of establishing the credibility of extrapolations to SSC scale. At present we have the example of decelerating the Tevatron beam to explore operation at low field in superconducting magnets. As the R&D program progresses such modeling, or analogue, experiments should be expected.

Program Schedule

Figure G1 is a projected schedule of activities. Of greatest urgency is the designation of an SSC coordinator for the experimental program. He can then see that a proposal and experimental group are organized for the first experiment at the Tevatron. A proposal sufficiently detailed for establishing a collaboration with Fermilab is needed at first so that preparation can get underway. Tevatron operations are scheduled from February through June in 1985, followed by a shutdown until late fall that year.

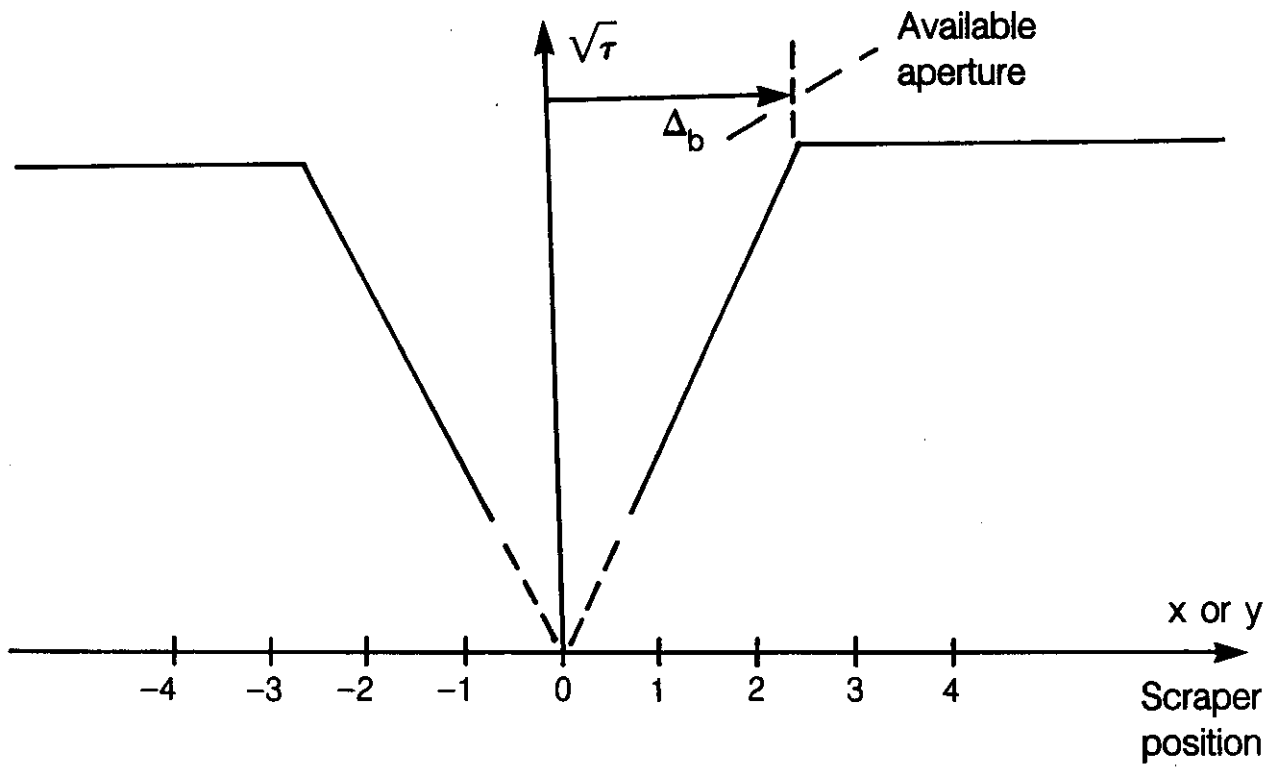


Fig. G1

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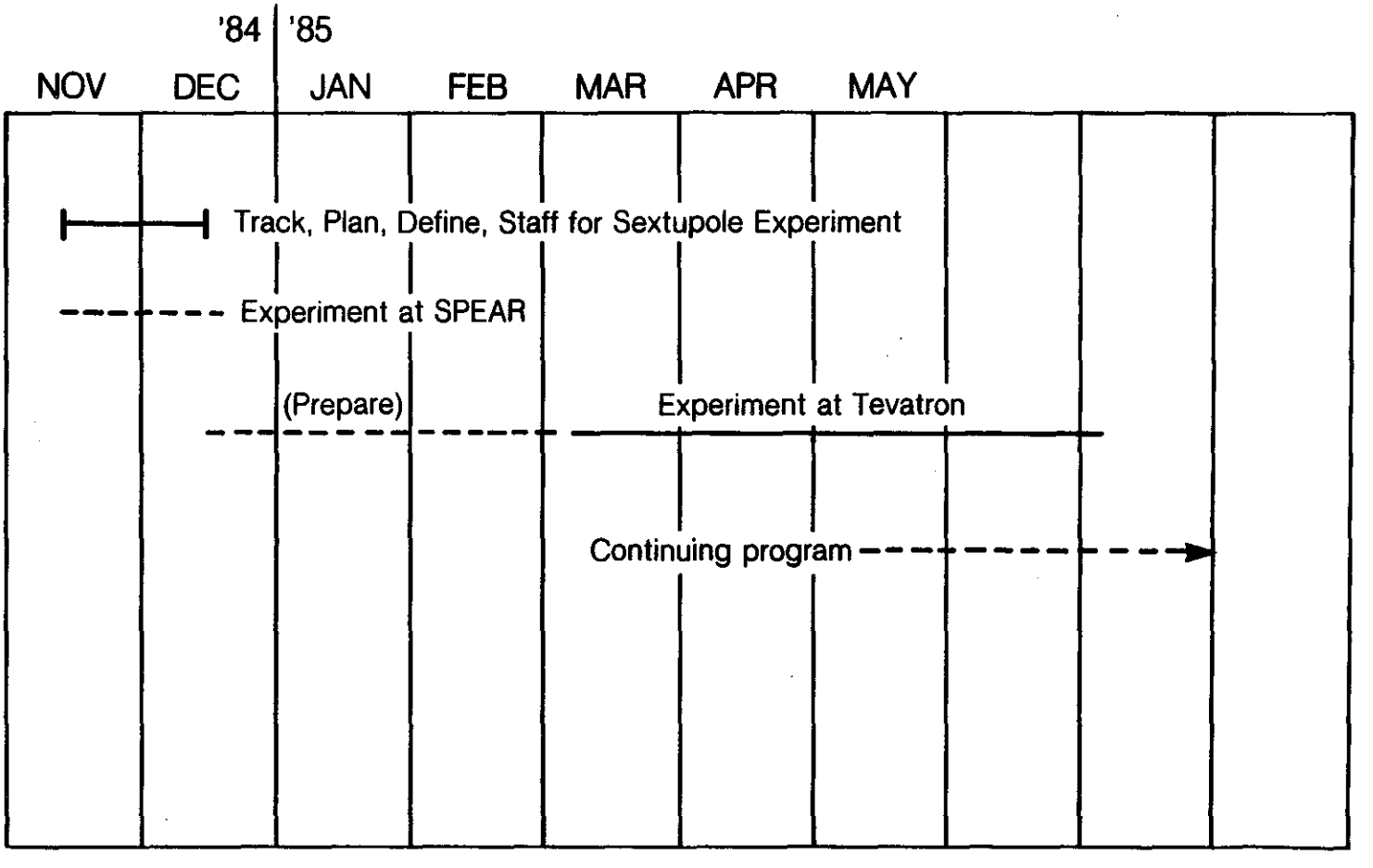

Figure G2. SSC-ATF Experiments Schedule

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APPENDICES

Appendix 1. SSC Aperture Workshop Prospectus

Purpose of the Workshop

1) Design a course of action for determining needed physical and dynamic aperture and commensurate magnetic field specifications for a high luminosity, 20 TeV beam energy proton collider.

2) Prepare a proposal for carrying out the program in two steps, a short-term step of approximately four months and a longer term effort of duration to be determined as a result of workshop efforts.

Introduction

To have a useful impact on the SSC magnet program, specifications for physical aperture and B(r) need to be available in something like 8 months or sooner. The basic challenges are: (1) determine how much good field aperture we need for a 20 TeV, high luminosity proton collider; (2) give construction specifications for the magnets which guarantee the needed good field aperture.

Today we have no unique, time-tested recipe for answering any of the questions. We have, however, accumulated considerable experience with proton synchrotrons from which to extrapolate, and directly applicable information is being accumulated currently with the Tevatron. In addition, our calculational ability both with simulations and numerical experiments and with analytical approaches has been steadily improving. The consensus of experts, meeting on various occasions over the past year such as the Ann Arbor workshop, the

Snowmass Summer Study and a recent planning meeting at BNL, is that a concerted effort to bring these tools to bear on the aperture problem now is likely to be fruitful. Thus, given the critical importance of the aperture for both cost and operational reliability of large proton storage rings, it is important to make this concerted effort during the early design and development phase of Super Collider magnets.

In view of the fact that aperture studies related to the SSC are now being carried out by many individuals and institutions, it would seem mandatory for more efficient use of manpower and computer resources to coordinate and focus these activities. To this end it is hereby proposed that an Aperture Task Force (ATF) be formed to address the principal aperture question. It is envisioned that the ATF would carry out its work in the course of the next several months through a combination of workshops, individual and small group work at the Design Center and at the various participating institutions.

The Workshop

To lay the technical groundwork for such a Task Force and to propose a time scale and specific assignments for an ATF, a workshop is proposed for November 5-9, 1984, at the Design Center. Its activities will be carried out by eight working groups, each led by a Coordinator. A particular algorithm for aperture requirement and magnet specification generation has been proposed to give some technical focus for the Workshop:

1) Choose regular lattices with some basic periodicity, S, between two and six with simple straights so that lattices with various Q, , etc., can be generated easily.

   a) For various magnet styles put in best current knowledge of systematic and random errors as a function of r, the half aperture (radius). These errors will include misalignment and mispowering. (Field errors through n-th pole will be used where n is to be a matter of study at the workshop.)

   b) Determine needed good field aperture, A_n from numerical experiments on equilibrium orbit establishment with realistic position detector systems, beam stacking procedures, and collision mode phenomena, i.e., find $A_n(r,S,L,Q,\mu...)$ by extrapolation from experience using simulation.

   c) Screen lattices used in (b) by analytical methods examining tune shifts, resonance widths, island overlap, etc.

   d) Using currently best tracking routine(s) on lattices passing the (c) screen, determine "achieved" aperture $A_a(r,S,L,Q,\mu...)$. Magnet errors and synchrotron oscillations must be included. While it is anticipated that operation at injection energy will be the most demanding in terms of aperture, a survey of operation at other energies must be included.

2) Study influence of "real IR's" using best available tracking routine(s) on derivatives of "existing" SSC lattices by "with" and "without" comparison to get some idea of safety factor needed in using results of (1) in specifying r and <x>, the rms position error tolerances. Tracking for at least 100 synchrotron periods may be necessary.

3) Develop real lattices for the various magnet design types based on (1), (2) and check with best available tracking routine(s) after analytical screening.

The task of the Workshop will be to criticize this algorithm and improve it and to study, in detail, all the various tools and procedures needed to carry it out. Some of the existing tools and procedures can be used as is; some will require improved input and data base formats; some will need significant improvement. Detailed specifications for needed improvements should be generated by the Workshop, taking into full account parallel work going on in Europe and Japan.

For a first pass through the algorithm to get our bearings, existing tools and procedures must be used to the greatest possible extent. It will be the task of the workshop to study the minimal set of improvements needed for sensible execution of the first pass and to suggest specific assignments for providing that minimal set and making the first pass. At the same time, the working groups will suggest specific assignments for the next round of improvements and an appropriate time scale for that.

The work of the Workshop will be embodied in a report which will serve as the basis for negotiation of detailed agreements between the Central Design Group and various individuals and institutions who wish to participate in the ATF.

The Working Group

As a result of a planning meeting of experts held at BNL September 5,6, eight working groups were defined and leadership for them designated:

A. Test Lattices, A. Chao

B. Aperture Requirements, D. Edwards

C. Magnet Errors, E. Fisk

D. Formats, Data Bases, Networks, and Lattice Codes, S. Peggs

E. Improving Lattice and Tracking Codes, A. Dragt

F. Analytical Screening, C. Leemann

G. Experiments on Existing Machines, H. Edwards

Considerable cross participation in groups is expected. Some groups will be able to finish in a time short compared to the 4 1/2 days of the Workshop, others will need the full time. A detailed agenda and workshop schedule will be forthcoming shortly.

Following are more detailed descriptions of specific work items foreseen for the working groups.

A. Test Lattices, A. Chao

The objective of this working group is to define the test lattice(s)--both linear and nonlinear--that will allow tracking and analytic evaluations to be performed. These lattices will presumably be very much simplified versions of the realistic ones, but they will have to contain all important information concerning the dynamic aperture.

The working group will try to reach consensus or at least to make useful comments on the following issues:

1) Does the lattice consist of

   a) a string of cells, or

b) cell strings interrupted by "simple IR's" which allow varying β^*, ν, η^*, ..., or

c) the up-to-date complete lattice designs.

In other words, how important are the details of the IR's on the determination of dynamic aperture

2) Do we need 3 lattices each for one magnet style How to choose the integer and the fractional parts of the tunes How to choose phase advance per cell Do we need low β^* for 1 TeV injection lattice

3) To which order of multipole errors--systematic as well as random--should we include Conventional wisdom says 10; is that justified

4) Nonlinear lattice would be a difficult issue. This working group will have to join effort with the "analytic screening" group to work out an acceptable sextupole solution for the test lattice. Do we need 2nd order lattice function matching Do we want "achromat" cells for the arcs Do we need octupoles in the cells as correctors

5) We can perhaps help Groups F and G to decide on a most simplistic test lattice for the sole purpose of comparing analytic methods and tracking results and/or comparing the accuracy among the various tracking techniques. This simplistic lattice is not meant to represent SSC per se.

6) Should the test lattice include the following effects

- magnet misalignment/mispowering plus the subsequent orbit correction
- define sextupoles to be used for <u>random</u> sextupole errors

- injection errors at 1 TeV
- various noise effects
- terrain following
- IR clustering
- do we need to study also a 20 TeV lattice
- beam-beam nonlinearity

B. Aperture Requirements, D. Edwards

The assignment for Group B can be divided into two parts:

1) Develop a performance-oriented specification.

2) Attempt to incorporate the above and the considerations of the other groups into an algorithm for magnet evaluation.

These two aspects are discussed below. Only problems that have some possibility of resolution in the near term (i.e., less than one year) are mentioned.

1.0 Performance Specification for Beam Behavior

In the various modes of operation, what are the ranges in oscillation amplitude and momentum to be accommodated What are the stability of lifetime requirements

Examine the questions above in light of the requirements for the various operational modes, at least some of which are characterized in the following subsection. Where appropriate, specify short-term calculations and simulations that need to be carried out to clarify the specification. Here, short-term means the variety of calculation that can be done in a range of a few days (i.e., longer than the workshop) to a few months.

1.1 Commissioning

Determine the aperture required for automatic tracking of the beam to obtain a first turn. It is likely that this will require an extension of the work that Raja and Russell carried out for the Tevatron, and that Meyers did during the Reference Design activity for the SSC.

Extend the foregoing through the stages of orbit closure, closed orbit improvement, and elementary measurements.

The work by Meyers suggests that survey errors will be the dominant factor, if quadrupole placement inaccuracies are at the 1 mm level. For the purposes of this study, it is probably necessary to treat the placement inaccuracy as an input parameter, an analysis of survey methods would take too long.

1.2 Single Beam Injection

Examine tolerances for transverse and longitudinal matching from injector. Does injection oscillation damping have any impact on aperture

Examine tolerances for transverse and longitudinal matching from injector. Does injection oscillation damping have any impact on aperture

1.3 Diagnostics and Studies

What measurements require large oscillation amplitude and how large How large a momentum offset should be accommodated

1.4 Injection of Second Beam

Investigate the fate of the two beams as filling proceeds. Although there are intangibles, the orbit and time shifting parts of the varying beam-beam interaction can be quantified.

1.5 Acceleration

Are there any problems unique to this phase in the cycle

1.6 Storage

What are the best available guidelines for field quality consistent with long-term storage Can the additional aperture needed for halos be quantified Some of the latter work was initiated by van Ginneken for the Reference Design.

2.0 Method of Magnet Evaluation

Is it possible to agree on a procedure for magnet evaluation For instance, one might propose a procedure such as the following. The performance specification above and the conclusion of Group C (magnet errors) provide input to a "Do Loop." In the first step, a main magnet coil aperture is chosen and placed in a test lattice (Group A). The analytical screening process (Group G) adds the correction and adjustment magnet system and passes the complete assembly on to the tracking apparatus of Group F. If the performance specifications are not satisfied (or if they are dramatically exceeded), the loop is executed again, with a variation of the coil aperture.

C. Magnet Errors, E. Fisk

At this time we have only very limited test data on actual SSC magnet designs. However, for cosine theta magnets we have data from Tevatron and CBA magnets and considerable past experience with iron-dominated magnets to extrapolate from. In addition, for both types of magnets we have ab initio calculations for expected field profiles and error distributions.

It will be the task of Group C to put these together and make the best possible projections of expected field profiles and error distributions for both types of magnets as a function of magnet gap (physical aperture) and B . These projections can be fed into the specification algorithm and improved as actual data from magnet measurements become available.

D. Formats, Data Bases, Networks, and Lattice Codes, S. Peggs

Thesis:

Lattice and tracking studies should be carried out with a variety of programs, and the results should be compared for validity. Such comparisons, as well as communication between various research groups would be facilitated by the use of common or compatible input/output formats and procedures. Moreover, there should be a central data base that would contain various proposed lattices, and would be accessible by all research groups. Finally, efforts should be made to provide file transfer capability and networking between the computing facilities of the various research groups.

Suggested Agenda:

1) Presentation of input/output formats for commonly used existing programs.

2) Discussion of and agreement upon common format and/or the construction of translators.

3) Discussion of and agreement upon organization of central data base for lattices.

4) Presentation of current file transfer and networking facilities and technology.

5) Discussion of and agreement upon procedure for file transfer and networking among the computer centers of the various research groups.

On the lattice codes, the aims are:

a) To reach a consensus among many of those people who will be further involved in SSC design on what ideal lattice design program would do. In roughly increasing order of difficulty, several types of design problems exist:

   i) Finding the Twiss parameter, chromaticities, etc., for a given lattice.

   ii) Making small perturbation, e.g., doubling β^*.

   iii) Analyzing non-linearities, e.g., powering families of sextupoles.

   iv) Constructing physical models, such as first turn injection algorithms, the effect of misalignments, or orbit correction performance.

   v) Setting up a rough lattice from scratch, e.g., with the right integer tune.

   vi) Combinations of i) to v), e.g., lattice compatibility at injection/storage, or the merits of IR clustering.

Further, at least four design modes exist--local searching, global searching, 'hands-on' interactive graphics searching, and piecewise insertion matching. Which programs from the existing spectrum (including AGS, DIMAT, MAD, MAGIC/COMFORT, MARYLIE, SYNCH, TEVLAT, TRANSPORT, TURTLE and Z) use which of these modes, and what are their relative merits Can parts, or features, of these programs be combined into one program which would perform well at many of the above tasks

b) To design a process which will be used at a subsequent workshop to select a small number of 'standard' programs.

This probably needs a common input format for the candidate programs. The advantage of redundancy in having more than one standard program is offset by the incoherencies and incompatibilities that arise with a large number of programs. To make as realstic a comparison as possible between the candidate programs, the selection process should include, if possible, concurrent analyses of two or three common problems, at many terminals in one room.

Agenda on lattice codes:

a) What should ideal SSC design codes do in the immediate future

b) What does each current design code do, and how

c) Which standard physical problems, e.g., from i) and ii), should be used in a comparison

d) How to compare them--what standardization is necessary and possible (This interacts strongly with group D).

e) What improvements can be made to the codes, in the medium to long term

E. Improving Tracking Codes, A. Dragt

Thesis:

The determination and understanding of the dynamic aperture for various lattice designs (with their attendant magnet placement, powering, and systematic and random multipole errors) requires long-term tracking studies and powerful analytic codes. The tracking studies should include synchrotron oscillations and may have to be carried out for at least 100 synchrotron periods.

Present tracking programs do not simultaneously incorporate synchrotron oscillations, errors, high multipole content, good graphics, and high speed. They also do not properly exploit the parallel processing capacities of class VI computers such as the CRAY and CYBER 205. Present lattice programs do not provide optimal analytic information. Attention should be devoted both to near-term improvements and long-term development.

Suggested Agenda:

1) Review of existing lattice and tracking codes with their various strengths and weaknesses.
2) Definition of 'ideal' lattices and tracking codes.
3) Determination of near-term improvements to be undertaken immediately, and identification of persons to do the work.
4) Outline of program for long-term effort.

F. Analytical Screening, C. Leemann

"Analytical procedures" in the present context refers to all methods of analysis (mathematical and numerical) other than long-term

tracking. As presently perceived the availability of such procedures is desirable for several reasons:

- It is conjectured that by such means we might arrive at early tentative specifications of minimum magnet quality requirements.
- Computing resources will be used most effectively in that magnet/lattice combinations predicted to be inadequate will not be tracked. Similarly not all of several configurations that are identical with respect to the important criteria need to be tracked and, furthermore, guidelines for the choice of initial conditions for tracking runs will be helpful.
- It is hoped that analytical procedures will provide a tool to identify and understand patterns and trends in the results of long-term tracking calculations and to facilitate the interpretation of and extrapolation from experiments on existing machines.

The goals envisaged for the workshop are the following:

- Review and criticize proposed methods and procedures of analysis.
- Establish and agree upon a screening procedure to be followed in the course of the SSC aperture determination by selecting specific methods and criteria.
- Devise simple but representative test cases to verify the predictive power of the adopted procedure.
- Organize work beyond workshop.

In summary, as an outcome of the workshop an outline of an agreed upon procedure ought to be in place and work beyond the workshop should focus on establishing calculational methods where still needed for full implementation.

An incomplete list of topics to be discussed as ingredients of the procedure includes:

- Calculation of tune dependence on amplitudes and momentum deviation, $Q(I_x,I_y,\delta)$. The first-order approach to this is well established but the need for and procedures of higher order approximations need to be investigated. Criteria for acceptable values other than those from the DAE algorithm need to be considered.
- Construction of integral manifolds, invariant tori can be envisaged as being useful although they will not allow definitive statements about long-term stability with $n_{DOF}>1$. Procedures to construct these objects must be reviewed (established). Criteria for acceptable deviations from decoupled, elliptical trajectories in (x,p_x), (y,p_y) planes need discussion and their consequences for limiting allowable multipole strengths should be explored.
- Resonance analysis might provide further insight. The calculation of $Q(I_x,I_y)$ is an integral part of this in that the first step of the analysis consists in determining the sets (I_x,I_y) $mQ_x(I_x,I_y) + nQ_y(I_x,I_y) = N$. Calculations of resonance widths and spacings allow the identification of irregular (stochastic) areas in phase space. Required work

will include the verification of the approximations typically used in these calculations, the development of criteria for the order of resonances to be avoided and, most desirable, the development of test cases to be compared with numerical (tracking) results.

- Procedures to sort (shuffle) magnets and the development of higher order correction strategies could also be considered by this group.

G. Experiments on Existing Machines, H. Edwards

Calculations of aperture needs and correlation of achieved aperture with known errors cannot be considered an engineering science at this time. Thus the verification of calculational procedures by experiment remains of high importance. Opportunities for carrying out these experiments are sharply limited by the preciousness of beam time. The experiments themselves are difficult, often requiring instrumentation that is not available.

Following up on discussions at Ann Arbor '83 and Snowmass '84, it is the challenge to this group to propose specific experiments on existing machines to illuminate critical aperture issues. To be useful the proposal(s) need to be in a form suitable for presentation to the relevant Lab managements.

Summary of Workshop Prospectus

It will be the task of the Coordinators and their Workshop colleagues, working together with the Design Center Management, to issue the Workshop report in a timely fashion and in a form that will be directly useful in issuing an ATF proposal to the relevant Lab managements before the end of November.

Appendix 2. Elementary Lattice Considerations (Dave Neuffer)

In the SSC, ~90% of the lattice is FODO cells and the parameters of the cells determine the beam dynamics. In initial evaluation thin lens formula for the Courant-Snyder beam dynamics parameters are adequate and are displayed in Table 2.1.

Elementary practical considerations limit parameter choices.

1. The beam must remain small. If we require the beam at three standard deviations be less than 0.5 cm, we obtain

$$3\sqrt{E\ \beta_{max}} < .5 \text{ cm}$$

which implies $L_{cell} < 300$ m, independent of phase advance ϕ and bending field B.

2. Off momentum orbits must remain small. If we require that an orbit at $\frac{\Delta p}{p} = \pm.001$ remain less than 0.5 cm, we find

$$\eta_{max}\ \frac{\delta p}{p} < 0.5 \text{ cm}$$

η_{max} depends, significantly on B and on phase advances ϕ. The constraint is more restricting for B = 6T magnets:

$$L < 80 \text{ m for } \phi = 90^\circ \text{ and } L < 150 \text{ m for } \phi = 60^\circ$$

For 3T magnets lengths may be greater:

$$L < 160 \text{ m for } \phi = 90^\circ \text{ and } L < 300 \text{ m for } \phi = 90^\circ .$$

3. Quadrupole magnets must not be too long. All current magnet styles use the same magnet gradient: $B' \approx 125$ T/m so this constraint is the same for all. If we require $\ell_Q/L < .1$ we find

$$\ell_Q = \frac{B\rho}{B'L}\, 2 \sin\frac{\phi}{2} < 0.1L$$

implies $L > 80$ m.

4. A similar constraint follows from sextupole strength. To correct chromaticity a strength S_D is required

$$S_D = -\frac{P}{2\,\eta_{min}} = \frac{B\rho}{L^3 B}\,\frac{\sin^3 \phi/2}{2 - \sin \phi/2}$$

with a maximum value of S_D estimated as

$$S_D = \frac{B_s \ell_s}{r_s^2 B\rho} = \frac{1.1}{(.02)^2 66700} = .0375 \text{ m}^{-2}$$

This constraint is not very restrictive and is weakly dependent on B and $\phi/2$: $L > 40$ m.

5. Magnet errors also restrict L. For example, the tune shift due to a systematic magnet multipole b_{2n} in the dipoles is, approximately,

$$\Delta\nu \approx 2nb_{2n}\,\frac{L}{2\sin(\phi/2)}\left[\frac{L\,\theta}{\sin^2 \phi/2}\,\frac{\delta p}{p}\right]^{2n-1}$$

which demands small $L\theta$ for a given b_{2n} and tune shift limit $\Delta\nu$. Combining the requirements places the cell length for B = 6T at ~L = 100 m. The B = 3T lattice may also use L = 100 m but may permit weaker focusing, up to L = 200 m.

The workshop group has decided to generate lattices at $\phi = 60^\circ$ and $\phi = 90^\circ$. The 60° case has significantly diminished momentum aperture and may have greater error sensitivity. It is, however, more economic in quadrupole and sextupole usage.

T. Collins has suggested that lattices be scaled to obtain equal $L\theta$(= 0.8 m). This obtains equal η functions and equal sensitivity to some errors. For the cases in the Reference Designs Report the following scaling is obtained:

A :	B	=	6.5 T	L	=	100 m	
B' :	B	=	5.0 T	L	=	115 m	(Dave Johnson)
C :	B	=	3T	L	=	150 m	

An alternate scaling which should not be dismissed is to maintain equal focusing (and equal β) by keeping L constant. This option permits identical matching and low beta sections and an equal quadrupole packing factor; thus equally practical and expensive (to first order).

Table 2.1 Thin Lens Equations for FODO Cell Parameters

$$\beta_{max} = \frac{L}{\sin(\phi_o/2)} \left(\frac{1 + \sin(\phi_o/2)}{1 - \sin(\phi_o/2)} \right)^{1/2}$$

$$\beta_{min} = \frac{L}{\sin(\phi_o/2)} \left(\frac{1 - \sin(\phi_o/2)}{1 + \sin(\phi_o/2)} \right)^{1/2}$$

$$\sin \frac{\phi_o}{2} = \frac{pL}{2} \qquad \text{with} \qquad p = \frac{B'_Q \ell_Q}{B}$$

$$\eta_{max} \frac{L\theta}{2 \sin^2(\phi_o/2)} \cdot (2 + \sin(\phi_o/2))$$

$$\eta_{min} \frac{L\theta}{2 \sin^2(\phi_o/2)} \cdot (2 - \sin(\phi_o/2))$$

$$\theta = \frac{BL}{B'\rho}$$

Appendix 3: Program for Tune Choice
(Melvin Month)

1. Analysis of Tune Choice

   Integral Part:
   - Implications of L_θ = 0.8m choice
   - Consequences for beam size (Stronger focusing?)
   - Consequences for instabilities - e.g. momentum compaction
   - Horizontal - Vertical separation of tunes

   Fractional Part:
   - Working point - SPS, Beam - Beam Shift, Low order resonances
   - Beam tune Distribution
     - Tune vs. Amplitude, Momentum, Bunch Phase
     - Contributions
       - Chromaticity Sextupole
       - Random Octupoles
       - Beam-Beam
   - Working Region
     - Resonances in Beam (What Resonance order allowed?)
     - Estimate effects of such Resonances for parameter modulation and drift
   - Modulation and Drift Parameters
   - Ripple (small in SC magnets?)
   - Intrabeam Scattering
   - Beam-Beam Interaction
     (Effect of bunch length crossing angle, and β^*)
   - Synchrotron Motion
     (Can a form of scaling be used to make tracking possible with such time modulation or drift?)

2. Do 6 Different Lattices have different tunes or different consequences?

3. Are there constraints on superperiod tune?

4. Analyze effects of low-order resonances on past real machine experiments - primarily ISR and SPS-as input to justification of tune choice.

5. Analyze consequences of change in working point.

Appendix 4. Comment on the Fractional Part of the Superperiod Tune (D. Neuffer)

In sample SSC lattices the contribution to the linear chromaticity due to the interaction region (IR) quads is roughly equal to the remainder of the lattice. The IR contribution to the "second order" chromaticity

$$\frac{d^2\nu}{d(\frac{\delta p}{p})^2} \quad , \quad \frac{d\beta/\beta}{d(\frac{\delta p}{p})}$$

can, however, be much greater. These factors are consequently quite sensitive to the fractional part of the superperiod tune. Table 4.1 shows some DIMAT simulation results for simple SSC lattices, showing a sensitive dependence on ν.

This dependence can be approximately understood by consideration of the perturbation theory expression for $d\beta/d(\frac{\delta p}{p})$

$$\frac{d\beta}{d(\frac{\delta p}{p})} = \int_0^L \beta \frac{dk}{d(\delta p/p)} \frac{\cos 2(\nu\pi - |\mu - \mu'|)\, ds'}{2 \sin (2\nu\pi)}$$

$$= \int_0^L \frac{\beta}{2} \frac{dk}{d\frac{\delta p}{p}} \cos 2|\mu - \mu'| ds' \cot 2\pi\nu$$

$$+ \int_0^L \frac{\beta}{2} \frac{dk}{d\frac{\delta p}{p}} \sin 2|\mu - \mu'| ds'$$

The first term scales as cot $2\pi\nu$, becoming small as $\nu \to .25$ or .75. The contributions to the second term from the IR quads to the IR β (or IR quads' β) becomes small since $\sin 2|\mu - \mu'| \cong 0$, as $\nu \to .25$ or .75.

In Table 4.1 the scaling suggested by this discussion is seen.

It may therefore be desirable to place ν close enough to .25 or .75 so that the IR contribution to higher order chromaticity is less than that of the remainder of the lattice. For this example $\nu \cong .25 \pm .02$ or $.75 \pm .02$ is indicated as most desirable.

Table 4.1 Period 6 tune sensitivity.

Fractional Superperiod Tune ν	$6 \cdot \frac{d^2\nu}{d(\frac{\delta p}{p})^2}$	$\frac{d\beta^*}{d\frac{\delta p}{p}} \Big/ \beta^*$	$\cot(2\nu\pi)$
.754	.0087	.09	-.02
.20	-.024	-.32	.34
.64	-.073	-.82	.80
.42	.188	2.11	-1.83

Units for $\frac{\delta p}{p}$ are percent.

Appendix 5. Data Bases and Libraries
(J. Niederer)

To ease the computing work of the SSC design effort a number of measures should be considered for orderly handling of data and programs. The problem may be somewhat complicated because different computers, programs, and data groupings are now in use among the various participants. Other discussions within the workshop have tried to achieve agreement on common programs and input data forms, and have offered thoughts toward a unified scheme of a design program environment in which computations appear as modules within the larger framework of common inputs, data structures, and outputs.

The longer term effort will involve large amounts of information in the form of libraries and programs and of input statements describing lattices and elements. As programs and displays may depend upon the results of the programs of others, additional intermediate files will become a part of the data management picture. As parts of the accelerator are obtained, extensive collections of engineering data in gigabyte quantities, will accumulate. Lastly, documentation will generally be in machine-readable formats so it may be readily treated as part of the general data ensemble.

Presently, larger programs are handled conventionally as files of source statements and, if in a library system at all, tend to be managed by means of programs such as UPDATE, PATCHY, or HISTORIAN, or by the more comfortable file managers and editors of VAX, etc. The VAX-Cray interchange more or less requires transmitting source files or update controls, with a choice eventually needed as to where the

standard copies of program sources and lattice data are to be kept. This will necessarily make use of LBL network and computer services which treat the narrowly complicated problems of communications.

Modern computer systems offer quite effective means for managing this spectrum of data. Operating systems such as UNIX contain tools for constructing and debugging programs and managing their storage and integrity. Furthermore, these libraries/files are broadly compatible among many kinds of computers now, and probably will reach to all systems shortly, including Cray. For example, BNL is employing UNIX systems and computer work stations for program construction duties now, in particular for MAD. In addition to their excellent graphics capability, the work station approach is very well suited to the present style of remote computing among widely scattered SSC workers. The most common compatibility problems do not occur in the UNIX approach.

The larger engineering data base needs can be approached in several directions. CERN has elected to purchase a large-scale commercial data base system, ORACLE. In their fullest form, these systems provide form definition and naming services, data entry and prompting, security and access control, backup, filing, storage, and indexing services, and various interfaces to user programs, graphics, and report generators. Another system developed for nuclear reactor engineering at the Idaho National Engineering Laboratory is included in this report. The Project should be aware of the need for a significant size of staff to insure compatible data, standards, and procedures as the data volumes grow. There are smaller scale data base alternatives

which range all the way down to personal computer models. Again, workstations offer significant advantages in that rather large sets of active data may be transmitted rapidly for local analysis and temporary storage to and from a more central resource.

A very important consideration is that the computers and methods selected for data and program storage be viable over the duration of the SSC project. It is extremely troublesome and expensive to reformat huge volumes of data when a computer system becomes extinct, or to be forced to maintain the extinct system because the data cannot effectively be forwarded to new systems.

Appendix 6. An Economical Solution to SSC/CDG Long Term Data Base Needs (S. Peggs)

Vast quantities of data will be generated as the SSC effort proceeds through design and into the construction phase. Much of this data will be engineering data related to the construction and testing of the magnets. Storage of this data in a centralized data base at the CDG facility will be necessary so that all participants will have quick, efficient access to the data.

Extensive data base support software has been developed recently at the Idaho National Engineering Laboratory (INEL) in conjunction with an interactive graphic simulation system. Some features of this data base support software are described below:

> The system is supported by a relational data base used for storage and retrieval of nearly all essential information.
>
> A multi-user data base is provided which allows individuals to select or edit information from their own area or use information from another area. Each user has his/her own physically separate data base area.
>
> An editor is provided for updating and editing the various sections of the data base using the "forms" technology.
>
> A data base recovery facility is provided for damaged or destroyed data bases.
>
> New data base areas are created automatically as new users enter the system. These data bases are maintained under the individual's own ID and charged to his account.
>
> A facility is provided to allow migration of data between individual data base areas.

Although this data base software was developed to support a specific application, it is very general and would certainly be adequate for the needs of the CDG.

An attractive feature of this data base software over any commercially available package is the price. This software (and possibly installation support) can be provided by INEL at little or no cost. There will be continued INEL support for the software for the foreseeable future because it is integral to an ongoing, NRC-funded project. This software package is currently operating on a CDC cyber 176 at INEL. Plans for conversion to a CRAY machine are currently being negotiated with NRC.

Inquiries regarding the structure and application of the data base software should be directed to Howard Stewart (208-526-9103, FTS 583-9103) or Bob Hagen (208-526-9645, FTS 583-9645) at INEL.

Negotiations for delivery and installation support will be coordinated by Eric Ottewitte (208-526-1751, FTS 583-1751).

Appendix 7. Report of the Group on a Common Input Format

Participants: Dave Douglas, Liam Healy, Christoph Iselin, Rob Ryne

The group on I/O and Data Bases, Group D, headed by Steve Peggs, concluded that those who use and maintain the various tracking and design codes should be strongly encouraged to adopt a common language for specifying lattice arrangement. Towards this end, an informal group on common input format was formed to decide the syntax and interpretation of specifications in such a common input language. It is hoped that eventually all codes will be modified so that they will be able to read directly or with minor changes the lattice specifications, but in the meantime, the standards are established so that one person may understand another's lattice and construct an appropriate input file for a given code.

As a starting point for such a standard, we used the paper by Carey and Iselin entitled "A Standard Input Language for Particle Beam and Accelerator Computer Programs" prepared for the 1984 SSC Snowmass conference. We agreed that the standard should be as given in that paper, but with the following modifications and additions:

1) The formal arguments to a beam line should be placed after the name in the definition, instead of placing it after the keyword 'LINE'. For example,

```
CELL(SF,SD): LINE = (QF,D,SF,D,B,D,QD,D,SD,D,B,D)
```

instead of

```
CELL: LINE(SF,SD) = (QF,D,SF,D,B,D,QD,D,SD,D,B,D)
```

2) The definition of variables is made in a simple FORTRAN-like assignment statement, instead of using the keyword 'PARAM'. For example,

KF = 0.0128

instead of

KF: PARAM = 0.0128

3) The keywords KØ, K1, K2, etc. in elements with multipole moment(s) are defined, in the absence of the statement 'MOMFACT' explained below, as K_0^{std}, K_1^{std}, K_2^{std}, etc., where

$$B\ (x,s) = B\rho \sum_{n=0}^{\infty} \frac{K_n^{std}(s)}{n!} \quad x^n$$

and B is the magnetic field perpendicular to the median plane. The quantity x is the displacement from the design trajectory in the median plane, s is the distance along the beam, and Bρ is the magnetic rigidity. Thus, for instance, a quadrupole is horizontally focusing if its strength is positive. Other sign and factorial conventions may be specified with the statement

MOMFACT, MØ = , M1 = , M2 = ,

Presence of this statement indicates that all multipole moments K0, K1, K2, etc., are to be interpreted as K_0^{user}, K_1^{user}, K_2^{user}, etc., where $K_n^{std} = M_n * K_n^{user}$. The default values for the M_n are all 1.

4) Units for all physical quantities are assumed to be the following:

   a) lengths in meters

   b) angles in radians

   c) magnetic fields in Teslas

   d) electromotive force in megavolts

   e) energy, momentum and mass in GeV

   f) frequency in Megahertz

   g) current in milliamperes

   Alternate units may be specified with the statement:

   UNIT, L = , ANGLE = , B = , EMF = , E = , FREQ = , I =

   The quantities specified after each keyword provide the factor that the user's quantities should be multiplied by to get that quantity in standard units. For example, ANGLE = PI/180. will allow angles to be input in degrees if PI has been defined as π. Default values are all 1.

5) The beam qualities will be specified with

   BEAM, BRHO = , GAMMA =

   where BRHO is the rigidity ($B\rho$), and GAMMA is $\gamma = (1-\beta^2)^{-1/2}$.

6) The meaning of RBEND and SBEND are clarified as follows. Both can be used to describe any bending magnet, however, RBEND describes the geometry in rectangular coordinates, and SBEND describes the geometry in polar coordinates, and thus the former is more suitable for a parallel-face magnet and the latter more suitable for a normal-entry magnet. The quantities are described as follows:

a) RBEND: L is the straight-line distance from the entry point to the exit point of the design beam. ANGLE is the bend angle. E1 and E2 are the angles between the normal to the entry and exit polefaces and the chord of the arc in the bend, positive when rotated away from the center of the bend. Default values for both E1 and E2 are 0, thus describing a symmetric parallel face magnet.

b) SBEND: L is the path length of the design beam from entry point to exit point. ANGLE is the bend angle. E1 and E2 are the angles between the normal to the entry and exit polefaces and the design trajectory, positive when rotated away from the center of the bend. Default values for both E1 and E2 are 0, thus describing a normal entry magnet.

7) The following elements will be renamed and added:

   a) SROT will become ROLL and will be a rotation of the particles clockwise about the axis of the beam, when looking in the direction of beam motion.

   b) OCTUPOLE will be made into two elements, EOCTUPOLE and MOCTUPOLE for electric and magnetic octupole respectively.

   c) ELSEPARA will become SEPARATOR. Septa will be called ESEPTUM and MSEPTUM for electric and magnetic septa respectively.

8) The variable PI shall mean

   $\pi = 3.14159265358979323846264...$

   to the appropriate number of digits for the machine being used.

While it is hoped that everyone will conform to these standards as much as possible, it is understood that many codes will have provisions for lattice characteristics not specifiable within this framework. Furthermore, it is acknowledged that there are ambiguities in these standards. Therefore, all non-standard usage and clarification of the standard usage should be documented in the input lattice file using the comment facility ('!' character), and a corresponding proposal to amend the standard forwarded to the group on common input formats at the Central Design Group. In addition, any suggestions for improvements or further specifications are actively solicited. For the present, send these proposals to Steve Peggs. He will then consult with other members of the Group before accepting or rejecting such proposals.

APPENDIX 8

EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH

CERN LEP-TH/84-10

A STANDARD INPUT LANGUAGE FOR PARTICLE BEAM AND ACCELERATOR COMPUTER PROGRAMS

D.C. Carey* and F.C. Iselin

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G E N E V A
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A STANDARD INPUT LANGUAGE FOR PARTICLE BEAM AND ACCELERATOR COMPUTER PROGRAMS

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Motivation for a Standard and History

With the growing size of modern particle accelerators and charged particle beam lines the input data sets needed to describe these devices to computer programs become increasingly bulky. This makes data preparation a laborious and error-prone process. The situation gets even worse if data are to be prepared for several computer programs with widely different input formats.

To tackle these problems, a workshop was organised in May 1984 at SLAC by K.L. Brown, D.C. Carey, and F. Rothacker. During this workshop the two authors of this paper were asked to elaborate a standard accelerator and beam line description language. The following aims were set:

- The accelerator structure must be described such that data can be exchanged easily between all programs conforming to the standard.
- The input must be easily readable by a human reader, and avoid unnecessary work like repetition and expansion of symmetry.

So far the standard language covers only the structure description. It is however highly desirable that action commands are also standardized, if only with regard to their format.

Definition of the Standard Language

Statements

The information is presented to the computer program by means of definitions and commands. A definition introduces or redefines a beam line element, a sequence of elements, or a parameter. A command calls for a specific action to be performed using previously entered definitions. In the sequel we refer to both definitions and commands by the term statement.

Statements are entered sequentially. Normally a statement occupies one input line. Three special characters are provided to signal exceptions:

- ";" Separates statements on the same input line.
- "&" Signals continuation of a statement on the following line. Any characters following the "&" on the same line are ignored.
- "!" Signals a comment. The "!" terminates a statement. Any characters following it on the same line are ignored.

Empty statements, like blank cards, two ";" in a row, are permitted, as well as comment lines beginning with a "!".

Examples for statement formats:
statement-1
statement-2; statement-3 & comment
statement-3 (continued) ! comment

Keywords and Labels

Keywords denote program defined actions and their parameters, as well as element types and their parameters. They are defined in the standard as sequences of letters and digits such that the first four characters are unique. A program checking four characters may safely ignore excess characters without causing confusion.

Labels denote beam elements, sequences of beam elements, and user-defined parameters. They consist of a letter followed by up to seven letters or digits, as chosen by the program user.

Element Definitions

The general format for an element definition is
label: type-keyword [, parameter-keyword = value] ;
Subsequent statements refer to an element by its label. The type-keyword selects the element type (dipole, quadrupole, drift space, etc.) to be used. An element whose type-keyword is unknown to a program is treated like a drift space and flagged with a message.

The table of elements is open-ended. The standard elements are shown in Table 1. Element parameters are given with parameter-keywords. The standard parameter-keywords are listed in Table 2. Parameters accepted for various elements and their default values are shown in Table 3. If a parameter-keyword is unknown to a program, the parameter is ignored with a message.

Examples for beam elements:

```
D1:    DRIFT,   L=0.2
QF7:   QUAD,    L=1.6,K1=0.012834
B:     SBEND,   L=5,ANGLE=0.0001
```

Table 1: Standard beam elements

DRIFT	Drift Space
RBEND	Rectangular (Parallel-faced) bending magnet
SBEND	Sector (Normal-entry) bending magnet
QUADRUPO	Quadrupole
SEXTUPOL	Sextupole
OCTUPOLE	Octupole
MULTIPOL	General Multipole
SOLENOID	Solenoid
ELSEPARA	Electrostatic separator
RFCAVITY	RF cavity
HKICK	Horizontal orbit corrector kicker
VKICK	Vertical orbit corrector kicker
SROT	Change of reference by rotation on longitudinal axis
ECOL	Elliptic collimator
RCOL	Rectangular collimator
MATRIX	Arbitrary matrix
HMONITOR	Monitor for horizontal plane
VMONITOR	Monitor for vertical plane
MONITOR	Monitor for both planes
MARKER	Marker (serves to denote a position for matching)

Table 2: Standard parameter keywords

L	Element length
ANGLE	Bending angle or rotation angle
K0	Dipole strength
K1	Quadrupole strength
K2	Sextupole strength
K3	Octupole strength
K4	Decapole strength
K5	Dodecapole strength
KS	Solenoid strength
E1	Entrance edge angle for bending magnet
E2	Exit edge angle for bending magnet
H1	Entrance pole face curvature
H2	Exit pole face curvature
HGAP	Half gap size of bending magnet (for fringe field)
FINT	Field integral for fringe field
KICK	Kick angle for orbit correctors
FREQ	RF frequency
VOLT	RF voltage
LAG	RF phase lag
XSIZE	Horizontal half-aperture
ZSIZE	Vertical half-aperture

Table 3: Standard Element Parameters and Default Values

DRIFT	L=0.0
RBEND	L=0.0, ANGLE=0.0, K1=0.0, E1=0.0, E2=0.0, K2=0.0, H1=0.0, H2=0.0, HGAP=0.0, FINT=0.5
SBEND	L=0.0, ANGLE=0.0, K1=0.0, E1=0.0, E2=0.0, K2=0.0, H1=0.0, H2=0.0, HGAP=0.0, FINT=0.5
QUADRUPO	L=0.0, K1=0.0
SEXTUPOL	L=0.0, K2=0.0
OCTUPOLE	L=0.0, K3=0.0
MULTIPOL	L=0.0, K0=0.0, K1=0.0, K2=0.0, K3=0.0, K4=0.0, K5=0.0
SOLENOID	L=0.0, KS=0.0
ELSEPARA	L=0.0, E=0.0
RFCAVITY	L=0.0, FREQ=0.0, VOLT=0.0, LAG=0.0
HKICK	L=0.0, KICK=0.0
VKICK	L=0.0, KICK=0.0
SROT	ANGLE=0.0
ECOL	L=0.0, XSIZ=0.0, ZSIZ=0.0
RCOL	L=0.0, XSIZ=0.0, ZSIZ=0.0
MATRIX	$R_{ij}=\delta_{ij}$, $T_{ijk}=0.0$
HMONITOR	L=0.0
VMONITOR	L=0.0
MONITOR	L=0.0
MARKER	

Beam Line Definitions

Beam lines are described by the construct

label: LINE=($member_1$, $member_2$, ..., $member_n$)

Each $member_i$ may be one of the following:

- A beam element name,
- The name of another beam line,
- A sequence of names, separated by commas and enclosed in parentheses.
- One of the above, preceded by
  - a repetition count and an asterisk to indicate repetition,
  - a minus sign to indicate reflection,
  - a minus sign, a repetition count and an asterisk.

Examples for beam lines:

```
CELL:    LINE = (QF,D,B,D,QD,D,B,D)
PERIOD:  LINE = (3*CELL,QF,-3*CELL,D,B,D)
INSERT:  LINE = (QF,D,B,D,QF)
```

Conventions for Multipole Signs

The sign conventions for quadrupoles and higher multipoles and the numeric factors involved, and the orientation of coordinates differ in different programs. It is thus necessary to state which convention is being used. The desired option is selected by entering a single keyword:

KTRA Meaning TRANSPORT conventions,
KMAD Meaning MAD conventions.

The last option set will be used for all beam elements. The conventions may be described as follows:

$$\text{let } B = B_0 + B_1 x + B_2 x^2 + B_3 x^3 + \ldots$$

The TRANSPORT convention uses

$$\begin{aligned} h &= +B_0/(B\rho) \\ K_1 = -hh^2 &= +B_1/(B\rho) \\ K_2 = +\beta h^3 &= +B_2/(B\rho) \\ K_3 &= +B_3/(B\rho) \end{aligned}$$

and the horizontal axis points to the left. The MAD convention uses

$$\begin{aligned} h &= +B_0/(B\rho) \\ K_1 &= -B_1/(B\rho) \\ K_2 &= -B_2/(2B\rho) \\ K_3 &= -B_3/(6B\rho) \end{aligned}$$

and the horizontal axis points to the right. In both programs a positive bend angle bends towards negative x.

Possible Future Extensions of the Standard

Formal Arguments for Beam Lines

Frequently the structure of an accelerator is periodic with exception of special insertions in some straight sections. The exceptions may be beam monitors, correction magnets, or other devices. Such exceptions can readily be dealt with by adding formal arguments to a beam line. Each time such a line is used, it may be given different actual arguments.

Example for formal arguments:

```
CELL:   LINE(SF,SD) = (QF,D,SF,D,B,D,QD,D,SD,D,B,D)
SUPER:  LINE =
        (CELL(SF1,SD1),CELL(SF2,SD2),CELL(SF3,SD3)
```

The above beam line "LINE" would be expanded as

```
QF,D,SF1,D,B,D,QD,D,SD1,D,B,D,QF,D,SF2,D,B,D,
QD,D,SD2,D,B,D,QF,D,SF3,D,B,D,QD,D,SD3,D,B,D
```

Element Prototype Parameters

It is frequent that most quadrupoles in an accelerator have the same physical design, but different excitations. A few of them, located in injection or ejection regions, may however have a different design. In order to build an installation data base from the standard language input it is useful to assign quadrupoles a second label, which tells which design (in the terminology of magnet builders) is to be used. This may be done by adding a clause

TYPE = 'design'

to the quadrupole parameters. The quoted character string can be retrieved from the internal data structure and transmitted to a data base. It may also be used on program printouts. The same principle can be applied to other physical elements.

Coupling of Element Parameters

For matching it is frequently desired to vary certain parameters in a coupled way. This may be readily achieved by allowing expressions for element parameters involving parameters of other elements and/or globally known values. Varying independent parameters then automatically changes the independent parameters accordingly.

Examples for coupled parameters:

```
KF:  PARAM = 0.0128
QF:  QUAD, L=1.6, K1=KF
QD:  QUAD, L=1.6, K1=-KF

L1:  PARAM = 2
D1:  DRIFT, L=L1
D2:  DRIFT, L=10-L1
```

Action Commands

It would be desirable that the action commands are also standardized. For the time being this is however difficult to achieve.

Examples

```
!
! DRIFT SPACES:
!
L1:   DRIF,L=5.0
L2:   DRIF,L=2.8
L3:   DRIF,L=47.5083
!
! BENDING MAGNETS:
!
BW:   RBEN,L=23.4,ANGLE=0.753741D-03
B4:   RBEN,L=23.4,ANGLE=0.7537411D-02
B6:   SBEN,L=35.09,ANGLE=0.11306116D-01
!
!QUADRUPOLES:
!
QS1:  QUAD,TYPE=QS,L=5.0,K1=0.51741915D-01
QS2:  QUAD,TYPE=QS,L=3.0,K1=-0.4574919D-01
QS3:  QUAD,TYPE=QS,L=2.0,K1=0.37887276D-01
QF:   QUAD,TYPE=MQ,L=1.6,K1=-0.2268553D-01
QD:   QUAD,TYPE=MQ,L=1.6,K1=0.22683642D-01
!
!SEXTUPOLES
!
SF1:  SEXT,L=0.4,K2=0.13129
SD1:  SEXT,L=0.76,K2=0.26328
!
!BEAM LINES
!
GCT:  LINE=(LOBS,RFS,DISS,ARC,DISL,RFL,LOBL)
LOBS: LINE=(L1,QS1,L2,QS2,L3,QS3,L4,QS4)
RFS:  LINE=(L5,QS5,L5,QS6,L5,2*(QS7,L5,QS8,L5))
DISS: LINE=(QS11,L25,BW,L2X,QS12,L25,B4,L2X,QS13,L25,&
      B4,L2X,QS14,L25,B4,L31,QS15,L25,B4,L32,SF2,L23,&
      QS16)
ARC:  LINE=(L21,B6,L22,SD2,L23,QD,15*CELL,&
      L24,B6,L41,QF,L21,B6,L22,SD4,L23,QD,15*CELL,&
      L24,B6,L22,SF3,L23)
DISL: LINE=(QL16,L34,B4,L2X,QL15,L33,B4,L2X,QL14,L25,&
      B4,L2X,QL13,L25,B4,L2X,QL12,L25,BW,L2X,QL11)
RFL:  LINE=(2*(L5,QL8,L5,QL7),L5,QL6,L5,QL5,L5)
LOBL: LINE=(QL4,L14,QL3,L13,QL2,L12,QL1,L11)
CELL: LINE=(L24,B6,L22,SF,L23,QF,L21,B6,L22,SD,L23,QD)
```

Appendix 9. First Turn Steering in the SSC

A simple tracking study by Meyers during the Reference Design Study showed that the first turn beam storage algorithm used successfully in the Tevatron ran into difficulties when adopted for the SSC. It was only found to be possible to steer beam around about 35% of an ensemble of lattices composed of 100 simple FODO cells, with quadrupole displacement errors of 1 millimetre and an aperture radius of 15 millimetres. There was one detector and one corrector per cell for each transverse plan, at the appropriate focussing quadrupole.

The algorithm assumes that it is possible to detect a beam with an intensity low enough to avoid quenching the superconducting magnets, if it is lost. It is straightforward in principle to advance around the lattice at a more or less steady rate, reading the detectors in the new region explored by the latest shot, adjusting the correctors in that region, and then injecting another shot. When there is a one to one correspondence of detectors and correctors, the observed orbit displacements can be reduced to the level of the measurement noise. This does not mean that there are no orbit distortions away from the beam detectors - as shown by the failure of the algorithm.

Most electron storage rings work in a configuration with a redundancy of position detector information, with a detector at every quadrupole and a corrector at every focussing quadrupole. Meyers shows that with this configuration, doubling the number of position detectors, the failure rate of the injection algorithm is reduced to only about 1% of an ensemble of simple SSC lattices. The additional

information allows the orbit to be made flatter but, somewhat paradoxically, even perfect detectors now show non-zero displacements.

Properly instrumented low quality beam transfer lines can be persuaded to pass most of the charge injected into them, even if iterated motion through them is clearly unstable. In a worst case analysis the SSC could be seen as such a transfer line. Even assuming that the linear motion is stable, the available dynamic aperture decreases rapidly as a function of the number of stored turns. Both of these arguments imply that closed orbit establishment is more difficult than first turn establishment, so long as enough money is spent on adequate instrumentation.

Detailed first turn and closed orbit simulations of the SSC must be carried out to predict the true root mean square orbit deviation as a function of quantities of interest. The results of such simulations are essential in specifying the surveying accuracy required, and may be important in specifying the needed good field aperture in the dipoles. While it probably remains true that quadrupole displacements are more important than any other form of magnet misalignment, such as dipole or quadrupole roll, this should be checked and quantified.

The role of corrector and detector densities can be further analysed in a simple model, as can the dependency of orbit errors on the phase advance per regular cell in each transverse plane. More sophisticated models of realistic lattices should include the effects of linear and non-linear chromaticity errors, injection energy errors, sextupole fields in dipoles, and long range beam-beam interactions.

Although major problems are not anticipated from high order multipole feed down, or during the transition from high to low collision beta lattices between injection and collision conditions, these effects can be checked if it is felt necessary.

In conclusion, there do not appear to be fundamental physical problems in establishing the first turn. First turn and closed orbit simulations should be used rather to investigate how much money it is necessary and advisable to spend on items like detectors, correctors, power supply stabilization, surveying accuracy, and, to a lesser extent, the good field aperture in dipoles. In common with past accelerator experiences, there are presumably great dividends to be earned in operating efficiency and flexibility by making a major investment in extensive instrumentation. Measured as a fraction of the total cost, ideal instrumention in the SSC would still be very competitive when compared to instrumentation costs in present accelerators.

Reference: P.D. Meyers, SSC Magnet Alignment and Aperture, April 12, 1984.

Appendix 10. Talks and Reports Presented in Group E

S. Peggs - 'Hadron Collider Behaviour in the Non Linear Numerical Model EVOL'

B. Leemann - 'Summary of Tracking Studies on SSC-like Lattices'

A.G. Ruggiero - 'Kick Codes of the Patricia Family'

A.G. Ruggiero - 'Calculation of Aberration Effects with PATRIS'

J. Niederer - 'MAD/LILA Merger Estimates of Scale'

T.L. Collins - 'Distortion Functions'

E. Keil and F. Ch. Iselin - 'Talk on MAD - 6 Nov. 84'

F. Ch. Iselin - 'The MAD Program (Methodical Accelerator Design) Reference Manual'

L. Healy - 'Report of the Group on a Common Input Format'

A. Wrulich - 'HERA and Tracking with RACE TRACK'

M. Donald - 'Improvements in HARMON and other Analytical Methods'

A. Russell - 'First Turn Algorithms'

G.F. Dell - 'Recent Additions to PATRICIA'

A. Garren - 'Use and Features of SYNCH'

R. Ruth - 'Super Convergent Tracking and Convergent Invariant Tori'

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