LBL-18026
c.2

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

RECEIVED
LAWRENCE
BERKELEY LABORATORY

JUL 24 1984

LIBRARY AND
DOCUMENTS SECTION

Accelerator & Fusion Research Division

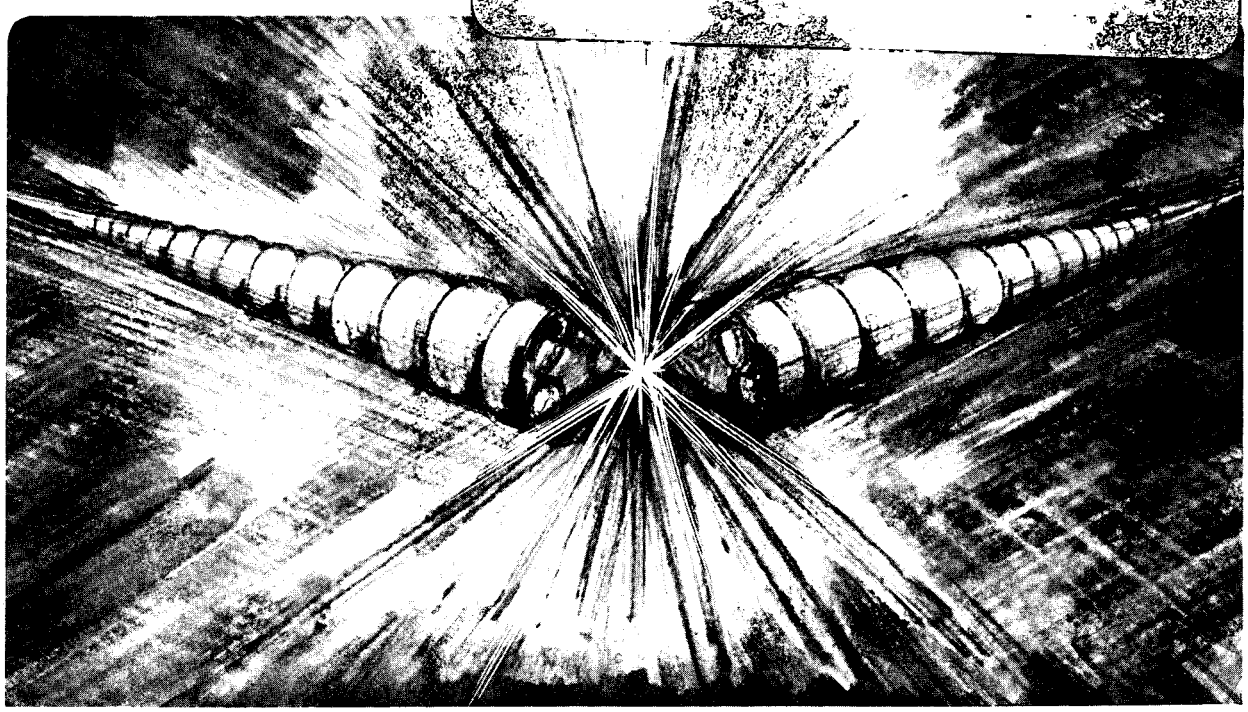
Invited Talk presented at the Superconducting Super Collider Fixed-Target Workshop, The Woodlands, TX, January 26-30, 1984

PRELIMINARY DESIGN IMPLICATIONS OF SSC FIXED-TARGET OPERATION

M.S. Zisman

June 1984

TWO-WEEK LOAN COPY
This is a Library Circulating Copy
which may be borrowed for two weeks.



Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

LBL-18026
c.2

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

Invited Talk - Presented at the
Superconducting Super Collider
Fixed-Target Workshop, The Woodlands, Texas
January 26-30, 1984

LBL-18026
SSC Note-29

PRELIMINARY DESIGN IMPLICATIONS OF SSC FIXED-TARGET OPERATION*

M.S. Zisman

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

June 1984

* This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, High Energy Physics Division, U.S. Dept. of Energy, under Contract No. DE-AC03-76SF00098.

PRELIMINARY DESIGN IMPLICATIONS OF SSC FIXED-TARGET OPERATION*

M. S. Zisman

Lawrence Berkeley Laboratory, University of California, Berkeley, CA 94720

I. Introduction

This paper will cover some of the accelerator physics issues relevant to a possible fixed-target operating mode for the Superconducting Super Collider (SSC). In the brief time available, no attempt has been made to "design" this capability into the SSC. Rather, I have tried to evaluate what the performance of such a machine might be, and to indicate the hardware implications and extraction considerations that would be part of an actual design study. Where appropriate, parameters and properties of the present LBL design for the SSC have been used; these should be taken as being representative of the general class of small-aperture, high-field colliders being considered by the accelerator physics community. Thus, the numerical examples given here must ultimately be re-examined in light of the actual parameters of the particular accelerator being considered.

A few of the main parameters of the LBL SSC design are listed in Table I. (A preliminary parameter list can be obtained by writing the author of this paper.)

II. Extraction Possibilities

There are two basic beam extraction techniques that can be utilized at the SSC: fast extraction and slow extraction. The former technique is used to extract the entire circulating beam from the accelerator in a single revolution. The latter technique, which generally involves resonant extraction, is used for fixed-target physics experiments at existing proton synchrotrons.

Fast Extraction

In the context of the SSC, the use of a fast extraction system for doing fixed-target physics comes almost "for free." This is because there is a critical need for a beam abort system, quite independent of any concerns for the experimental program. Each beam in the SSC carries a stored energy on the order of 500 MJ. If this energy were allowed to dump indiscriminately into the septa of the extraction system magnets or--even worse--into the superconducting magnets themselves, severe damage would result.

To avoid this problem, a safe and reliable beam abort system must be provided. The design for such a system is already well under way at LBL.[1] Following suggestions from the 1979 ICFA Workshop,[2] the fast extraction system will not have an electrostatic septum element, but will have a fast kicker followed by magnetic septa. This approach not only eliminates the weakest link in a normal extraction system (the electrostatic septum, which is subject to sparking at the high fields needed), it permits the extraction to take place over a shorter distance, thus making the system more easily compatible with a moderate length insertion.

From the point of view of a fixed-target program, a fast extraction system gives the best performance in terms of integrated luminosity (because the machine cycle time is minimized). In practice, however, the instantaneous intensity is much too high to be useful for experiments. For the LBL machine, use of the fast extraction technique would involve the dumping of 1.7×10^{14} protons in 300 microseconds, giving an instantaneous rate of 5.7×10^{17} protons per second. From the ICFA Workshop[2] and from discussions at PSSC meetings, it would appear that a usable rate is more like 1×10^{13} particles per second.

It does appear, however, that a modified form of fast extraction technique could be useful for certain kinds of "beam dump" experiments, e.g., those involving neutrinos. The idea, discussed at the PSSC Fixed-Target Working Group meeting of November 18, 1983, would involve having a circulating beam with many (say 20-30) "gaps" to allow the kicker to fire. Each time the kicker fired, one segment of the beam (containing fewer than 10^{13} particles) would be extracted to the beam dump. In this way, the beam would be completely extracted from the machine in 20-30 pulses spaced over a few hundred seconds. Although this technique is clearly not a substitute for a full fixed-target program, it may allow--at rather modest incremental cost--some productive physics experimentation during the required beam dumping operations at the SSC.

Table I

Selected Parameters for the LBL SSC Design

Energy	: 20 TeV x 20 TeV pp collider
Magnetic Field	: B_{max} = 6.5 T
Luminosity	: 1×10^{33} cm^{-2} sec^{-1}
Circumference	: 90.48 km (6 IR's)
Beam Intensity	: 1.7×10^{14} protons (each ring)
Bunch Structure	: 6000 bunches, Δt = 50 nsec
Magnets	: 4032 dipoles: 16-m long; 2-in-1 1076 quadrupoles; 4.25-m long; 2-in-1

*This work supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, High Energy Physics Division, U. S. Dept. of Energy, under Contract No. DE-AC03-76SF0098.

Slow Extraction

A slow extraction system for the SSC has not yet been designed. Indeed, the priority for doing so is considerably lower than that for arriving at a workable and convincing design for the collider itself. In order to assess the ramifications of a fixed-target program, therefore, we will consider two scenarios for slow extraction cycles, as illustrated schematically in Fig. 1.

For both Cycles A and B we will assume a spill time of 200 seconds. This time was chosen, somewhat arbitrarily, as a compromise between the need to achieve a useful duty factor for experiments and the need to maintain reasonable specifications for the slow extraction system itself. As will be obvious later, a 200 second spill time clearly favors the former requirement over the latter.

To determine the machine cycle completely, we must additionally specify times for the injection, acceleration, and reset portions. For injection, we will assume that the 1 TeV High Energy Booster (HEB) is an accelerator having roughly the dimensions and cycle time of the present Fermilab main ring. Because of the limited aperture envisioned for the SSC itself, complicated injection gymnastics will likely be precluded. Thus, the transfer scheme from the HEB to the SSC rings is expected to involve simple "bunch-to-bucket" transfer. Given the ratio of ring circumferences, this will require 15 injector cycles to fill (each) SSC main ring. Making the rather optimistic assumption of a 40 second cycle time for the HEB, the injection time required for fixed-target operation would be

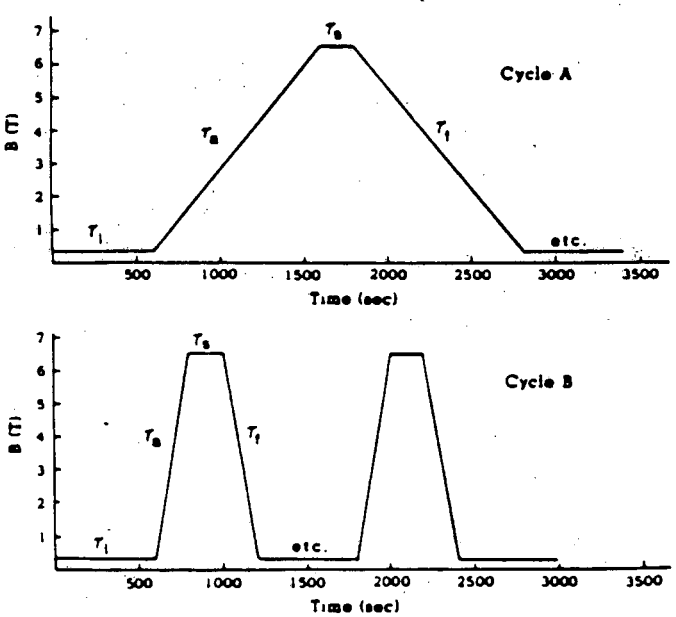


Fig. 1. Possible fixed-target operating modes for the SSC. Parameters for Cycle A are τ_i = 600 sec, $\tau_a = \tau_f$ = 1000 sec, τ_s = 200 sec. For cycle B, $\tau_a = \tau_f$ = 200 sec. (See text.)

600 seconds.

The acceleration (and fall) times for the two cycles were chosen to be 1000 seconds (Cycle A) and 200 seconds (Cycle B). The 1000 second ramp time is identical to that specified for the LBL collider operation; the 200 second time is felt to be the fastest one that is reasonable in light of the hardware issues to be discussed in Section IV of this paper.

With these assumptions, the overall period and duty factor for Cycles A and B, respectively, are:

Cycle A: cycle time 2800 sec; duty factor 7%

Cycle B: cycle time 1200 sec; duty factor 17%.

Note that decreasing the acceleration time by a factor of 5 improves the duty factor by only a factor of 2.5.

III. Luminosity Considerations

With the assumed cycle times given in the previous section, it is possible to make estimates of the luminosity that would be available for a fixed-target program at the SSC. The purpose in doing so is to see whether the achievable rates will provide the capability to do "interesting" physics. In particular, we should make a comparison with HERA, a proposed 30 GeV e x 820 GeV p collider that is expected to begin operation in about 1990.

Average particle intensities for Cycles A and B, respectively, (assuming full extraction of the 1.7×10^{14} circulating protons) would be:

$$\Phi_A = 6.1\times10^{10}$$
$$\Phi_B = 1.4\times10^{11}.$$

The instantaneous intensity during the 200-second spill is 8.6×10^{11} protons per second. Corresponding values from the Fermilab main ring are approximately 3×10^{11} (average) and 1×10^{12} (instantaneous).

It appears likely that much of the physics that would be done with the SSC in a fixed-target mode would involve secondary beams, such as muons or neutrinos. Production rates for these beams were estimated in Ref. 2 to be about 10^{-5} of the incident proton intensity. Thus, for either muons (up to 10 TeV) or neutrinos (up to 4 TeV), the intensity would be 6.1×10^{5} or 1.4×10^{6} for Cycles A and B, respectively.

Target thickness is then the remaining parameter needed to specify the luminosity. We have chosen two representative targets, consisting of 100 m of liquid hydrogen (density 0.07 g/cm^3) and 50 kg/cm^2 of iron. These give thicknesses (in nucleons/cm^2) of 4.2×10^{26} and 3×10^{28}, respectively.

With these assumptions, we arrive at the luminosity values listed in Table II; integrated luminosity values are

Table II

Estimated Luminosity Values for SSC Secondary Beams

Luminosity (cm^{-2} sec^{-1})

	$\mu,\nu + H_2$	$\mu,\nu + Fe$
Cycle A	2.6×10^{32}	1.8×10^{34}
Cycle B	5.9×10^{32}	4.2×10^{34}
During Spill	3.6×10^{33}	2.6×10^{35}

Integrated Luminosity[a] (cm^{-2})

	$\mu,\nu + H_2$	$\mu,\nu + Fe$
Cycle A	2.6×10^{39}	1.8×10^{41}
Cycle B	5.9×10^{39}	4.2×10^{41}

(a) Assume 4 month (10^7 sec) dedicated fixed-target operation.

also given there. These latter values are calculated by assuming that the SSC would operate as a dedicated fixed-target machine for 4 months (10^7 seconds) per year. If we postulate that HERA would operate for 8 months per year, it would have an integrated luminosity of 1×10^{39} cm^{-2}. We can conclude, therefore, that the SSC fixed-target program might be competitive with HERA, for some experiments, in spite of the 3-year delay.

Table III gives various count rate estimates for SSC secondary beam experiments. Based on the assumed cross sections (included in Table III), the number of events per year would fall in the range of 10^5-10^7. Peak rates would in all cases be quite modest and should not be a problem from the point of view of detector capability.

It is worth noting, however, that a similar statement does not apply in the case of primary proton beams. Even for a 1-m liquid hydrogen target, the instantaneous luminosity is 3.6×10^{36} $cm^{-2}sec^{-1}$. Corresponding count rates, given in Table IV, are probably unmanageably high. As reference values, the collider presently envisioned at LBL would give a count rate of 2×10^8 per second, or 10 events per bunch crossing.

IV. Hardware Implications

The primary effects of the rapid cycling of the SSC operating in a fixed-target mode are related to power demand. In addition, there are possible ramifications for the quench protection system. These topics will be discussed below.

Magnet Power

The peak power required for the superconducting magnets is given by

Table III

SSC Secondary Beam Cross Sections and Count Rate Estimates

Cross Sections[a]

$$\sigma_{\mu p} = 10^{-34}\ cm^2$$

$$\sigma_{\nu p} = 7 \times 10^{-39}\ E_\nu\ cm^2$$

$$= 3 \times 10^{-35}\ cm^2 \quad \text{(at 4 TeV)}$$

Count Rates[b]

Integrated (events/year)

	$\mu + H_2$	$\mu + Fe$	$\nu + H_2$	$\nu + Fe$
Cycle A	2.6×10^5	1.8×10^7	7.8×10^4	5.4×10^6
Cycle B	5.9×10^5	4.2×10^7	1.8×10^5	1.3×10^7

Peak Rates

Per 200 sec spill	72	5200	22	1560
Per second	0.36	26	0.11	7.8
Per "bunch" (50 nsec)	1.8×10^{-8}	1.3×10^{-6}	5.4×10^{-9}	3.9×10^{-7}

(a) Ref. 2.

(b) For 100-m liquid H_2 or 50 kg/cm^2 Fe target.

Table IV

SSC Fixed-Target Proton Count Rates

Cross Section

$$\sigma_{pp} = 5.0 \times 10^{-26}\ cm^2$$

Count Rates[a]

Peak Rates

Per 200 sec spill	3.6×10^{13}
Per second	1.8×10^{11}
Per "bunch" (50 nsec)	9.0×10^3

(a) For a 1-m liquid H_2 target; instantaneous luminosity is 3.6×10^{36} $cm^{-2}sec^{-1}$.

$$P = \frac{dU_s}{dt}$$

where U_s is the stored energy. Since U_s is proportional to B^2, we can rewrite this as

$$P = 2U_s \frac{\dot{B}}{B}.$$

For the LBL dipole design, the stored energy is 0.056 MJ/m. Therefore, the total stored energy for one ring (4032 magnets) is

$$U_s = 3.6 \times 10^3\ MJ.$$

If we assume the magnet ramp is linear, then

$$\frac{\dot{B}}{B} = \frac{0.95}{\tau_a}$$

and

$$P = \frac{6.9\times10^3}{a} \text{ MW} .$$

A plot of peak power vs. acceleration time is shown in Fig. 2. The points corresponding to Cycles A and B are indicated. It is clear that the power required to accelerate at a rate faster than about 200 seconds starts to become prohibitive. Of course most of this power is fed back into the grid during the discharge part of the cycle, but this too can be difficult for the utility company to absorb.

One possible way to mitigate this power cycling problem would be to use the magnets in the other ring to store energy during the cycle. If this technique were successful, it would make rapid pulsing of the SSC considerably more manageable.

RF Power

For the present LBL design, the required peak RF voltage will be about 14 MV per turn for a 1000-second acceleration time. Decreasing the acceleration time to 200 seconds would necessitate 70 MV per turn.

It is clear that the most power efficient way to increase the acceleration voltage is to provide additional

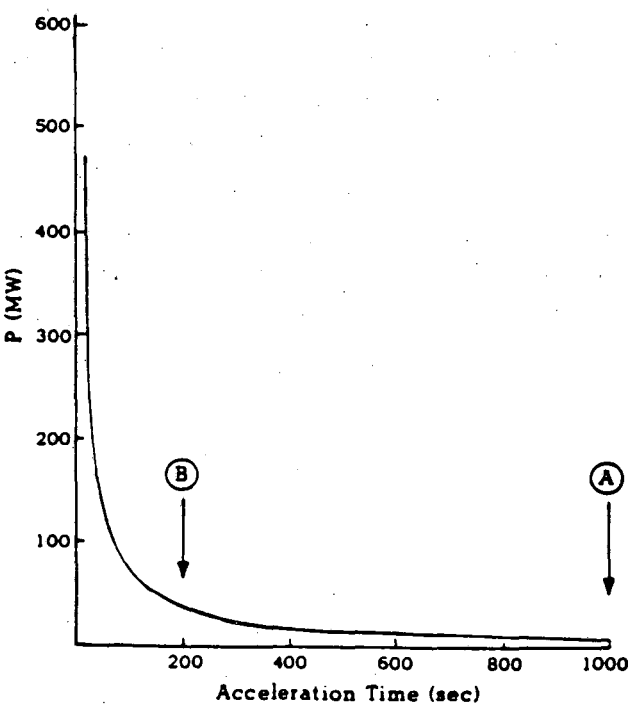


Fig. 2. Peak magnet power demand as a function of acceleration time for SSC fixed-target operation. Values shown correspond to LBL superconducting magnet specifications.

Table V

Estimated Cryogenic System Power for Fixed-Target Operation

Cycle	Steady State (MW)	Increment (MW)	Total (MW)
Collider	20	--	20
A	20	3	23
B	20	15	35

accelerating cavities, in which case the power goes up linearly (rather than quadratically) with voltage. Based on some very preliminary estimates, the length of the acceleration structure for the LBL machine would increase from about 300 to 1500 m, and the power would increase from about 10 to 50 MW.

Here too, we find that the required power is proportional to the reciprocal of the acceleration time, and thus will increase by a factor of 5 in going from a 1000-second to a 200-second ramp time.

Cryogenic System Power

In order to estimate the effect of rapid pulsing on the cryogenic system, it is necessary to have information on the magnet design. In the absence of detailed data, I will rely on the estimate from the LBL magnet design group that the AC loss is about 60 J/m per half-cycle, and that the steady-state load, about 0.4 W/m, corresponds to a room temperature power requirement of 20 MW.

Given these values, we can estimate the power requirements listed in Table V. We see that the incremental load on the cryogenic system from continuous ramping at 1000 seconds is only about 15% of the steady-state load, but the 200-second ramp time causes the power requirement to nearly double. Thus, running the SSC as a fixed-target machine with Cycle B would require essentially doubling the refrigerator capacity.

Quench Protection

One ramification of the cycle time that does not involve power considerations concerns the quench protection system. Present plans for the LBL version of the SSC involve the use of a passive (diode) quench protection system. At cryogenic temperatures these diodes will fire at about 3.5 V. It is important, of course, to avoid the possibility of false quenches, and this means that the voltage required to ramp up the magnetic field should not be too close to the diode breakdown voltage.

The voltage "seen" by the diode is

$$V = L \frac{dI}{dt}$$

where L is the magnet inductance. This can be rewritten

in terms of the stored energy as

$$V = \frac{2U_s}{I^2}\frac{dI}{dt}.$$

For the LBL dipoles the stored energy (per aperture) is about 0.9 MJ and the maximum current is about 6000 A. Therefore, for a 1000-second ramp time we have dI/dt = 5.7 A/sec and a required voltage of 0.3 V. The corresponding values for a 200-second ramp time are 28.6 A/sec and 1.4 V.

It is possible that the latter voltage still affords enough of a safety margin, but this cannot be stated with certainty at this time. In principle, a "double diode" system could be adopted, which would double the breakdown voltage. However, this means that more time is needed to remove the current from a magnet that undergoes a quench, thus leading to a greater temperature rise in the coil. To determine whether this solution is acceptable will require further study.

Summary

A summary of the peak power requirements for fixed-target operation of the SSC is given in Table VI. The obvious message is that a power increase of a factor of 3 is needed to gain a duty factor increase of only a factor of 2.5. It is worth noting at this point that one of the chief reasons for this "inefficiency" is the rather long injection time needed to fill the SSC. Making the injection time shorter would clearly allow a more favorable ratio of duty factor to acceleration time. However, the same considerations that apply to the main ring apply as well to the HEB, albeit with lower magnitude. Thus, decreasing the booster cycle time merely moves the power problem to a different part of the site.

If, on the other hand, the duty factor can be improved by increasing the spill time, the gain comes essentially for free. Unfortunately, as we will demonstrate in the next section, the 200-second spill time already places severe constraints on the design of an extraction system.

V. Slow Extraction Considerations

As with most proton synchrotrons, the slow extraction process would probably make use of the so-called third-integer extraction technique. In this technique the betatron frequency ("tune") of the particles is moved close to a one-third integer so that the particles can resonate with a non-linear kick provided by a sextupole element in the lattice.

A crucial consideration for a machine such as the SSC involves the efficiency of the extraction process. It was pointed out at the ICFA Workshop[2] that the energy loss mechanism for 20 TeV protons differs from that at lower energies; at 20 TeV, the energy loss comes mainly from nuclear interactions. This leads to a very large energy deposition in anything hit by the beam. Thus, without extra care, energy deposition sufficient to quench magnets--or even melt the septum--will occur.

To avoid such problems, it is necessary to aim for an extraction efficiency of about 99%. We can obtain an estimate for the efficiency by noting that the beam loss is given approximately by the ratio of the septum thickness to the size of the jump made by the beam during its last three orbits before extraction. For a (perhaps optimistic) septum thickness of 0.1 mm, the required extraction efficiency of 99% implies a minimum jump size, Δx_T, of 10 mm.

For a given lattice, the position of the septum corresponding to a particular jump size is given by

$$x_T = \left[\frac{4}{3}\,\frac{B\rho}{S\ell}\,\frac{1}{\beta_S}\sqrt{\frac{\beta_T}{\beta_S}}\;\Delta x_T\right]^{1/2},$$

where $B\rho$ is the beam rigidity, $S\ell$ is the sextupole strength, and β_S and β_T are the values of the betatron amplitude at the position of the sextupole and thin septum, respectively.

To calculate the septum position for the purposes of this paper, the sextupole strength was estimated by scaling up the value used at the CERN SPS. This gives $S\ell$ = 6000 T/m. The beta values were taken from the present LBL SSC lattice. For a sextupole located where the beta value in the regular cell is maximum, and a septum located where the beta value in the insertion is maximum, we have β_S = 270 m and β_T = 1500 m. With these parameters we find that x_T = 3.6 cm, a value considerably beyond the available physical aperture of 1.5 cm radius.

The dependence of the septum position (x_T) and the beam size elsewhere in the ring (x) on the integrated sextupole strength is presented in Figs. 3 and 4 as a function of $(\beta_T/\beta_S)^{1/2}$. In Fig. 3, the jump size is fixed at 20 mm, corresponding to a beam loss of about 0.8%. Figure 4 is for a fixed jump size of 10 mm, which corresponds to a beam loss of about 1.6%. For a fixed ratio of beta functions, the septum position corresponding to a given jump size decreases as the strength of the kick

Table VI

Summary of Peak Power Requirements for SSC Fixed-Target Operation

Cycle	Magnets (MW)	RF (MW)	Cryogenics (MW)	Total (MW)
A	7	10	23	40
B	35	50	35	120

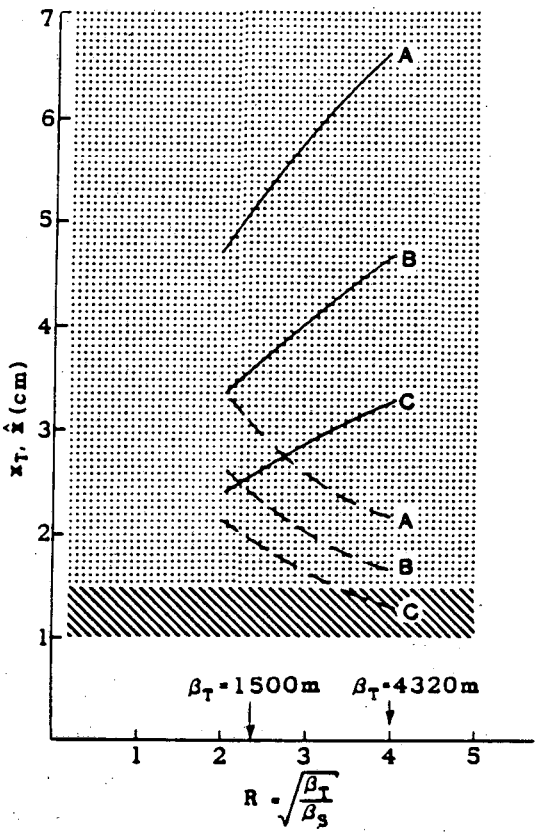


Fig. 3. Septum position x_T (solid curves) and maximum beam size in the arcs $\hat{x}$ (dashed curves) as a function of the square root of the ratio of beta function at the thin septum position, β_T, to that at the sextupole location (β_S = 270 m). The assumed jump size of 20 mm corresponds to a beam loss of about 0.8%. Three sextupole strengths are shown: (A) 6,000 T/m; (B) 12,000 T/m; (C) 24,000 T/m. The 1 cm good field region and the 1.5 cm beam pipe radius are indicated.

increases. To maintain an acceptable beam size elsewhere in the ring a large value of $(\beta_T/\beta_S)^{1/2}$ is needed. For a 10 mm jump size (Fig. 4), it does appear possible to keep the beam in the arcs to within a postulated 1 cm "good field" region. The required septum position is somewhat outside the 1.5 cm beam pipe radius, but this is not a fundamental problem because the beam pipe could be enlarged in the (dipole-free) extraction region.

There are two issues that have been, to some extent, sidestepped in the above discussion: the "allowable" sextupole strength and the precise definition of "good field" region for the slow extraction process. Both issues will require tracking studies for the particular SSC magnets and lattice under consideration. It is worth noting, however, that the demands on the good field region from slow extraction will be more stringent than those from the circulating collider beams. Thus, although a 1 cm good field region for slow extraction is comparable in magnitude to that discussed for the collider mode, the implications of a slow extraction capability on the SSC magnet design (and cost) remain to be investigated.

Tracking Requirements

To estimate the tracking requirements of the slow extraction process, we imagine that a beam having a tune spread $\Delta\nu$ is being swept across the third-integer resonance by changing the focusing, i.e., the current in certain quadrupoles. The rate of spilled particles is

$$\frac{dN}{dt} = \rho(\nu)\,\dot{\nu} \ .$$

For a constant spill rate,

$$\frac{dN}{dt} = \frac{N}{\tau_s} = \bar{\rho}\,\frac{\Delta\nu}{\tau_s}$$

so that

$$\dot{\nu} = \frac{\bar{\rho}}{\rho(\nu)}\,\frac{\Delta\nu}{\tau_s} = s(\nu)\,\frac{\Delta\nu}{\tau_s} \ .$$

Finally, taking a uniform distribution in tune space (s=1) gives

$$\frac{\dot{\nu}}{\nu} = \frac{1}{\tau_s}\,\frac{\Delta\nu}{\nu} = \left(\frac{\dot{I}}{I}\right)_{quad} \ .$$

If we assume that the beam is blown up to have a tune

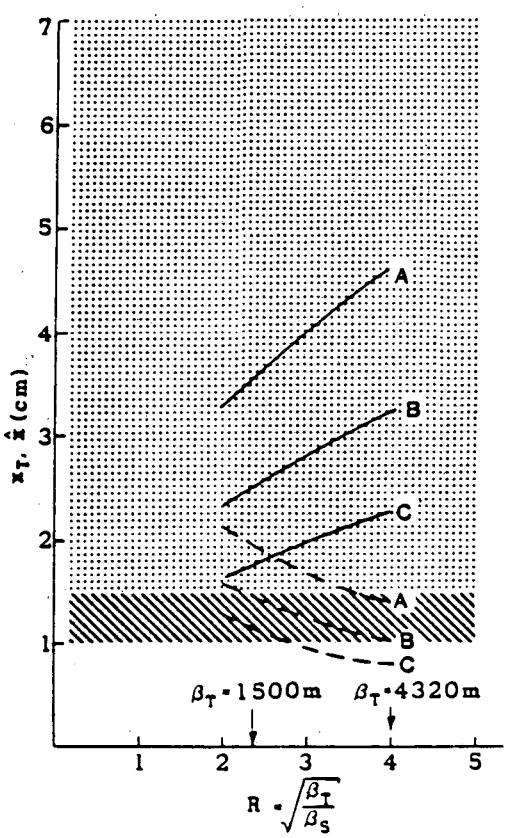


Fig. 4. Same as Fig. 3, but for a jump size of 10 mm, corresponding to a beam loss of 1.2 to 1.6%.

spread of 0.01, and that the trim quadrupoles that move the tune have a tuning range of 1% of the total tune (which is about 97 for the LBL lattice), then a 200-second spill time requires $\dot{I}/I = 5\times10^{-5}\ \mathrm{sec}^{-1}$. This would necessitate very precise control of the power supply ramp.

Ripple Requirements

Another factor that can affect the beam spill is power supply ripple. Suppose that the quadrupole current is given by

$$I_{quad} = Kt + \hat{I}\sin\omega t\ .$$

Then,

$$\frac{\dot{I}}{I} = \frac{K}{I} + \frac{\hat{I}\omega}{I}\cos\omega t$$

$$= \frac{1}{\tau_s}\frac{\Delta\nu}{0.01\ \nu} + \frac{\hat{I}\omega}{I}\cos\omega t\ .$$

In order to avoid 100% beam modulation, we must have

$$\frac{\hat{I}}{I} < \frac{1}{\omega\tau_s}\ \frac{\Delta\nu}{0.01\ \nu}\ .$$

For the spill parameters adopted above and a frequency of only 1 Hz we already find that we need $\hat{I}/I < 8\times10^{-6}$. (A 60 Hz ripple would lead to a 60 times tighter ripple requirement.) It is clear that this requirement would at best be difficult to achieve, and would lead to a need for exceedingly expensive power supplies.

It may be possible to avoid the modulation problem, however, by adopting some type of novel extraction scheme, such as stochastic extraction. Alternatively, the problem may be eliminated by using the synchrotron radiation energy loss to change the tune of the machine.

If we turn off the RF (allowing the beam to debunch), the particles will lose energy at a rate of about 0.12 MeV per turn, or 4×10^{-4} TeV/sec. Over a spill time of 200 seconds, this energy loss changes the momentum by $\Delta p/p = 4\times10^{-3}$. For a rather modest chromaticity of 2.5, we can get the required change in tune of 0.01. Unfortunately, because the maximum dispersion in the LBL lattice is 2.5 m, the maximum displacement arising from this momentum change is 1.25 cm. Although this value is outside the expected good field region, a shorter spill time, say 100 seconds, might be acceptable.

Preliminary Conclusions

From the discussion in this and the preceding section, we can draw the following tentative conclusions:

(1) Significant changes to the machine design would be required to accommodate a fixed-target operating mode.

(2) The job would be difficult, but (based on the work done up to now) not clearly impossible.

VI. Future Work Needed

It seems likely that the issue of fixed-target physics at the SSC will not "disappear" without a serious study of whether a slow extraction system can be made compatible with "reasonable" collider parameters. Therefore, it should benefit both the proponents and opponents of this option to encourage and participate in such a study. Possible topics for (the proverbial) **"someone"** to investigate include:

(a) Required aperture. (Can it be localized to one insertion?)

(b) Extraction efficiency needed to avoid quenching/overheating.

(c) Novel extraction techniques (e.g., stochastic, synchrotron radiation loss).

(d) Power supply requirements.

(e) Mitigating power demands from pulsing.

(f) Improving the injection time.

And, most importantly,

(g) **Etc.**

VII. Points to Ponder

As a closing issue, I would like to raise the following questions. First, must the HEB have a fixed-target capability as well as the SSC itself? If so, what are the physics trade-offs involved in raising the booster energy to, say, 2-5 TeV and then restricting the fixed-target program to the booster only? Such a design change would clearly benefit the duty factor available for the (admittedly lower energy) fixed-target program, and might also minimize problems associated with the rather low injection field specified in the present collider scenario.

Acknowledgments

I would like to thank S. Loken, Chairman of the PSSC Fixed-Target Working Group, for several helpful discussions. In addition, the technical inputs to this paper provided by M. Cornacchia, D. Hopkins, H. Lancaster, Ch. Leemann, M. Puglisi, and C. Taylor are greatly appreciated.

References

1) B.T. Leemann, "A Fast Extraction System for the 6.5 Tesla SSC Lattice," SSC Note-11, LBID-827, 1983, unpublished.

2) Proceedings of the Second ICFA Workshop on Possibilities and Limitations of Accelerators and Detectors, Les Diablerets, Switzerland, October 4-10, 1979, ed. by U. Amaldi.

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720