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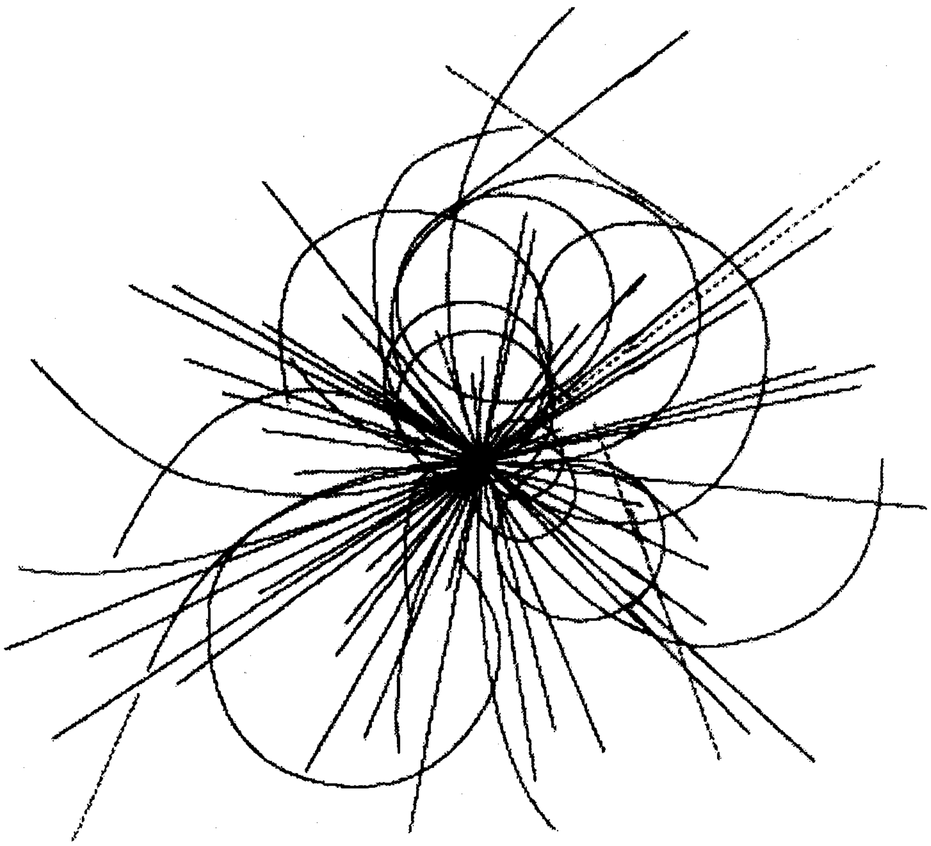

Superconducting Super Collider Laboratory

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Accelerator Physics Issues at the SSC*

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ACCELERATOR PHYSICS ISSUES AT THE SSC

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I. INTRODUCTION

Realization of the design energy and luminosity goals of the Superconducting Super Collider (SSC) will require proper resolutions of a number of challenging problems in accelerator physics. The status of several salient issues in the design of the SSC will be reviewed and updated in this paper. The emphasis will be on the superconducting accelerators.

II. LATTICE AND BEAM LINE DESIGN

A. Collider

A new configuration for the lattice of the Collider[1] has been adopted, in which space has been created in the north and south arcs, by the removal of a small number of dipole magnets. The magnets have been removed in pairs separated by 180° in phase advance, so that the perturbation to the dispersion function is local and minimal. The rest of the dipoles in the ring will be operated at a slightly higher field to attain the same energy, and the margin will be retained by lowering the operating temperature by about 0.1°K. Some of the resulting free space provided in the arcs has been utilized to allow cryogenic and electrical feed point placement consistent with surface land acquisition sites for utility buildings. Additional free space will be filled with empty cryostats initially, but will be available for use in the future for purposes such as beam scraping, polarization preserving devices, damping systems, and other as yet unspecified needs. An additional modification to the lattice now being studied is the option of a larger aperture (≥48mm) quadrupole in the Collider arcs. This is motivated by a desire for uniformity with larger aperture quadrupoles in the utility and IR regions; simplification of quench protection for a larger bore quadrupole; and ease of magnetic measurements with an increased bore tube inner diameter in both dipoles and quadrupoles. The larger aperture quadrupole would develop a smaller gradient, and so would require a larger slot length, which is provided by the space previously allocated to mid-half-cell correction systems (see below).

In addition to the modifications described above for the arcs of the Collider, parts of the straight sections (specifically the West Utility Region and the East Interaction Region) have undergone significant design evolution.

The current design[2] of the East Interaction Region incorporates three additional families of independently powered quadrupoles. These quadrupoles are used to change the optics from injection to collision while the final triplet quadrupoles are held constant. This feature of the design allows the two rings to be "squeezed" independently. The new design has two secondary foci where the IP is imaged, located symmetrically on both sides of the IR. Additional changes from the previous design include: 1) A significant reduction in the peak value of β at injection, 2) larger bore (5cm) triplet quadrupoles, 3) a standard design for the vertical bends, 4) a reduced total length of magnets. The design can accommodate different β^*'s at the two IP's, and a range of values between 40 and 180m is possible for the space allocated to a detector at each IP.

Crossing angle control is achieved through local steering dipoles. This introduces undesirable anomalous dispersion due to the necessarily large orbit excursions through the high beta triplets. A scheme has been proposed[3] to correct this dispersion, using opposite polarity quadrupole pairs separated by 180° in phase and located in the arcs, just prior to entry into and after exit from the IR's. The IR design incorporates a phase advance between these quadrupoles and the IR triplet such that the anomalous dispersion from the triplet is fully canceled.

The Collider West Utility region has also undergone considerable design development[4]. The maximum β values have been reduced by a factor of two to about 600m. The complexity and plurality of different components (quadrupoles, spools, warm-to-cold transitions) in the region has been reduced. The abort line admittance has been increased, and specific locations for damping systems have been identified.

B. High Energy Booster

The lattice of the High Energy Booster (HEB) has also been modified in order to increase its dynamic aperture. The cell length has been decreased from 78 to 64m. The stronger focusing increases the dynamic aperture from 9σ to 11σ at injection. Additional minor modifications to the lattice in the short straight sections are under consideration to obtain further increases in dynamic aperture.

C. Beam Lines

The optics of several of the beam lines which interconnect the synchrotrons has also been redesigned, in order to increase simplicity, reduce cost and improve operability. These include the 12 GeV/c LEB-MEB transfer line[5], the 200 GeV/c MEB-HEB transfer lines[6], and the 2 TeV HEB-Collider transfer lines[7]. All these transfer lines are fabricated from resistive magnets. The general guidelines in these redesigns have been to minimize sensitivity to magnet and alignment errors, and to provide flexibility, and orthogonality, for amplitude and dispersion function matching between the rings. In the case of the higher energy transfer lines, for which the beam transfer

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takes place into or between superconducting accelerators, provision for control of beam loss and considerations of component failure scenarios (particularly kicker misfires/prefires) are incorporated into the designs[8].

III. COLLIDER CORRECTION SYSTEMS

A. Linear Coupling

A decoupling scheme has been proposed[9] which utilizes 44 skew quadrupole correctors, located within the arcs in missing dipole spaces, and in the utility straight sections. The system can be operated to achieve global decoupling in two families of 12 skew quadrupoles or in four families of 24 skew quadrupoles. Alternately, all 44 skew quadrupoles can be independently set if desired to achieve both global and local decoupling. The strengths of the quadrupoles will be sufficient to achieve $\Delta\nu<0.003$ with the expected sources of coupling in the ring (systematic $a_1 = 0.1 \times 10^{-4}\ cm^{-1}$ in the dipoles, random $a_1 = 1.25 \times 10^{-4}\ cm^{-1}$ in dipoles, and 0.5 mrad rms quadrupole roll.)

B. Chromatic Correction[10]

The sextupole correctors in the Collider arcs are intended to compensate for both the natural chromaticity of the machine and the high field systematic sextupole of the dipoles. In addition, the system must compensate for chromatic effects introduced by the IR's in collision optics. The IR's can make a significant contribution not only to the first order chromaticity, but also to the second order chromaticity[11]. Because of cancellation between adjacent IR's, the second order effects are small if the IR's are separated by an odd multiple of $\pi/2$ and they are operated at the same value of β^*. However, large second order chromatic effects can arise if the adjacent IR's are operated at different values of β^*, or if the tune departs substantially from the design value. To ameliorate this problem, a local sextupole correction scheme is planned, utilizing four families of sextupoles in the arc sections next to the IR regions. Global chromatic correction is achieved through the bulk of the arc sextupoles; local control is achieved by these four families near the IR's. The strength of the global and local sextupoles is planned to be adequate for correcting natural chromaticity, that from $b_2 = 0.8 \times 10^{-4}\ cm^2$ in the dipoles, and that from the two low-β and two high-β IR's.

C. Dipole/Quadrupole/Decapole/Octupole Correctors

The dipole corrector system is planned to be sufficient to correct, at the 4σ level, quadrupole misalignments of 0.4mm rms, and dipole rolls of 0.5 mrad rms. The quadrupole correction system has two principal functions. It will correct the differential dipole-quadrupole saturation, and will also allow tune adjustments of up to ± 3 units.

In the previous designs for the Collider, octupole, decapole, and skew quadrupole correctors were envisioned for some mid-half-cell locations. As noted above, the current plan for skew quadrupoles utilizes space in the arcs provided in the current lattice design, which eliminates the need for skew quadrupoles in mid-half-cell locations. Recent analysis has indicated that if the dipoles meet the specifications for systematic and random octupole and decapole harmonics, then octupole and decapole correctors in the spool pieces will be sufficient. A separate system in mid-half-cell locations is not needed. All the prototype dipole magnets manufactured to date have met the required specifications. Hence, it has been decided to eliminate all mid-half-cell correctors, which will result in considerable simplification and cost savings.

IV. EMITTANCE CONTROL

One of the principal challenges in achieving the SSC design luminosity is that of preserving the beam brightness throughout the accelerator chain and during storage in the Collider.

A. Emittance Growth in the Accelerator Chain

In the accelerator chain, there are several threats to brightness; one of these occurs in the LEB due to the strong space-charge effects at injection. This has been extensively studied[12] and it is believed that the current design of the LEB can cope with these effects without excessive emittance dilution. Another threat to brightness occurs during each beam transfer, where injection oscillations, and amplitude and dispersion function mismatches, can lead to emittance dilution due to phase space filamentation. The recent redesign of the beam lines noted above, which has emphasized ease of matching from one ring to another and reduced sensitivity to errors, should lesson this threat. Another significant issue in the accelerator chain is that of coupled bunch instabilities, which can lead to emittance growth if not properly controlled. Damping systems[13] are planned for each accelerator to provide multi-bunch stability control and reduce sensitivity to dipole mode injection errors.

B. Long-Term Emittance Growth

In the Collider, during storage, additional issues arise related to sources of long-term emittance growth. These include the effects of power supply ripple and possible ground motion effects.

The low revolution frequency of the Collider causes the lowest betatron sideband to occur at a frequency in the range of 700 - 900 Hz, depending on the exact value of the fractional part of the tune. The amplitude of ground motion or power supply noise in general grows as the frequency is lowered, so the effect of these perturbations on the beam's betatron motion can be expected to be relatively more important in the Collider than in existing machines with larger revolution frequencies. These are difficult issues to study, and particularly to quantify accurately, although some progress has recently been made[14]. Measurements of ground motion and vibration in the tunnel environment are planned, and the damping of such motion will be considered in the design of the Collider components and their support systems. The effect of power supply ripple has been simulated, and it is believed that the baseline power supply filter system[15] will be adequate to limit emittance growth due to power supply ripple to less than 20 percent per 24 hours. Provision for retrofit of an active filter system has been allowed.

C. Field Quality

Field quality is primarily an issue in the higher energy machines. In the MEB, field quality requirements dictate the specifications on the dipoles, particularly at the lowest fields. However, these specifications are not difficult to meet with some care in magnet fabrication. In the superconducting machines, field quality is tied directly to the requirements (principally aperture) on the superconducting dipoles. For both the HEB and the Collider, dipoles with a 5cm diameter coil will have adequate static field quality to meet the requirements. For the HEB, there is a special problem related to the rapid ramp rate (0.062T/sec): the field harmonics due to transient eddy currents arising during the ramp must be small enough that sufficient linear and dynamic aperture is maintained during acceleration. The bipolar ramp cycle of the HEB makes for a particularly challenging environment in which to meet this demand.

V. BEAM LOSS CONTROL

Beam loss control is of particular concern in the superconducting accelerators, in which even small amounts of beam-related energy deposition can cause quenching of the superconducting magnets. As noted above, this issue has been kept in mind during the design of beam injection, extraction, and abort systems for these machines. In addition, control of the beam halo and localized beam loss in the vicinity of the Collider IP's is crucial to maintaining a relatively low background environment for the Collider detectors. An extensive system[16] of collimators and beam scrapers has been proposed for the Collider in order to achieve the necessary low beam loss conditions.

A particularly thorny problem related to beam loss control is that of maintaining an adequately high level of vacuum in the Collider. Degradation of the Collider vacuum is directly related to the presence of synchrotron radiation in the machine[17]. The Collider will be the first proton synchrotron for which the beam energy is high enough to produce significant amounts of synchrotron radiation. The major effect of this radiation, which is absorbed by the cold beam tube walls, is to place a significant dynamic heat load on the Collider's cryogenic system. This is handled in a straightforward way by proper sizing of the 4°K refrigeration system. However, as in electron synchrotrons, the synchrotron radiation will also desorb gas (primary H_2) from the beam tube walls. Unlike in electron synchrotrons, this gas will be cryopumped onto the walls of the beam tube. Since it is very loosely bound, the effective cross-section for photodesorption of this cryosorbed gas is quite high. Thus, there is a constant "recycling" of gas molecules from the surface into the beam tube vacuum, which produces a "dynamic" gas density[18]. If sufficiently dense, this gas can lead to substantial beam loss and even local overload of the cryogenic system due to scattered high energy radiation. At this point, machine operation stops and the beam tube wall must be warmed to ~20°K to allow the H_2 to be pumped out.

Several approaches are available as potential solutions to this problem. The simplest is to ensure that the total hydrogen gas flux evolved from the surface is low enough that the time associated with surface buildup of cryosorbed H_2 gas is long (~ one year).

The gas flux evolved is determined by the effective photodesorption coefficient and the amount of gas initially trapped on the surface or in the bulk of the beam tube material. Recent experiments[19] have indicated that the effective photodesorption coefficient is substantially suppressed (relative to its room temperature value) at cryogenic temperatures, which will limit the total amount of gas evolved. The gas load may also be reduced by proper fabrication and cleaning of the beam tube. An extensive series of investigations into possible options in this area is underway at SSCL and its subcontractors.

If this approach does not succeed in limiting the gas density evolved by photodesorption, another technique is the introduction of a liner[20]. This solution involves the use of an insert in the magnet bore tube, with holes to allow photodesorbed gas to be pumped by cryrosorbent material located between the liner and the beam tube. The cryosorber, shielded from the photons by the liner, would accumulate gas for a long period before warm-up was required. An engineering design of an 80°K[21] liner has recently been completed. Engineering design is planned for a liner operating at 4°K, which has advantages in simplicity and reduced photodesorption coefficient, and disadvantages in pumping speed and cryogenic efficiency, relative to the 80°K solution. The increased bore tube size mentioned above in the first section provides sufficient physical aperture to adopt this solution if it is required.

VI. COLLIDER RF SYSTEMS

The baseline RF system for the Collider is a 20 MV, 360 MHz room temperature 5-cell cavity system. Recently, the possibility of the utilization of superconducting RF for the Collider has come under consideration[22]. Superconducting RF has advantages in the areas of reduced higher-order-modes, a smaller number of cavities, and reduced RF power (and window power) requirements. Disadvantages relative to room temperature systems lie in the areas of increased development and support requirements at SSCL, possibly lower reliability, and possibly larger initial capital costs (vs lower operating costs). A decision of which path to proceed along is expected in the near future.

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