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Status of the SSC

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Abstract

The Superconducting Super Collider (SSC) is a proton-proton colliding beam accelerator which, when completed, will provide collision energies of 40 TeV in the center-of-mass, at a luminosity of $10^{33}/cm^2/sec^{-1}$. This paper will describe the current status of the design and construction of the project.

I. INTRODUCTION

The basic concept for the Superconducting Super Collider goes back over ten years, to the DPF summer study of 1982. Based on technical successes in high field superconducting magnet developments for the Tevatron, a 40 TeV center-of-mass proton-proton collider was proposed as the next major step in the high energy physics (HEP) program. In 1983 HEPAP recommended that the SSC be built as the highest priority in the USA HEP program.

In the following years, detailed conceptual designs established the basic feasibility of the approach, leading to a presidential decision to proceed with the project. A site in Texas near Waxahachie was selected from over 43 proposals in 25 states. In 1989, a contract was signed with Universities Research Association to build and operate the SSC, marking the formal beginning of this ambitious construction project.

Over the past four years, enormous progress has been made in the construction of the SSC, and in the establishment of a new scientific laboratory on a "green field" site. At the present time, the staff working in Texas exceeds 2000 people, and civil construction activities, including the completion of over five miles of tunnel for the collider, are well underway.

In this paper, we present a brief overview of the current status of the accelerator design, development, and construction activities. A recent SSC publication can be consulted for additional details, including the status of the overall SSC program [1].

II. BASIC PARAMETERS AND THE SSC COMPLEX

The requirements established at the outset of the SSC project call for

- 20 TeV on 20 TeV proton-proton collisions
- a luminosity of 10^{33} cm^{-2} sec^{-1} at two or more interaction regions
- four interaction regions provided for experiments (initially), and
- a design reference mission of 4500 hours/year,

The baseline parameters of the colliding beams that meet these objectives are those given in Table 1. The individual bunch intensities and beam-beam tune shifts are conservative by comparison with current practice. The transverse emittance represents a significant advance over currently achieved performance. The very large number of bunches, and the stored energy in the beams, is a major step beyond current experience (in beam stored energy, by about two orders of magnitude). The large size of the ring also leads to low revolution frequencies, and very low frequency (< 1 kHz) resonances with the betatron motion.

Table 1
SSC Colliding Beam Parameters

Protons per r.f. bunch	0.75×10^{10}
Bunch spacing/rep rate	5 meters/60 MHZ
Emittance (RMS)	1π mm-mrad
Beam radius at interaction point (RMS) (β^*=0.5M)	5 micrometers
Average number of events per bunch crossing	1.5
Beam-beam tune shift (total) head-on =.003 long range =.004	.007
Ring circumference	87.12 KM
Rotation frequency	3.44 kHz
Total number of bunches	17,424
Total particle energy/ring	418 megajoules
Cycle time	24 hours
Synchrotron radiation power/ring	8.75 kilowatts

An important influence on this choice of parameters is the desire for a limited number of proton-proton collisions for each beam pulse crossing (average of about 1.5 at the design luminosity). This parameter and the bunch rate of 60 MHz strongly influence the design of the experimental detectors.

At a particle energy of 20 TeV, the synchrotron radiation is becoming an important factor in the collider design. The synchrotron radiation heat load of about 18 kW is about half of the total 4.2-K cryogenic load. In addition,the irradiation of the vacuum wall by the energetic photons (Ecrit = 288 eV) will cause gas desorption, as in high energy electron rings. The 4.2-K beam tube may not provide adequate pumping capacity for hydrogen; an R&D program is underway to evaluate the desorption phenomenology and to investigate approaches for its mitigation.

The choice of a peak bending magnet field of about 6.6 T in the collider dipole magnets lead to a ring circumference of 87 km. A schematic of the collider is shown in Figure 1. On the west side, the injector complex is located on about 10,000 acres of land. Two interaction regions are also located on the west side. The large general purpose detectors will be located

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on the east side of the ring, to take advantage of the more favorable geological conditions in that area.

The main parameters of the various machines in the injectors are given in Table 2. The two collider rings and the bipolar HEB ring use superconducting magnets.

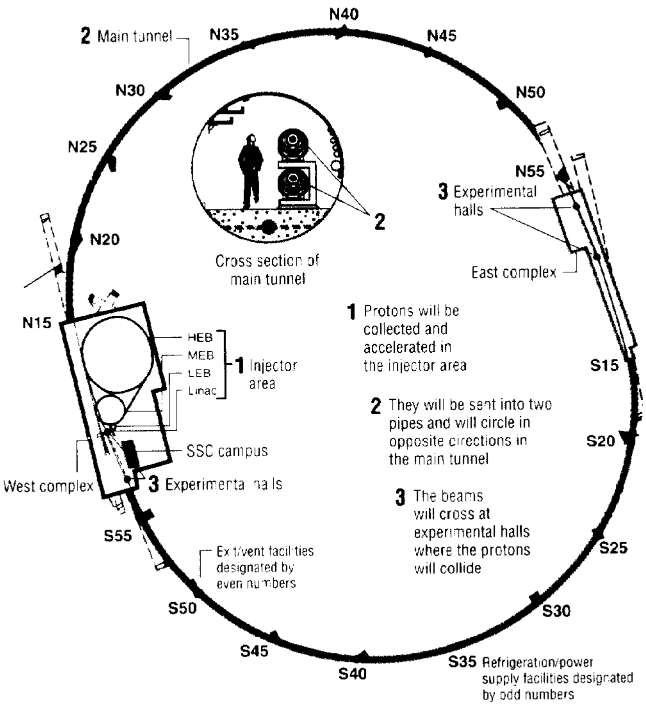

Figure 1. The overall layout of the SSC with the injector and west complex located on the left and the east complex on the right of the diagram.

III. SUPERCONDUCTING MAGNETS AND THE ACCELERATOR SYSTEM STRING TEST

The superconducting magnets represent the most costly single element in the SSC project, and it is also a relatively new technology compared to the other technical systems. A major R&D program was established at FNAL, BNL, and LBL to develop SSC superconducting magnets, following the 1983 decision by HEPAP. When the SSC Laboratory was established in 1989, a major effort was undertaken to acquire the capability on site (in people and facilities) to continue this R&D effort, and to create the industrial capability to do high rate production of the magnets.

In January 1990, the SSC Laboratory decided to increase the aperture of the collider dipole magnets from 40 mm to 50 mm to meet the dynamic aperture requirements during the injection phase. This change required significant changes in the collider dipole development plan. At this time the Laboratory committed to a system demonstration of one collider half-cell (the Accelerator System String Test) using industrially-assembled dipole magnets, to be completed by October 1992. The half-cell consists of five dipole magnets, one quadrupole magnet, a spool piece, and prototypical quench protection and sensor data acquisition systems.

The development of dipole magnets for this demonstration was carried out by FNAL and BNL, in collaboration with the SSC Laboratory. Once the industrial contracts were in place, General Dynamics sent a team to FNAL, and Westinghouse sent a team to BNL, to build the dipole magnets for the test. These magnets all demonstrated excellent performance, and the system test was successfully completed in August 1992, six weeks ahead of schedule.

Table 2.
Injector/Collider Parameters

Parameters	Linac	LEB	MEB	HEB	Collider
Kinetic Energy	0.6 GeV	11.1 GeV	180-200 GeV	2 TeV	20 TeV
Circumference (km)	(110 m long)	0.57	3.96	10.80	87.12
Cycle time	0.1 sec	0.1 sec	8 sec	2x4.3 min	≈24 hours
Proton/ cycle	---	10^{12}	8×10^{12}	2×10^{12}	1.3×10^{14}
Protons/ bunch	---	10^{10}	10^{10}	10^{10}	0.75×10^{10}
Normalized rms emittance (π mm mrad)	<0.4	0.6	0.7	0.8	1

Tests of individual dipole magnets were run at temperatures below 4.2K, to explore the mechanical limits of these magnets. At a temperature of 1.8K, the quench current increased to almost 10 kA, as expected if it followed the theoretical short sample limit. This corresponds to a magnetic field of about 9.5 T, lowered somewhat from the 1 T/kA scaling because of iron saturation at these higher fields.

At this point, over 20 full-length 50-mm prototype collider dipole magnets have been tested. About 25 of the earlier 40 mm versions were also constructed and tested. Magnetic multipoles of the 50 mm dipoles are well within the range required by the collider. With this highly successful prototype development work completed, the superconducting magnet program is now beginning the transition to industrial production capability, aimed at high rate production (10 magnets/day). General Dynamics, the collider dipole magnet "lead" contractor for development, is well advanced in the construction of their production plant in Hammond, Louisiana. A full length prototype magnet should be available for testing in a few months. Westinghouse, the "follower" for the collider dipole and principal contractor for HEB dipoles, is constructing a plant in Round Rock, Texas. Babcock and Wilcox, contractor for the collider quadrupole magnets, is outfitting their facility in Lynchburg, Virginia.

One issue remaining in the superconducting magnet program is the observation of relatively large ramp rate dependencies of the quench current in some recent prototypes. This is not expected to be an issue for the collider, which ramps at about 4 A/sec, but it is a potential problem for the high energy booster magnets which ramps at about 60 A/sec. A program to resolve this issue is underway, as a collaborative effort involving Westinghouse and the SSC Laboratory, with cooperation from BNL and FNAL.

IV. STATUS OF THE INJECTOR AND COLLIDER

The basic parameters of the machines are given in Table 2. A description of these machines and their design features can be found in a recent conference paper [2] and in the SSC Annual Report [1]. In this summary, only a few highlights of recent accomplishments will be given.

To achieve the emittance goal of the SSC, we must start with a very high brightness beam out of the ion source and through the Linac. The design goal for the Linac emittance is several times smaller than that achieved at FNAL, BNL, or LAMPF. An additional challenge is the very high level of reliability required to meet the overall availability goals for the SSC.

An RF-driven negative ion volume source built by LBL for the SSC has operated at normalized transverse emittances less than 0.12π mm mrad (RMS) at 30 ma. A dual Einzel lens is used for the low energy beam transport (LEBT) section, to match into the RFQ. This lens has introduced aberrations that limit the transport through the RFQ to about 18 mA (in agreement with particle simulation). The RFQ section was built by Los Alamos National Laboratory, and it has recently been operated, accelerating the H^- beam to about 2.5 MeV. Very recent measurements of the emittance out of the RFQ indicate an emittance around 0.25π mm mrad at 18 mA, very close to the design goal [3].

The next acceleration stage is the Drift Tube Linac, which will accelerate the beam to 70 MeV. The first DTL tanks should be delivered around January 1994. The DTL consists of four tanks (supplied by Accelerator Systems Technology, Inc.) each powered by a 4 MW klystron (from Thompson CSF). The Coupled Cavity Linac tanks are being manufactured by IHEP, Beijing. Commissioning of the first CCL module is scheduled for October 1994, and the Linac commissioning is currently expected to be completed by April 1995.

The LEB magnets (resistive) are part of a collaboration with BINP in Novosibirsk. Delivery of the first production magnet is scheduled for October 1993. BINP is also collaborating on the correction magnets, the energy storage inductors, and the RF system. Two tuner designs are currently being tested, since this element is one of the higher risk items in the LEB.

The MEB is a large, normal conducting synchrotron similar to those at Fermilab and CERN. A model dipole magnet has been built by FNAL, and is currently beginning the testing phase. An agreement has been reached with Moscow Radio Technical Institute to provide the dipole and quadrupole magnets, following a successful prototype demonstration phase.

The HEB is a superconducting synchroton, using superconducting magnets similar to those used in the collider. The novel feature of the HEB is its bipolar operation, required to inject oppositely-directed proton beams in the two collider rings. Bipolar tests of magnets at FNAL and KEK have not indicated any difficulties. The main issue in the HEB is the ramp rate dependence of the dipole magnet quench current mentioned in the previous section.

Significant advances have been made in a number of areas in the collider design and development activities, besides the superconducting magnets. The Utility Regions include components such as injection magnets, beam abort systems, and RF systems. These components are currently undergoing detailed design. The Interaction Region optics has received extensive review, and detailed design of the numerous specialty magnets required for this region is underway.

As mentioned in Section 2, the gas desorption from synchrotron radiation in the collider arcs is an outstanding issue. An extensive R&D program is underway to evaluate the impact of this phenomenon on collider operation, and to study various approaches for mitigating its effects [4]. Studies of gas desorption in cold tubes have been carried out at BINP. The most recent data indicates strong reductions in the desorption rate at lower temperatures, in disagreement with SSC-CDG experiments in the late 1980's. Mitigation effects include optimizing the copper plating process, coating the tube with thin layers of gold, and using cryosorbent materials to increase the local pumping capacity.

V. CIVIL CONSTRUCTION

The first major civil construction on the permanent "campus" site is at the N-15 area, on the northern edge of the west campus. The Magnet Development Laboratory (MDL), an 82,000 square foot building, is currently being used to fabricate prototype superconducting magnets. It will be used in the future to make the small quantities of specialty magnets used in the cluster regions of the collider. Adjacent to MDL are buildings which house the cryogenic facilities for the N-15 section of the collider, and the Accelerator System String Test. Another nearby building, the Magnet Test Laboratory (MTL), is complete and equipment is currently being installed. It will have ten test stands for cold testing of full length magnets, and it also contains a three magnet test string. Cable winding equipment and numerous short magnet test areas and are also provided in the MTL.

The first vertical shaft down to the collider tunnel was excavated at N-15 (about 250 ft.). This oval shaped shaft, 30 ft. by 60 ft., provided access for the first tunnel boring machine. In the future, this shaft will be used for the delivery of magnets and other components to the tunnel. Four other shafts of this size will be spaced around the collider ring.

Several other shafts in the northern half of the ring have been completed, and four tunnel boring machines are in operation. At the present time, over five miles of tunnel has been excavated, about 10% of the collider ring. The construction crews have broken a number of world records for the tunneling "rate of advance" for four to five meter class hard rock tunnel boring machines (best day, best week, and best month). The aggregate tunneling progress has been close to one mile per week from all four machines.

The construction of the tunnels and buildings for the first machines in the booster chain is also well underway. Beneficial occupancy of the Linac tunnel is imminent, and installation of equipment will begin this summer. The LEB tunnel excavation is complete, and the LEB-MEB transfer line tunnel has been constructed. Beneficial occupancy of the LEB tunnel is scheduled for January 1994. Bids have been received on the MEB tunnel, and an award is expected soon.

VI. CONCLUSIONS

The SSC construction is underway. There has been excellent progress in the superconducting magnet program, now undergoing a transition to industrial production, and in the civil construction (tunneling at the rate of about one mile per week). Since these activities are the critical path for completion of the project, the technical progress still supports a date of October 1999 for first beam to experiments. The required funding levels in the past two years, and the current guidelines from the Administration for the next four years, do not support this schedule. The project is currently in the process of replanning its activities, in accord with current budget guidance. It is expected that the schedule will slip by 2–3 years relative to the original baseline.

VII. ACKNOWLEDGMENTS

This paper is a report on the work of several national laboratories, including SSC, and a large number of industrial contractors. The author hopes that their collective accomplishments are accurately portrayed in this brief report.

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