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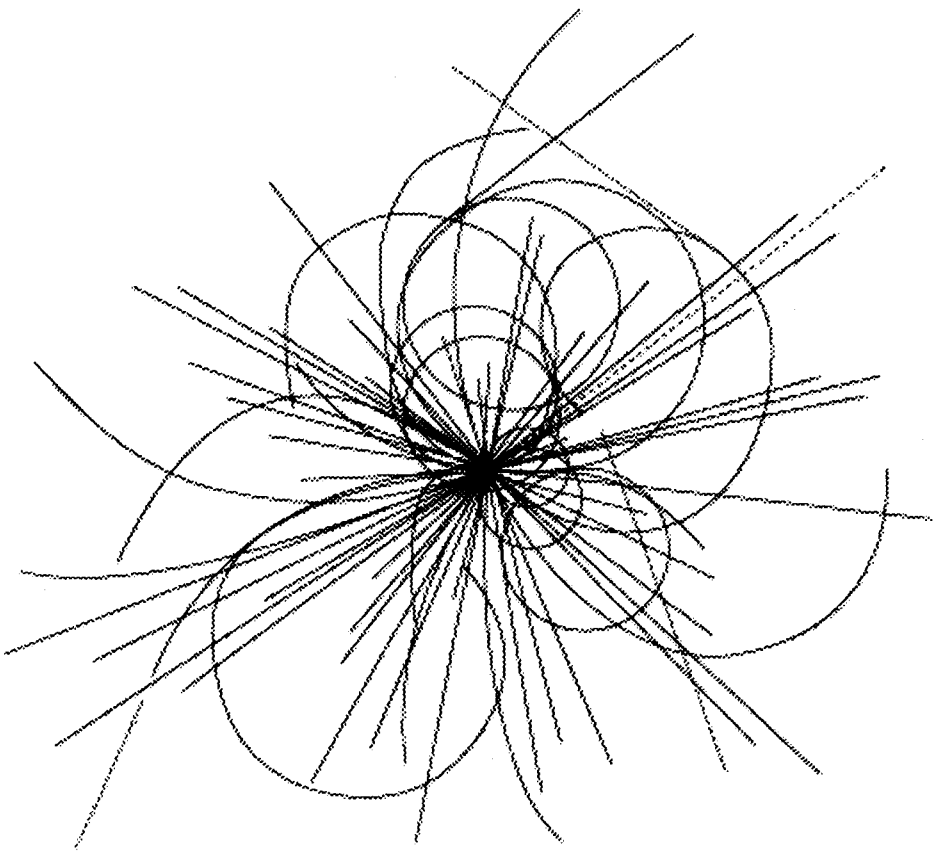
Status of the SSC



Superconducting Super Collider Laboratory

SSCL-Preprint-343

Status of the SSC*

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May 1993

* Presented at the International Committee on Future Accelerators in Hamburg, Germany.

† Operated by the Universities Research Association, Inc., for the U.S. Department of Energy under Contract No. DE-AC35-89ER40486.

STATUS OF THE SSC

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ABSTRACT

The Superconducting Super Collider (SSC) is a high-luminosity proton-proton colliding-beam accelerator, providing access to particle collision energies at least an order of magnitude greater than are available at existing facilities. The SSC will have a maximum energy of 40 TeV in the center-of-mass and a luminosity of $10^{33}\text{cm}^{-2}\text{s}^{-1}$ when completed. This paper will describe the current status of the design and construction of the SSC.

Introduction

The SSC Collider consists of two rings of superconducting magnets, separated vertically, with a circumference of some 87 km. The rings are brought into coincidence in four locations where collisions can occur. Protons are injected into the two rings in counter-rotating directions at 2 TeV/c and are accelerated to 20 TeV/c, where they are stored, subjected to a beta-squeeze, and brought into collision. The injection complex consists of a source and linear accelerator chain, followed by three booster synchrotrons in cascade, similar to previous accelerator complexes. The final booster is a synchrotron with superconducting magnets; the others have conventional copper and iron magnets in order to permit rapid cycling. The principal design parameters of the SSC are shown in Table 1.

Parameter	Value	Units
Initial Luminosity	10^{33}	$\text{cm}^{-2}\text{s}^{-1}$
Center-of-Mass Energy	40	TeV
Bunch Spacing	5	m
Circumference	87.12	km
Particles/Bunch	0.75	10^{10}
Total Number of Particles	1.3	10^{14}
Rotation Frequency	3.441	kHz
Collision Frequency	60	MHz
Cycle Time	24	h
RMS Transverse Emittance (Normalized)	1π	mm-mrad
Beta at Interaction Point (IP)	0.5	m
RMS Transverse Beam Size at IP	5	μm
Synchrotron Radiation Power/Ring	8.75	kW
Beam Stored Energy/Ring	400	MJ

Table 1 – SSC Parameters

* Operated by Universities Research Association, Inc., for the U.S. Department of Energy under Contract No. DE-AC35-89ER40486.

Accelerator Systems and Components

The injector complex includes a 600 MeV Linac, a 12 GeV/c rapid-cycling Low Energy Booster, a 200 GeV/c Medium Energy Booster, and a 2 TeV/c bipolar, superconducting High Energy Booster.

Linac

The linac consists of an H^- ion source, a 2.5 MeV RFQ, a 70 MeV Drift Tube Linac, and a 600 MeV Coupled Cavity Linac. These are schematically shown in Figure 1.

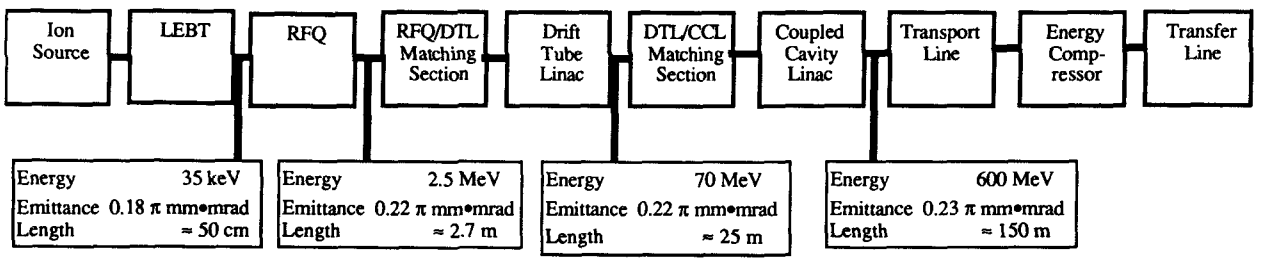

Figure 1 – Linac Conceptual Layout

An rf-driven volume source was built by Lawrence Berkeley Laboratory for the SSC and was successfully commissioned. The normalized transverse emittance was measured to be $\leq 0.12\pi$ mm-mrad at 30 mA. A dual Einzel lens was fabricated by Texas Accelerator Center for the Low Energy Beam Transport section. This lens was successfully commissioned. It currently suffers from some aberrations, but is fully adequate for commissioning of the subsequent components. Work on a second lens is underway. The Radio Frequency Quadrupole section was built by Los Alamos National Laboratory, and was recently commissioned, producing 2.5 MeV beam. An input current of 30 mA yielded an output current of 18 mA. Emittance measurements are currently being performed.

The Drift Tube Linac consists of 4 tanks, each powered by a 4 MW klystron. It will be equipped with permanent field quadrupoles. The quadrupoles are being produced by Aster Enterprises, and their field quality exceeds needed specifications. The first of the klystrons was delivered to the SSC, with the others to follow soon. The first modulator module is expected in August, and the first DTL tank will be delivered in mid-January, 1994.

The Coupled Cavity Linac consists of 9 modules, with 8 tanks and 7 bridge couplers. These are being manufactured at IHEP, Beijing. The CCL will be powered by 10, 20 MW klystrons, currently under production at Thompson CSF. Delivery of the first modulator is scheduled for late 1993, with the commissioning scheduled for October, 1994.

Low Energy Booster (LEB)

The LEB will be a rapid-cycling (10 Hz) synchrotron with superperiodicity 3 and a circumference of 570 m. It will be filled from the linac using multi-turn H^- injection. A layout of the LEB is shown in Figure 2. The LEB will be capable of operating both in a resonant 10 Hz mode and in a ramped 1/3 Hz mode, for studies.

The rf system for the LEB will tune over a wide range and will use perpendicularly-biased ferrites. Two tuner designs are under consideration. One design, built by BINP, Novosibirsk, utilizes conduction cooling for the ferrite. A prototype tuner was delivered to the SSC in January, 1993, and was power tested. Damage occurred during high-power operation. Another tuner design, using liquid-cooled ferrite, will be tested in early May.

The LEB lattice is composed of resistive, separated-function magnets. 48 dipoles and 90 quadrupoles are required. These magnets are planned as a collaboration with BINP. Prototypes of the magnets have been built at SLAC, LBL, and BINP, and have been tested at LBL, BINP, and the SSC. The final drawings were recently delivered to BINP and delivery of the first production magnet is scheduled for October, 1993.

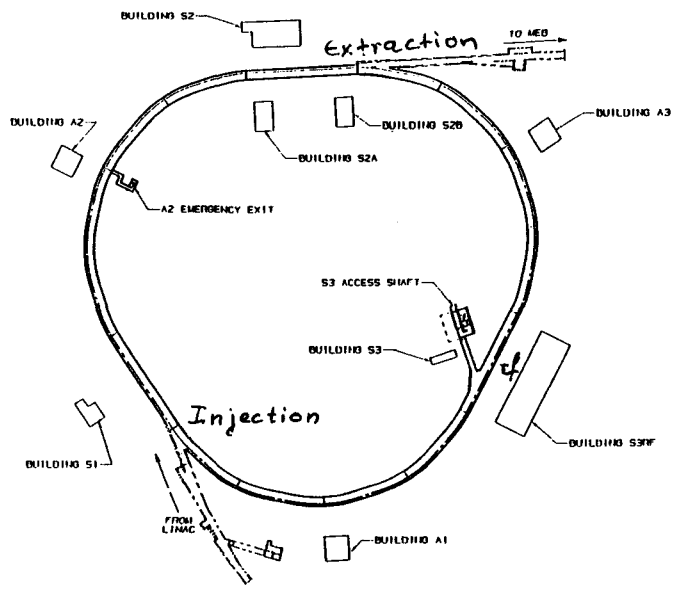

Figure 2 – Low Energy Booster Layout

Correction magnets for the LEB will also be furnished by BINP. Prototype corrector magnets were built both by BINP and the SSC. Delivery of the first production corrector magnet is scheduled for January, 1994

Medium Energy Booster (MEB)

The MEB will be a large synchrotron similar to those at Fermilab and CERN. It will be made of resistive magnets and will accelerate beam from 12-GeV/c to 200-GeV/c for injection into the High Energy Booster. The cycle time for the MEB will be approximately 8 seconds. In addition to producing beams for the HEB, the MEB will resonantly-extract 200-GeV/c test beams to experimental areas for detector development and calibration. A layout of the MEB is shown in Figure 3.

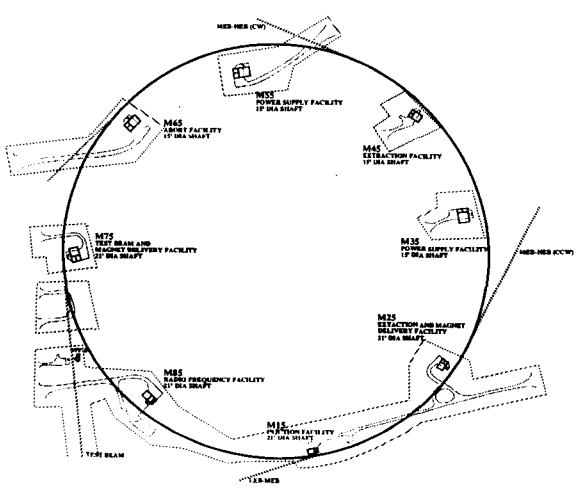
Figure 3 – Medium Energy Booster Layout

Model dipole magnets were built at Fermilab and are currently awaiting testing. An agreement was recently signed with Moscow Radio Technical Institute to build prototype dipole magnets. Successful completion of the prototype program will be followed with full dipole production by MRTI. A similar agreement has been reached with MRTI to develop a prototype quadrupole magnet.

An option exists to extend the agreement to cover full quadrupole production.

Other agreements have been signed with IHEP, Beijing to build the required correction dipole magnets and the chromaticity sextupoles. A prototype rf cavity will be built by BINP.

High Energy Booster (HEB)

The HEB is the last accelerator in the injector chain. A 200-GeV/c beam from the MEB will be injected and accelerated to 2 TeV/c for injection into the Collider. The HEB will use superconducting magnets very similar to those used in the collider. The circumference of the HEB is 10.8 km and it will be located in a tunnel approximately 46 meters below surface grade. The HEB is designed with 6 straight sections, two long sections for the two transfers into the Collider, and four shorter sections to be used for the two injection areas from the MEB and for the two required beam aborts. A future option, not currently in the SSC project, would allow 2 TeV beam to be extracted from one of the long-straight sections for future experimental programs. A layout of the HEB is shown in Figure 4.

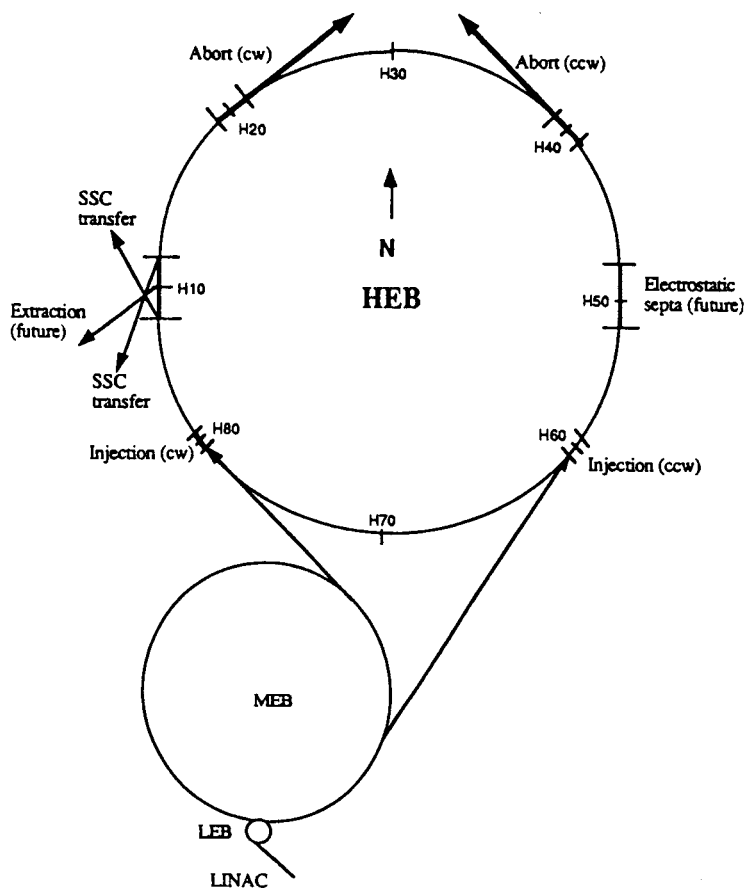

Figure 4 – High Energy Booster Layout

The most novel feature of the HEB is that it will operate in a bipolar manner in order to fill both Collider rings while requiring a minimum amount of transfer line and tunnel. Bipolar magnet tests were conducted at Fermilab and at KEK, and showed no unexpected behavior. Measurements of the magnet multipole moments showed no anomalies around zero, and the heating of the magnet due to a large hysteresis was within an acceptable range. The normal operational mode for the HEB is to regularly alternate positive and negative cycles, putting one HEB batch into the top collider ring followed with one into the bottom ring, and so on. In this manner, while there will effectively be two different operational HEB machines, each one (positive and negative) will always experience the same ramp and the same persistent-current fields.

The HEB superconducting magnet systems will include 512 13.2-m dipoles (peak field 6.7 T) and 318 2.5-m quadrupoles (peak gradient 184 T/m). Both dipoles and quadrupoles will have 50-mm apertures. This is required in order to provide sufficient dynamic aperture at injection. A design, development, and prototyping contract for the HEB dipoles was

initiated with Westinghouse Electric Corporation in January, 1992. This contract includes three model magnets, one of which was delivered to the SSC for testing in March, 1993. The contract also covers the production of 6 prototype, 20 pre-production, and 50 Low-rate production dipoles. The vendor for the remaining production dipoles will be selected in mid-1996. Design of the HEB quadrupole cold mass is underway at CEN/Saclay. This cold mass design will be combined with a cryostat design to be implemented by SSCL, leading to a build-to-print contract for the HEB quadrupoles to be awarded in 1994. Delivery of production quadrupoles is scheduled to start in mid-1996.

One of the major recent issues in the design of the HEB superconducting magnets is related to the relatively large ramp-rate dependence of the quench current seen in recent Collider model dipole magnets. A program to study and solve the ramp-rate dependence of the magnets is currently underway at Westinghouse, with cooperation from Brookhaven and Fermilab.[1,2]

Collider (SSC)

The Collider will be a pair of superconducting synchrotrons which will also function as storage rings at their top energy. The two rings will share a common circumference of about 87 km and will be located one 90 cm above the other. Injection from the HEB will occur at 2 TeV. The Collider design consists of two very long arcs made of regular 90° FODO cells, having a dispersion suppressing section at each end. The arcs are connected by two nearly straight clustered straight sections, which house two Interaction Regions (IRs) and one utility section per cluster. The utility regions will be used for injection from the HEB, beam aborts, rf, scrapers and collimators, and much of the diagnostics. The two IRs on the east side of the site will be configured for two high-luminosity 4π detectors, SDC and GEM. Experiments have not yet been approved for the IRs in the west cluster. The layout of the Collider is shown in Figure 5.

Collider arcs

The Collider arcs are made of 196, 180-meter FODO cells, each of which contains 10, 15-meter dipoles, 2, 6- meter quadrupoles, and 2 spool pieces, slightly less than 5 meters in length. The cooling for the Collider systems are provided by 10 LHe plants, each providing about 6.5 kW of cooling at 4 K and 14.4 kW of cooling at 20 K. The associated power systems for the magnets, as well as the cryogenic plants and auxiliary services will be located at 10 service areas distributed around the ring.

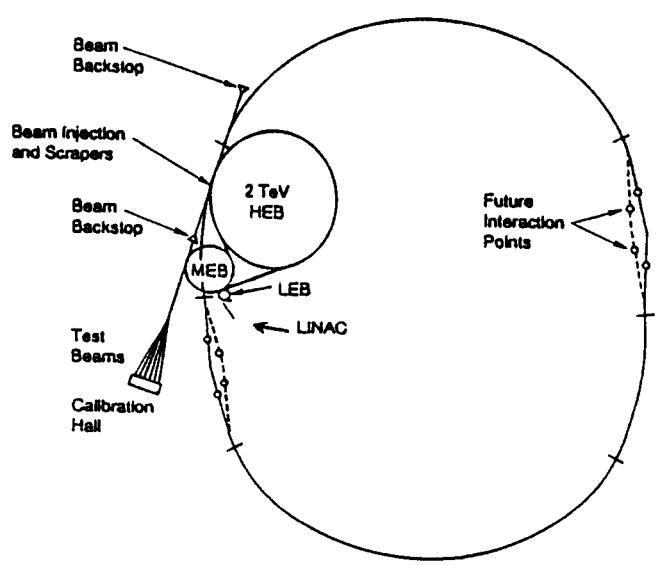

Figure 5 – Collider Layout

Quench protection and magnet energy dumping systems, required to protect the superconducting magnets, will

be located in niches below ground at the tunnel depth. The spool pieces will contain the corrector magnets, the cryogenic and power feed and turnaround connections, cryogenic recoolers, and the beam position monitors. Corrector magnets in all spool locations will consist of steering dipoles, tune-correcting trim quadrupoles, and sextupoles. The quadrupoles will also compensate for differential saturation in the main magnets. The sextupoles will correct persistent-current and saturation sextupole multipoles from the main dipoles as well as the natural lattice chromaticity. At selected positions, the spools will also contain octupole and decapole correctors. Skew quadrupoles will be places in groups in both the arcs and in the cluster regions in order to correct coupling due to magnet misalignment and skew multipole moments.

The Collider magnet program has been in progress for many years and is now well underway. A design, development, and prototype and low-rate dipole production contract was awarded to General Dynamics, with a follower contract going to Westinghouse. These two industries worked closely with Fermilab and Brookhaven National Lab to produce the full-length dipoles which were used in the Accelerator Systems String Test (ASST) which ran successfully in summer, 1992. Since that time, many more full-length dipole magnets have been fabricated and tested. Currently, 20 dipoles have been both built and tested. The magnets have been quite successful.[3] Magnet multipole measurements on these dipoles are well within the range required by the Collider.[4] Issues remaining in the dipole program include a decision on beam-tube vacuum requirements, transition of the production facilities to General Dynamics' newly-built facility in Hammond, Louisiana, and further study into the ramp rate quench and multipole dependence previously mentioned. The current dipole contract will terminate in 1994, and a fixed-price contract for the remaining production dipoles will be let.

The quadrupole program is also well advanced. A contract for design, development, and production of prototype and low-rate quadrupole magnets has been signed with Babcock & Wilcox, who have, in turn, subcontracted work with Siemens. B&W currently has an operational test facility and has recently completed the construction of a fabrication plant. They have installed a development and model magnet facility, and Siemens has established a prototype facility. To date, 9 full-length, 40-mm-aperture quadrupoles have been built and tested. Prototype quadrupoles had previously been built and tested at LBL, and retested by the SSC at BNL. In addition, 2, 50-mm-aperture quadrupole models were built and tested. The SSC is currently examining the adequacy of the 40-mm-aperture. An investigation into the ramifications of increasing the quadrupole aperture is ongoing.

The other major components of the Collider are in various stages of procurement. A prototype spool piece development contract is in place with Martin Marietta and Westinghouse. Prototype spool piece delivery is scheduled for September and November, 1993, with the bid award for final production scheduled for May, 1995. Contracts are in place for acquisition of the required 10 cryogenic plants for the Collider and 2 for the HEB. One plant has been delivered and is currently being installed and made operational. Contracts are also in place for the major power supply components.

Collider Interaction and Utility Regions

The Interaction and Utility regions of the Collider are significantly different from the Collider arcs to be treated in a separate manner. The magnets required for these regions are

more specialized, often requiring a larger aperture, having a different length and occurring in a smaller number than those in the arcs, and sometimes being quite unique. The IR, for example, has a region which requires the quadrupoles for both the Top and Bottom rings to share a common cryostat. In addition, the multipole requirements on the final low-beta triplets, while no more stringent than those for the arc quadrupoles, are considerably helped by being produced relatively late in the game. These small-quantity, specialty magnets are the subject of ongoing research and development at the SSC Laboratory and are currently planned to be fabricated in house. Future developments may lead them to be subcontracted to outside vendors.

The components required for the Utility Regions are currently under design. These components include the injection line magnets, lambertsons, and kickers; the beam abort systems; and the rf systems. These components will come from a combination of in-house work, foreign collaboration, and industrial participation. Currently, an investigation into the Collider rf systems in ongoing. The baseline design calls for 5-cell, 360-MHz cavities powered by very large klystrons. Alternatives under investigation include normal, single cell cavities as well as superconducting cavities. This investigation should be concluded early this summer.

Accelerator Systems String Test (ASST)

The Accelerator Systems String Test was designed to be a full system test of a prototype Collider half cell, consisting of a cryogenic and power feed spool, five industry-built dipole magnets, a quadrupole magnet, an end spool and turnaround, and the needed power and quench protection circuits. The purpose of this test was to demonstrate that industry could mobilize and build the necessary components within a reasonable time scale. This test was successfully completed in August, 1992.[5] The test used a 600-W cryogenic refrigerator and a full set of prototype Collider sensors and instrumentation. A quench protection system capable of examining the quench behavior of individual magnets as well as the normal magnet strings was utilized. The dipoles used were fabricated by General Dynamics and Westinghouse, and the quadrupole was an LBL coldmass which was cryostated by the SSC.

Since the completion of the string test, the area has been heavily utilized as an actual accelerator test bed. Numerous tests of various systems and components have been carried out in the facility. Work with this facility is expected to continue into mid-1995. At that time, the current plans are to modify the facility to perform a string test for the HEB, looking in particular at the cooling properties of the fast, bipolar ramp required by the HEB. This facility will continue to be a very valuable tool for several years in the future.

Civil Construction

Major civil construction is currently underway at the SSC. On part of the west campus complex, known as N15, construction activities have been in progress for nearly three years. Two major laboratory buildings, the Magnet Development Laboratory and the Magnet Test Laboratory have been constructed. The MDL, an approximately 82 000 ft^2 building, is used for magnet R&D and will be used in the future to make the small quantity specialty magnets required in the Collider cluster regions. Construction of the MTL, a similar sized building, is complete and will become operational this fall. It will house 10 single-magnet

test stands as well as a three magnet test string. It will also house short magnet and cable testing areas. Also in the N15 area, the facility for the ASST, string enclosure, control areas, and cryogenics facilities are complete. The interim cryogenic facility for the string test was recently moved to the Central Laboratory Facility in Waxahachie and replaced with the first production cryogenic plant.

Next to the buildings at N15, an exploratory excavation shaft was sunk to a depth of ≈ 250m. Two other shafts are now in the area, and a tunnel-boring machine has begun excavation of the main Collider tunnel. Currently, TBMs are in operation at four locations around the circumference of the Collider, and a total of 21 000 ft of tunnel and shafts have been excavated. A diagram of the Collider tunnel and present progress is shown in Figure 6.

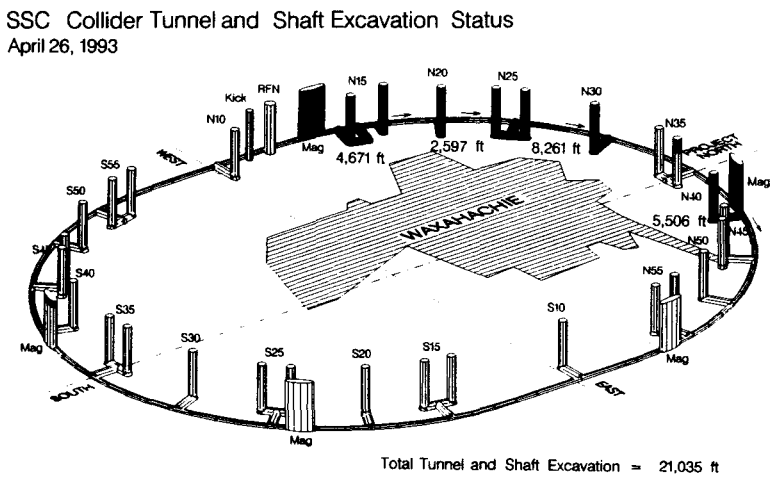

Figure 6 – Construction Progress on the Collider

Construction is also in progress on the accelerators in the booster chain. The linac enclosure has been excavated and construction of the linac gallery and building are nearly complete. Beneficial occupancy of the linac tunnel is scheduled for mid-May, 1993, and occupancy of the surface building is scheduled for June, 1993. The LEB tunnel construction is well advanced. Currently the entire tunnel area has been excavated and basepad for the LEB and for the LEB - to - MEB transfer line has been poured. Beneficial occupancy for the LEB tunnel and surface buildings are scheduled for January and April, 1994. Aside from the transfer-line tunnel, construction has not yet started on the MEB. Bids have been received for the construction project and are currently awaiting the Secretary of Energy's approval. The bids came in considerably under the laboratory's estimate.

Conclusions

The current design considerations for the SSC accelerator complex along with the present procurement and construction status have been presented. Progress on the SSC is substantial and in concord with the laboratory's schedule.

Acknowledgments

The accomplishments described in this paper are the result of the collaborative efforts of the staff of the SSC Laboratory, several other national laboratories (Fermilab, BNL, and LBL), SSCL subcontractor industrial firms (principally General Dynamics, Westinghouse, and Babcock & Wilcox), the AE/CM firm of Parsons, Brinckerhoff/Morrison Knudsen, and several civil construction firms.

The author would like to acknowledge that this report is an update to a previous paper by G. Dugan.[6]

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