Recent Work on Error Correction and Related Issues at the SSC.

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1. Introduction.

This will be largely restricted to being an enumeration of recent work on compensation of errors in the SSC. Much of this work is of a rather routine nature and will not be spelled out on that account. More fundamental new results by Neuffer on systematic corrections and by Forest on random corrections and other topics has been described by those authors at this workshop and will not be further described here.

Using the terminology of Willeke, the leader of the Compensation Scheme Group at this workshop, the SSC will be an "error dominated" not a "chromaticity dominated" machine. This means that some of the elegant, global compensation relationships described for small electron machines at this workshop are not really relevant. On the other hand, in large, error-dominated accelerators, it is important to understand the conspiracy between two (or more) bad effects, either of which, by iself, could be analysed simply. Two examples are coupling caused by orbit distortion, and random bend errors due to orbit shifts in elements possessing systematic errors.

Degradation due to nonlinear field errors has been quantified mainly by tune shifts and by "smear". A lengthy and inconclusive working session on standardizing usage as regards smear was held at the workship and none of that discussion will be reported here. In analysing the SSC the following approximate "principles" have repeatedly been found to be valid:

(*i*) systematic bend errors cause tune shifts and not smear, and

(*ii*) random bend errors cause smear and not tune shifts.

Though these are obviously not universally valid they represent a useful rule-of-thumb on what to pay attention to.

2. Some Terminology of Error Correction.

The ideas behind various correction schemes are not at all deep and understanding them often requires little more than an understanding of the meaning of the terms employed in describing them. This itself is not necessarily easy as the terms are often a bit vague and describe points on a "continuous spectrum" of possibilities. Some of the terms are:

(*i*) **local $\simeq$ distributed $\simeq$ bore tube correctors.** These are coils which, in the ideal limit, run the full length of the magnet and precisely "correct" the multipole element they are designed for. These have the effect of "fixing the magnet" itself rather than "fixing the accelerator". A bit of discussion at the workshop suggested that the former should be called "correction" while the latter should be called "compensation". Unfortunately, an appreciable minority felt the usage should be the reverse of that.

(*ii*) **lumped $\simeq$ remote correctors.** These are coils which are located in the lattice at points remote from the errors which they are "*compensating*". That is, they "fix the accelerator".

(*iii*) **magnet sorting** consists of ordering the placement of elements in the ring based on bench measurements of one or more of their multipole errors and in such a way that their errors tend to be mutually compensating. The simplest scheme would match magnets in pairs having a particular multipole approximately equal in magnitude but opposite in sign; these would be placed side-by-side in the lattice. Such schemes have fervent supporters who were well represented at the workshop. They can be perceived to be "free" or at least "cheap". For that very reason these schemes have been held "in reserve" in recent SSC investigations. They are not mutually exclusive of other schemes and can be used to compensate a lesser multipole if a greater multipole has been compensated (or corrected) some other way.

(*iv*) **shuffling.** As applied to playing cards this means mixing them up. As applied to magnet *laminations or other elements which have not been individually measured it* means mixing them up to convert systematic errors (either feared or known) into much smaller random errors. At one large U.S. laboratory the barbarous use of this term to mean sorting has been all too common.

(*v*) **binning correction.** This is just a minor variant of local correction. It works only to correct previously measured random errors and requires the existence of approximately local correction coils. Ideally every such coil would have an independent power supply powered to cancel the known error. After histogramming the measured values of the particular multipole error, one attaches all magnets falling in one bin to that power bus which cancels the center-of-bin value. This saves power supplies.

(*vi*) **Neuffer scheme ≃ Simpson's rule scheme.** Though not really synonyms these terms convey the same spirit. Neuffer uses traditional numerical integration weighting rules — for one likely configuration that means Simpson's rule. Neuffer economizes further, with little degradation, by coalescing the corrections adjacent to quadrupoles, thereby getting the benefit of an integration formula of order higher by one than the number of lumped correctors appears to indicate.

Generally speaking local compensation is easy to analyse but may be expensive or impractical. Remote correction is cheaper but harder to analyse. Much of the recent work at the SSC *has* be devoted to analysing these trade-offs.

3. Diagnostic Developement.

Some other topics which have been of recent interest but which have been described by other participants in the workshop are hysteretic behaviour of persistent multipoles (described by M. Harrison) and developement of diagnostic capabilities performed in conjunction with the beam dynamics experiment E778. (These have been described by S. Peggs.) These last two are closely related since the expected slow chromaticity variation accompanying the drifting persistent currents are expected to demand continuous chromaticity control of the SSC with measurement times much less than a minute. (Chromaticity control is relatively more critical in a *larger ring as tune variation tolerances are absolute; they become smaller relative to the* integer tune.) By modulating the Tevatron R.F. frequency first plus then minus by one part in a million the tunes were measured within five seconds and the chromaticity calculated within about 30 seconds using the Sun workstation data aquisition instrument MIRABILE developed at the CDG by Saltmarsh, Peggs, and the author and described by Peggs. Comparison of the measured chromaticities with theoretical values is given in Fig. 1.

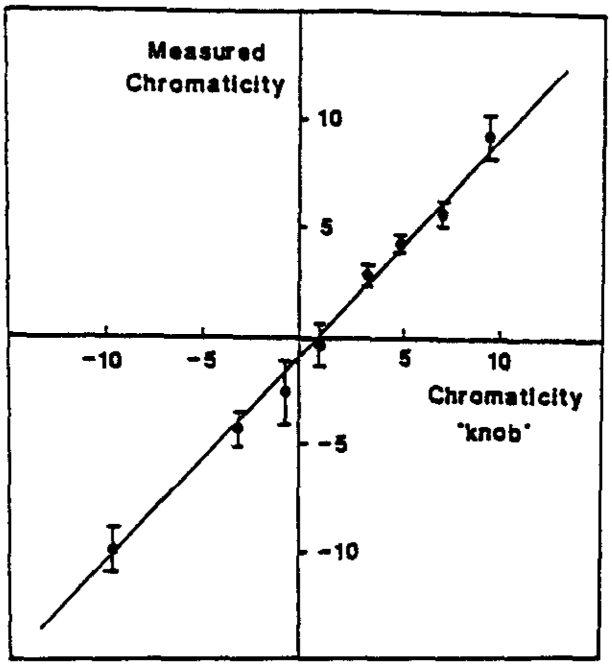

Figure 1. Comparison between chromaticity as calculated to calibrate a chromaticity "knob" with values measured and calculated on-line on the Tevatron.

4. Recent Reports on Multipole Compensation.

Some recent reports generated at the Central Design Group and describing different lumped schemes will now be enumerated. They are all mutually compatible and, as mentioned previously, are intended to replace sorting only in the sense of leaving that in reserve to compensate other multipoles.

Neuffer, SSC-132, June 1987, (and SSC-N-362, and other reports.) Lumped compensation of systematic multipoles is described and analysed.

Neuffer, SSC-N-384, March 1988, Compensation by octupoles of tunes shifts caused by second order sextupole tune shifts is described.

Forest and Peterson, SSC-N-383, September 1987. Using binning, lumped correction of random multipoles is shown to be effective.

Talman, SSC-N-413, December, 1987. Several lumped schemes are analysed and found to be effective both for randoms and systematics.

Neuffer and Talman, SSC-N-492, March, 1988. Of various lumped schemes of the same cost, the Neuffer scheme was found to be the most effective for systematics.

Sun and Talman, SSC-N-500, April, 1988. Of various lumped schemes of the same cost, using binning with strengths given by formulas of Forest, the Neuffer scheme was found to be the most effective for randoms.

5. Operational Simulation.

Work on interactive aspects of operational simulation is led by Schachinger. Computation is done on a cluster of Sun workstations. The analysis tool is the code TEAPOT, but, apart from the application to specific SSC design issues such as those just listed, recent work has been more in the area of graphical representation and developement of interactive capabilities. As mentioned above it is the possibility of conspiracy between bad effects which necessitates the simultaneous inclusion of many different errors and imperfections. Areas in which reasonably complete work has been done are checked off in Table 1. Possible future projects are also indicated. Recent work includes

Schachinger, SSC-N-433, December 1987, Interactive Global Decoupling of the SSC Injection Lattice.

Schachinger and Talman, SSC-167, March 1988, Simulation of Chromaticity Control in the SSC.

Paxson, Peggs, and Schachinger, in preparation, Interactive Closed Orbit Control.

6. Data Organization.

Accelerator data are generated by diverse groups and they are of interest to diverse groups. It is important that the accelerators being designed, manufactured, positioned, measured, controlled, etc. are in fact the same machine. To insure this it is important that internal inconsistencies not develop and that requires that every parameter be recorded in a unique "sacred" record. Every user needing that number must obtain it from that source. At the same time most data "belong" most naturally to one particular group. That is the group having the greatest stake in their correctness, and, one supposes, the best motivation to keep them current. To meet these requirements a "hub-and-spoke" top level data organization, as shown schematically in Fig. 2, is planned.

The main features are

(*i*) **A hub database** that manages the interaction between many spoke databases. It is primarily a "telephone directory" which contains addressing information permitting a worker in one spoke to locate information in another spoke.

(*ii*) **Spoke Databases.** These contain real data from experiments, planning, design and so on, specialized applications for internal data presentation, and well-defined

(*iii*) **public interfaces,** where responsibilities to and requirements from the wider user community can be specified without forcing inappropriate practices on specialized applications.

So far developement of this structure has been restricted to the spoke labelled Accelerator Design DBMS (Database Management System.) A commercial database has been selected and rudimentary generation from the database of a lattice file in standard format has been achieved by Saltmarsh and Peggs. Plans are afoot to start work soon on the spoke labelled Magnet Construction and Measurement Database. Referring back to Table 1, it can be seen that, as yet, there is no mechanism for obtaining operational simulation input data from the shared database.

OPERATIONS SIMULATION — Modeling Attribute \ Accelerator procedure	ORBIT: First turn	ORBIT: Iterated bump	ORBIT: Matrix inversion	OPTICS: Beta function adjustment	OPTICS: Global decoupling	OPTICS: Local decoupling	NONLINEAR SYSTEMATIC: $Q(\delta,\epsilon_x,\epsilon_y)$	NONLINEAR RANDOM: Smear, FFT, resonance	MULTI-PARTICLE: Tevatron simulation	DYNAMIC: Energy ramping	DYNAMIC: Beta squeeze	CONTROL: Real control performance specification
Analytic description	Y	Y	Y	Y	Y	Y	Y	Y	Y			
"Batch" mode -- file input	Y	Y	Y		Y	Y	Y	Y	Y			
Useable for design decisions?	Y	Y	Y		Y	Y	Y	Y	Y			
Realistic, interactive, graphical, interface	Y	Y			Y	R	Y	Y				
Shared database												
"Real time" response*	Y	Y						Y				

Table 1. Checklist of SSC features which have been simulated. Y means "yes", R means "rudimentary", blank means "not yet", * means enough computer power so that the procedure being simulated takes roughly as long as the actual procedure will take.

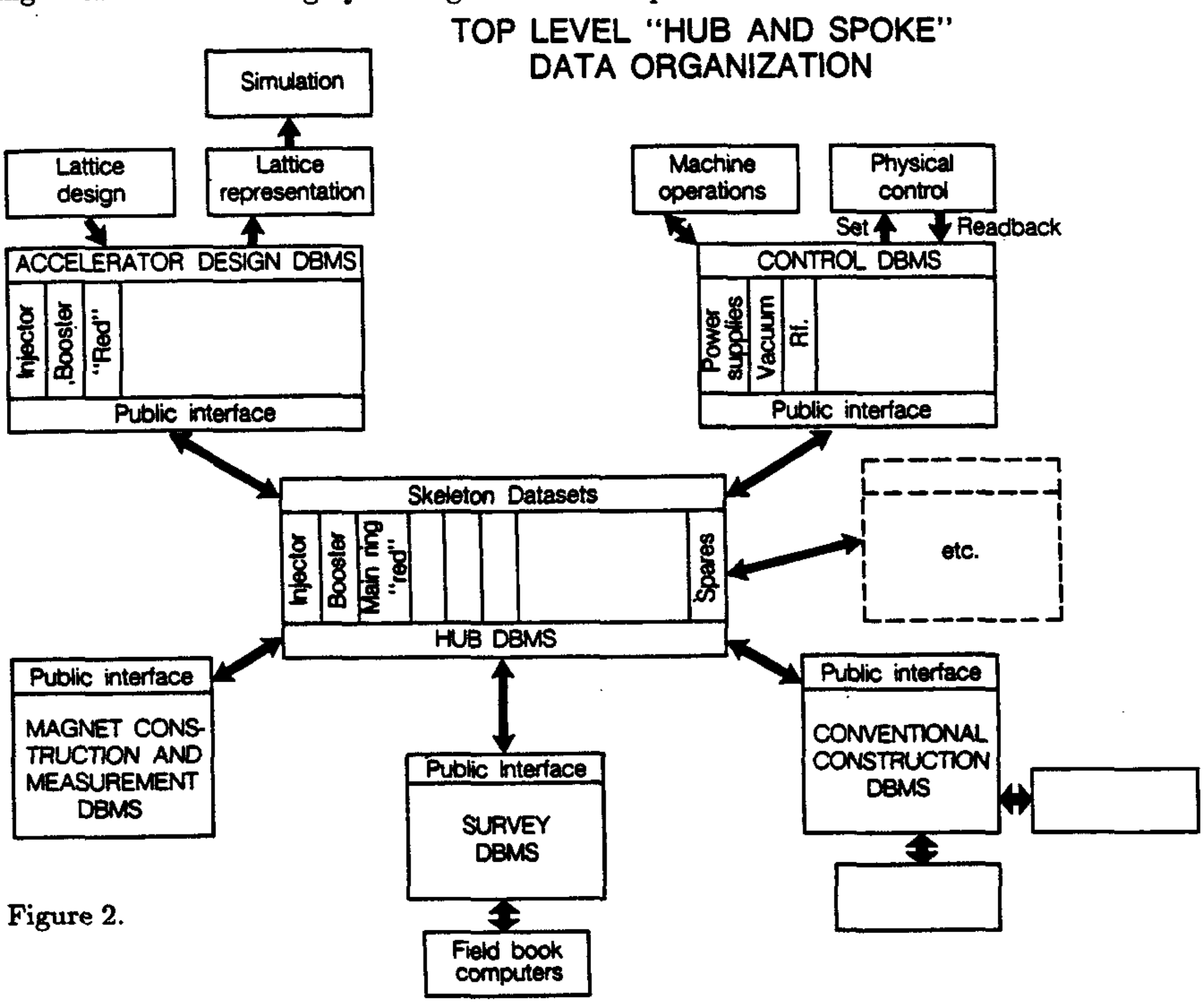

Figure 2.