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OVERVIEW OF SSC ACCELERATOR REQUIREMENTS

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INTRODUCTION

This paper will present a general overview of the requirements of the Superconducting Super Collider (SSC) accelerators. Each accelerator in the injector chain will be discussed separately, followed by a discussion of the collider itself. In conclusion, the top level requirements of the overall accelerator system will be presented.

For each accelerator, the primary operating parameters will be presented in tabular form. A brief narrative discussion of the principal technical features of each machine will be given. Finally, the principal technical design challenges for the machine will be noted, together with the currently planned solution to these challenges.

LINAC

The parameters of the Linac are presented in Table 1.

Table 1. Linac Parameters.

Machine Parameter	Requirement	Units
Input Energy	35	keV
Input rms normalized transverse emittance	0.2	π mm-mrad
Output Energy	600	MeV
Output rms normalized longitudinal emittance	0.9×10^{-6}	eV-sec
Output rms normalized transverse emittance	0.3	π mm-mrad
Cycle rate	10	Hz
RF frequency	428,1284(SCL)	MHz
Peak current	25	mA
Pulse length (max)	35	μsec
Length	146	m
Availability	98.4	%

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Beam (in the form of H^- ions) will be delivered to the first element of the Linac from a 35-keV magnetron ion source. This first Linac element is a 2.5-MeV, 428-MHz RFQ. Beam is accelerated in the RFQ and injected into a 428-MHz drift-tube structure (DTL) which accelerates the beam to 70 MeV. Both the RFQ and the DTL are powered by 4 MW klystrons. The DTL contains 14 quadrupoles for transverse focusing.

Beam from the DTL is matched into a side-coupled linac (SCL) operating at 1284 MHz. The side-coupled linac accelerates the beam to 600 MeV. It is powered by 10 20-MW klystrons, and it contains 61 quadrupoles for transverse focusing. Subsequent to exit from the SCL, the beam is transported to and injected into the Low Energy Booster (LEB).

The principal technical challenge for the Linac are the preservation of the tight transverse emittance specification noted in Table 1. This requires care in the design of the matching sections between the ion source and the RFQ, the RFQ and the DTL, and the DTL and the SCL. The details of the SCL lattice design are also important.

LOW ENERGY BOOSTER

The parameters of the LEB are presented in Table 2.

Table 2. Low Energy Booster Parameters.

Machine Parameter	Requirement	Units
Input Energy	600	MeV
Input rms normalized transverse emittance	0.3	π mm-mrad
Output Energy	11.1	GeV
Output rms normalized longitudinal emittance	$2\pi \times 10^{-3}$	eV-sec
Output rms normalized transverse emittance	0.6	π mm-mrad
Cycle rate	10	Hz
RF frequency	47.5–59.8	MHz
Rotation frequency	417–524	KHz
Protons/bunch	10^{10}	
Bunch spacing	5	m
Circumference	570	m
Betatron tunes(H/V)	11.65/11.60	
Transition gamma	22.14	
Availability	99	%

H^- ions from the Linac will be charge-exchange injected into the LEB at 600 MeV. The LEB is a rapid-cycling synchrotron with superperiodicity 3. The lattice of the machine is configured to place the transition gamma above the operating range of the machine, thus avoiding the need to cross transition. The rf system is required to tune over a substantial frequency range (see Table 2); this is planned to be achieved through the use of rf cavities

tuned via perpendicularly biased ferrites. The synchrotron's main magnetic fields are provided by conventional resistive magnets: 48 4-m dipoles and 90 0.6–0.7-m quadrupoles.

The principal technical design challenge in the LEB is the preservation of the beam transverse emittance during the low energy end of the machine's accelerating cycle. This will be difficult because of the substantial space-charge tune spread. If the baseline design fails to meet the emittance growth budget, the principal option for dealing with this is the provision for increasing the injection energy: the civil construction of the Linac tunnel will be performed in such a way as to accommodate easily a future upgrade to a 1-GeV Linac. Another option under consideration is the use of a higher harmonic rf system to reduce the peak bunch current.

Other technical challenges include preservation of the emittance during acceleration (made easier by the lattice design, which avoids transition); compensation for eddy current sextupole fields during ramping; and the control of transverse and longitudinal multibunch instabilities.

MEDIUM ENERGY BOOSTER

The parameters of the Medium Energy Booster (MEB) are presented in Table 3.

Table 3. Medium Energy Booster Parameters.

Machine Parameter	Requirement	Units
Input Energy	11.1	GeV
Input rms normalized transverse emittance	0.6	π mm-mrad
Output Energy	199.1	GeV
Output rms normalized longitudinal emittance	$2\text{–}4\pi \times 10^{-3}$	eV-sec
Output rms normalized transverse emittance	0.7	π mm-mrad
Cycle period	8	sec
Rotation frequency	75.7	kHz
RF frequency	60	MHz
Protons/bunch	10^{10}	
Bunch spacing	5	m
Circumference	3960	m
Betatron tunes (H/V)	25.4/25.4	
Transition gamma	23.27	
Availability	93.5	%

The MEB is a large, slow-cycling synchrotron which accepts 11.1-GeV beam from the LEB and accelerates it to 200 GeV/c. Transition crossing in this machine occurs at an energy near 25 GeV. The machine contains a conventional rf system providing a peak voltage of 2.1-MV. The accelerator's main magnetic fields are provided by 340 6.5-m dipoles and 206 2.4-m quadrupoles; all these magnets are resistive. Substantial power systems for the magnets are required: the dipoles, for example, require 16 5200-A, 16-kV power supplies.

The MEB delivers fast-extracted 200 GeV/c-beam to the High Energy Booster (HEB). In addition, it will deliver slow-extracted 200 GeV/c-beam to experimental areas for use in producing test beams for SSC detector calibration.

As in the case of the LEB, one of the technical challenges in the MEB is transverse emittance preservation during the lowest energy part of the operating cycle. However, the issue in this case is not so much space charge as the quality of the machine's magnetic field. This implies care in the design of the magnets to limit the influence of remnant fields at minimum magnet excitation. An additional technical challenge involves transition crossing, which must be performed with a minimum of transverse emittance growth.

HIGH ENERGY BOOSTER

The parameters of the HEB are presented in Table 4.

Table 4. High Energy Booster Parameters.

Machine Parameter	Requirement	Units
Input Energy	199.1	GeV
Input rms normalized transverse emittance	0.7	π mm-mrad
Output Energy	2000	GeV
Output rms normalized longitudinal emittance	0.004–0.035π	eV-sec
Output rms normalized transverse emittance	0.8	π mm-mrad
Cycle period	515	sec
Rotation frequency	27.76	kHz
RF frequency	60	MHz
Protons/bunch	10^{10}	
Bunch spacing	5	m
Circumference	10890	m
Betatron tunes (H/V)	39.42/38.415	
Transition Gamma	34.47	
Availability	89.1	%

The HEB is the last accelerator in the injector chain. It receives 200-GeV/c beam from the MEB and accelerates it to 2 TeV for injection into the Collider. Because of its high operating energy, it is most economically realized as a superconducting accelerator.

This machine will be a slow-cycling synchrotron. In order to optimize the beam transfer into the Collider, the machine will operate in a bipolar mode. It will have both clockwise and counterclockwise injection, extraction and abort systems. The principal superconducting magnet systems will include 512 13-m dipoles and 2318 1.6-m quadrupoles. Both dipoles and quadrupoles will have 50-mm coil diameters. This is required both to provide sufficient linear aperture at injection and to maintain the option (not implemented in the baseline design) for slow-extracted 2-TeV beam to the test beam areas. The superconducting systems will be

cooled to cryogenic operating temperatures using 2 LHe plants, each providing about 6kW of cooling at 4° and 7kW of cooling at 20°.

As in the other machines in the injector chain, one of the principal technical challenges in the HEB is the preservation of the beam's transverse emittance during the operating cycle. As noted above, this challenge is addressed by providing a sufficient coil diameter (50 mm) for the superconducting magnets. In addition, the bipolar nature of the machine's operation cycle is unprecedented for a machine of this type.

COLLIDER

The parameters of the Collider are presented in Table 5.

Table 5. Collider Parameters.

Machine Parameter	Requirement	Units
Input Energy	2000	GeV
Input rms normalized transverse emittance	0.8	π mm-mrad
Output Energy	20000	GeV
Output rms normalized longitudinal emittance	0.233π	eV-sec
Output rms normalized transverse emittance	1	π mm-mrad
Cycle time	24	hr
Rotation frequency	3.441	kHz
RF frequency	360	MHz
Protons/bunch	0.75×10^{10}	
Bunch spacing	5	m
Circumference	87120	m
Betatron tunes (H/V)	123.4285/123.265	
Transition Gamma	105	
Availability	81.7	%

The Collider is a pair of superconducting synchrotrons which also function as storage rings at their top energy. The two rings share a common circumference and are located one above the other, with a vertical separation of 90 cm.

The basic geometry of the rings is that of two arcs joining two long, straight sections. The long axis of the resulting figure points roughly north-south. Counterrotating beams of protons in the two rings are brought into intersection at four locations around the circumference. These points, called interaction points, are located in the long straight sections, two on the east side and two on the west side. At these points, proton-proton collisions occur with a center-of-mass energy of 40 TeV and are observed by experimental detectors.

The Collider contains a large number of superconducting magnets: there are 7704 15-m dipoles, 136 13-m dipoles, and 1564 5.2-m quadrupoles in the arcs alone. The required cryogens for the collider systems are provided by 10 LHe plants, each supplying about 6.5 kW of cooling at 4° and 14.4 kW of cooling at 20°. The associated power systems for the

magnets consist of both ramping and holding supplies capable of 7 kA. Extensive quench protection and energy dump systems, as well as beam abort systems for each ring, are required to protect the superconducting magnets. Finally, special magnetic optics is required in the vicinity of each interaction point to reduce the beam size to a small value in order to enhance the probability of high-energy collisions when the proton beams intersect.

Among the principal technical challenges of the Collider is the requirement of preservation of the transverse emittance, both at injection energy and during the steps leading to operation with intersecting beams. This requirement drives the aperture of the superconducting dipoles in order to achieve the field quality needed for sufficient linear and dynamic aperture for the beam. It also dictates the required correction systems needed for control of persistent currents, and it plays a role in determining the alignment requirements for the machine.

Additional technical challenges arise in connection with the intersection points. At these points, the proton-proton collisions will generate substantial amounts of high-energy radiation, some of which will be converted to heat in the adjacent quadrupole magnets. Maintaining these magnets in the superconducting state in the presence of this heat load is a difficult problem. The field quality requirements on these quadrupoles is also more stringent than those in the remainder of the machine.

Control of beam losses is an important issue in any superconducting accelerator because of the sensitivity of the magnets to beam-induced quenches. In a collider, the problem is compounded by the sensitivity of the experimental detectors to small amounts of beam loss. In addition, in this machine, because of its high energy and large size, the stored energy in the beam is more than 100 times greater than in any previous machines of this type. The consequences of a catastrophic local loss of the entire beam are dramatic and must be guarded against with great care.

Finally, these proton synchrotrons will be the first for which the proton energy is high enough that the phenomenon of synchrotron radiation becomes an important design issue. Photodesorbtion of hydrogen from the cold bore tube by synchrotron radiation, and the consequences for the bore tube vacuum, are important new considerations in this machine. The proper treatment of these issues represents an additional significant technical challenge.

SUMMARY

The parameters of the overall accelerator system are presented in Table 6.

Table 6. Overall Accelerator Parameters.

Parameter	Design Goal	Units
Initial luminosity	10^{33}	$cm^{-2}sec^{-1}$
Center-of-mass energy	40	TeV
Bunch spacing	5	m
Circumference	87120	m
Particles/bunch	0.75×10^{10}	
Number of bunches	17424	
Total number of particles	1.3×10^{14}	
Rotation frequency	3.441	kHz
Collision frequency	60	MHz
RMS normalized transverse emittance	1	π mm-mrad
Beta at IP	0.5	m
Beam rms transverse size at IP	5	μm
Beam-beam tune shift (total)	0.007	
Sync. Rad Pwr/ring	8.75	kW
Reliability/Availability	80%	Scheduled time
Stored Energy	400	MJoule

In meeting the luminosity goal given in Table 6, the principal technical challenge is that of transverse emittance preservation, both in the injector chain and in the Collider.

For the injectors, this requirement determines the choice of injector chain energies; the design of injector lattices and associated components to provide sufficient linear aperture; the impedance budgeting for each machine, and the implementation of damping systems as required; and the use of diagnostics and control in beam transfer to provide adequate matching.

For the collider, transverse emittance preservation influences the design of collider lattice, power systems, and correction magnet systems to provide sufficient linear aperture; the design and fabrication of magnet systems to provide adequate field quality and reliable performance; impedance budgeting and implementation of damping systems as required; implementation of diagnostics and the control of orbit, tune, and chromatic features during injection, acceleration, and squeeze; and control of the bore tube vacuum.

In addition to the difficult task of emittance preservation, perhaps an equally difficult requirement is the availability specification. This challenge will be met by the design of technical subsystems with redundancy and/or highly reliable components, the practice of design risk reduction whenever possible, and the use of proven technologies.