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AN INJECTION SYSTEM WITH TWO BOOSTERS AND ONE TRANSITION CROSSING FOR THE SSC

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Abstract

The possibility of sparing a booster ring, but with protons crossing transition, has been investigated. An Intermediate Energy Booster (IEB) could substitute both LEB and MEB, foreseen in the Conceptual Design; transition crossing should occur via rapid Q_H-jump. Several solutions have been considered, all characterized by the same bunching factor ($B = 0.25$) and Laslett tune-shift ($\Delta\nu = 0.16$) as in the LEB; linac kinetic energies vary from 1.38 to 2.74 GeV. Besides the HEB injection energy, i.e., the IEB top energy, must be rather high in order to avoid big sextupole and decapole components in the HEB field.

1. Introduction

The general idea behind this proposal is to modify as little as possible the parameters assessed in the Conceptual Design.[1] Of course the H^- linac energy shall be raised, according to some specific rules, and both the LEB and the MEB will merge into a unique booster, just the IEB, which will undergo transition crossing.

Instead the superconducting High Energy Booster (HEB) will remain almost the same, with some variations regarding its injection field and its repetition rate.

Above all, transversal and longitudinal emittances will be the same as conceived in the Conceptual Design, thus the Laslett tune-shift $\Delta\nu$ and the bunching factor B will be the same in all the possible IEB's considered. Then, the approximated formula for the incoherent Laslett tune-shift gives:

$$\beta\gamma^2 = \frac{r_p}{4\pi\epsilon_N B\Delta\nu} N_T \tag{1,a}$$

where β,γ are the usual Lorentz relativistic factors, $r_p = 1.535 \times 10^{-18}$ m is the classical proton radius, $\epsilon_N = 0.75$ mm mrad (as in the CD) is the normalized rms emittance, $B = 0.25$ and $\Delta\nu = 0.16$ as in the CD; N_T is the total number of protons in the IEB and depends strictly on the top energy of this booster; in fact the lower the energy, the shorter the IEB circumference, the higher the number n of IEB batches to be injected into the HEB.

Since the total number of protons accelerated by the HEB coincide with the total number of protons stored in one SSC ring, one has $N_T =$

N_{SSC}/n or

$$\beta\gamma = \frac{r_p N_{SSC}}{4\pi\epsilon_N B\Delta\nu}\frac{1}{n} = \frac{b}{n} \qquad (1,b)$$

with b = 44.466, for $N_{SSC} = 1.092 \times 10^{13}$ protons.

Solving Eq. (1,b) with respect to γ one obtains

$$\gamma = \sqrt{\frac{1 + \sqrt{1 + 4b^2n^{-2}}}{2}} \qquad (2)$$

which will yield the injection energy, into the IEB, as a function of the number of batches n.

Besides the product of n times the harmonic number h must be almost the same as in the MEB, in order to avoid big modification in the RF systems. Namely:

$$(nh)_0 = n_{MEB} \times h_{MEB} = 3 \times 396 = 1188 \qquad (3)$$

Maintaining the same bunching-spacing as before (i.e., $S_B = 4.8$m), recalling the "golden relation" $p = eB\rho$ and bearing in mind that the IEB circumference is $C = hS_B$, one obtains as the highest momentum p_M

$$p_M = \frac{eB_M(nh)_0\, S_B}{2\pi Fn} = \frac{P}{n} \qquad (4)$$

with

$$F = \frac{C}{2\pi\rho}$$

Assessing F = 1.63 and $B_M = 1.8$ T as in the MEB, one obtains P = 300 GeV/c. Then, making use of both Eqs. (3) and (4), the results gathered in Table I are obtained.

Table 1

n	W_i (GeV)	p_M (GeV/c)
8	1.375	40
6	1.703	50
5	1.939	60
4	2.261	75
3	2.735	100

Notice that Eq. (4) would yield $p_M = 37.5$ GeV/c for $n = 8$. This value has been increased up to 40 GeV/c, in order to avoid too low injection fields in the HEB.

Starting from the data of Table I, one can find several parameters of interest by adjusting the values of the IEB circumference, in such a way as to have $C/S_B = h =$ integer number. These results are shown in Table II, together with the new values of the injection-field B_m in the HEB.

Table II

n	p_M (GeV/c)	$2\pi\rho$ (m)	C (m)	F	h	nh	B_m (T)
8	40	465.7	715.2	1.54	149	1192	0.226
6	50	582.2	950.4	1.63	198	1188	0.283
5	60	698.6	1142.4	1.64	238	1190	0.340
4	75	873.2	1425.6	1.63	297	1188	0.425
3	100	1164.3	1900.8	1.63	396	1188	0.566

The last column deserves a few comments: sextupole and decapole coefficients, from persistent currents in 5 μm superconducting filaments, sharply increase below 0.3 Tesla roughly, as it can be seen in Fig. 1

(which reproduces Fig. 4.10-2 of Ref. 1).

The lowest HEB injection field still acceptable could be 0.283 Tesla, i.e., the IEB top-momentum cannot be less than 50 GeV/c.

The highest ratio of the HEB would now be

$$\frac{100 \text{ GeV}}{50 \text{ GeV}} = 20$$

which is equal to the ones foreseen for HERA (800 GeV/40 GeV) and SSC (20 GeV/1 TeV).

Figure 2 illustrates the time-dependence of the HEB magnetic field. *If the injection porch is included in the HEB full cycle, which is still* 60 s, the IEB and HEB ramps have to be adjusted accordingly:

$$\tau_{porch} = (n - 1)\ \tau_{IEB} \qquad (5,a)$$

(where n is the number of IEB-batches seen before)

$$\dot{B}_{IEB} = 2\ \frac{(B_M - B_{inj})_{IEB}}{\tau_{IEB}} \qquad (5,b)$$

$$\dot{B}_{HEB} = 2\ \frac{(B_M - B_{inj})_{HEB}}{\tau_{cycle} - \tau_{porch}} \qquad (5,c)$$

Bearing in mind that $(B_{inj})_{IEB} = \frac{p_i}{p_M} B_M$ *and setting* $(B_M)_{HEB} = 5.66$ T, *as* in Ref. 1, one obtains the data shown in Table III.

Table III

n	p_i (GeV/c)	B_i (Gs)	τ_{IEB} (s)	τ_{porch} (s)	$\dot{B}_{IEB}$ (Ts^{-1})	$\dot{B}_{HEB}$ (Ts^{-1})
8	2.114	951	2	14	1.705	0.236
6	2.469	889	2.8	14	1.222	0.234
5	2.720	816	3	12	1.146	0.222
4	3.058	734	4	12	0.863	0.218
3	3.551	639	4	8	0.868	0.196

2. RF System(s) and H^- Linac Current(s)

In all the Intermediate Energy Rings proposed an abort gap has to be created: this means that the number of bunches n_B must be slightly smaller than the harmonic number h. For continuity sake, the ratio h/n_B will be the same as in the MEB of the Conceptual Design. Recalling the definition of N_T and bearing in mind that the number of protons per bunch is $N_{ppb} = N_T/n_B$, one obtains the results gathered in Table IV.

Table IV

P_M (GeV/c)	h	n_B	$N_T \times 10^{-12}$	$N_{ppb} \times 10^{-10}$
40	149	137	1.365	0.996
50	198	182	1.820	1.000
60	238	219	2.184	0.997
75	297	273	2.730	1.000
100	396	364	3.640	1.000

The following simple relations apply for the revolution frequency and the RF frequency:

$$f_{RF} = hf_{rev} = \beta f_B \qquad (6,a)$$

$$f_{rev} = \beta f_\infty = \beta \frac{f_B}{h} \qquad (6,b)$$

$$f_\infty = \frac{c}{C} = \frac{c}{hS_B} = \frac{f_B}{h} \qquad (6,c)$$

$$f_B = \frac{c}{S_B} = 62.5 \text{ MHz} \qquad (6,d)$$

The corresponding periods are

$$\tau_{RF} = \frac{\tau_B}{\beta} \tag{7,a}$$

$$\tau_{rev} = h \frac{\tau_B}{\beta} \tag{7,b}$$

$$\tau_B = \frac{S_B}{c} = 16 \text{ ns} \tag{7,c}$$

Table V shows several data referred to the various choices of the injection momentum.

Table V

p_i (GeV/c)	f_{RF} (MHz)	τ_{RF} (ns)	τ_{rev} (μs)
2.114	57.13	17.5	2.61
2.469	58.43	17.1	3.11
2.720	59.08	16.9	3.70
3.058	59.75	16.7	4.96
3.551	60.43	16.5	6.53

In order to maintain the same Linac currents as in the Conceptual Design, the IEB bucket-filling should take place through 2 filled DTL-buckets out of 8 (vs. 2 out of 9 as in Ref. 1).

Again the IEB is filled in 20 turns via H^- stripping, i.e., the injection time varies from 52.2 μs to 131 μs, according to injection energy.

Then the DTL frequency is just eight times the IEB radio-frequency and, keeping the same ratio as before, the SCL frequency is another three times. Thus the following Table VI can be obtained:

Table VI

W_i (GeV/c)	f_{DTL} (MHz)	f_{SCL} (MHz)
0.400	445.2	1335.6
1.375	457.0	1371.1
1.703	467.4	1402.3
1.939	472.6	1417.9
2.261	478.0	1435.9
2.735	483.4	1450.3

The first row reproduces the Conceptual Design data.

The last column of Table IV indicates that the number of protons per IEB-bunch is practically 10^{10} for all the solutions considered. Since the DTL fills the IEB using 2 buckets out of 8, over 20 turns, one has

$$N_{H^-pb} = \frac{10^{10}}{2\times 20} = 2.5 \times 10^8 \ H^- \text{ per bucket}$$

as before, for all the possible IEB's.

Defining as instantaneous current

$$\hat{I} = e\, N_{H^-pb}\, f_{DTL}$$

and as current-over-macropulse

$$I_m = \hat{I}\,\frac{2}{8}\,\frac{\text{(filled buckets)}}{\text{(total \# buckets)}}$$

one has $\hat{I}$ varying from 18.3 mA to 19.3 mA (vs. 17.6 mA of the conceptual Design) and I_m varying from 4.6 mA to 4.8 mA (vs. 3.9 mA of the Conceptual Design).

3. Lattice

The number of cells N_c is chosen to be half the number of quadrupoles foreseen for the MEB of Ref. 1, i.e., $N_c = 48$. Chosen as transition gamma $\gamma_{tr} = 8.6$ and applying the simplest formula(2) yielding the FODO-cell parameters, one has:

Phase-advance per cell: $\mu = \frac{2\pi Q_H}{N_c} \simeq \frac{2\pi\gamma_{tr}}{N_c} = 64.5°$

($\sin\mu = 0.9026$, $\sin\frac{\mu}{2} = 0.5336$)

Cell-length: $L_c = \frac{C}{N_c} = \frac{S_B}{N_c} h = 0.1 \times h$ (m)

Quadrupole-gradient: $G = \frac{4\ B\rho}{L_Q L_c} \sin\frac{\mu}{2}$

where L_Q = Quadrupole-length = 0.80 m (vs. 0.75 m of Ref. 1)

Max Beta-function: $\hat{\beta} = \frac{1 + \sin\frac{\mu}{2}}{\sin\mu} \frac{S_B}{N_C} h = 0.167 \times h$ (m)

Max Dispersion: $\hat{D} = \frac{\pi}{2} \frac{1 + \sin\frac{\mu}{2}}{\sin^2\frac{\mu}{2}} \frac{S_B}{N_c^2} h = 0.0177 \times h$ (m)

Besides, being $\alpha \simeq \frac{1}{\gamma_{tr}^2} = 0.0135$ and $R = \frac{C}{2\pi} = \frac{S_B}{2\pi} h$, one has:

$\langle D \rangle = \alpha R = 0.0103 \times h$ (m)

Then the following Table VII can be obtained

Table VII

p (GeV/c)	L_c (m)	G (Tm^{-1})	L_Q (m)	$\hat{\beta}$ (m)	$\hat{D}$ (m)	D (m)
40	14.9	23.9	0.80	25.3	2.63	1.54
50	19.8	22.5	0.80	33.6	3.49	2.05
60	23.8	22.4	0.80	40.4	4.19	2.46
75	29.7	22.5	0.80	50.5	5.23	3.07
100	39.6	22.8	0.75	67.2	14.2	5.84

Data pertaining to the last row come from Ref. 1.

4. Conclusions

This paper displays a spectrum of possible choices, regarding the possibility of using a single Intermediate Energy Booster for accelerating protons from the H^--linac system to the superconducting High Energy Booster. The main issues are: the linac energy has to be raised with respect to the value assessed in the Conceptual Design, but the HEB remains substantally unaltered. Cost estimates should complete this work.

In a next note, a deep investigation will be carried out about the transition-crossing via a fast Q_H-variation.

References

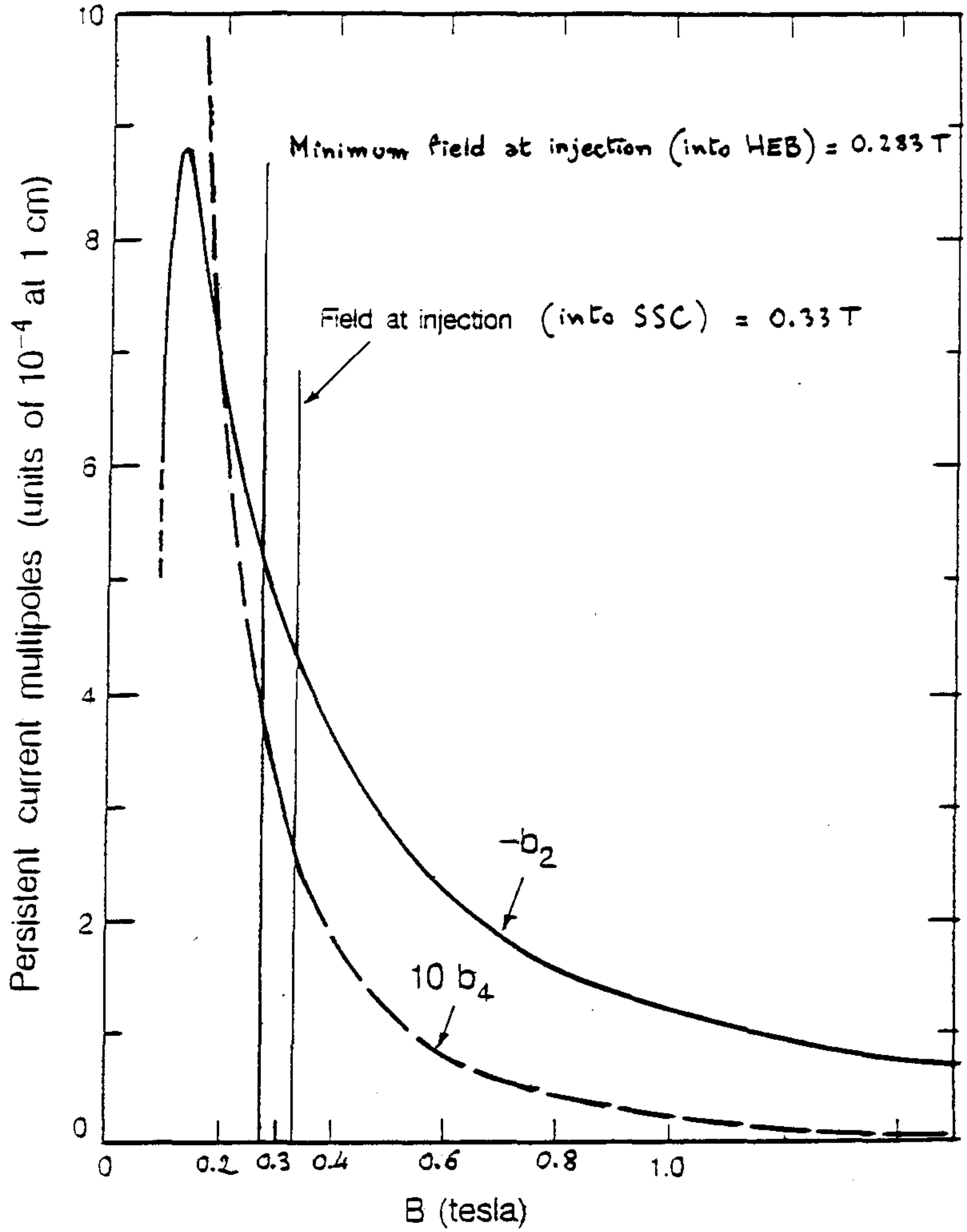
(1) Conceptual Design of the Superconducting Super Collider, SSC Central Design Group, SSC-SR-2020, March 1986.

(2) E. Keil, Linear Machine Lattices, Proceedings of the First Course of the International School of Particle Accelerators of the "Ettore Majorana" Centre for Scientific Culture, Erice 10–22 November 1976, CERN 77-13, p. 22.

Figure Captions

Fig. 1. Sextupole (b_2) and decapole (b_4) coefficients from persistent currents in 5 μm superconducting filaments as a function of main ring magnetic field (for the SSC bending magnet) (see Fig. 4.10-2 of Ref. 1).

Fig. 2. Time structure of the HEB guide field.



Minimum field at injection (into HEB) = 0.283 T
Field at injection (into SSC) = 0.33 T
$-b_2$
10 b_4
Persistent current multipoles (units of 10^{-4} at 1 cm)
B (tesla)
0
2
4
6
8
10
0
0.2
0.3
0.4
0.6
0.8
1.0

Fig. 1

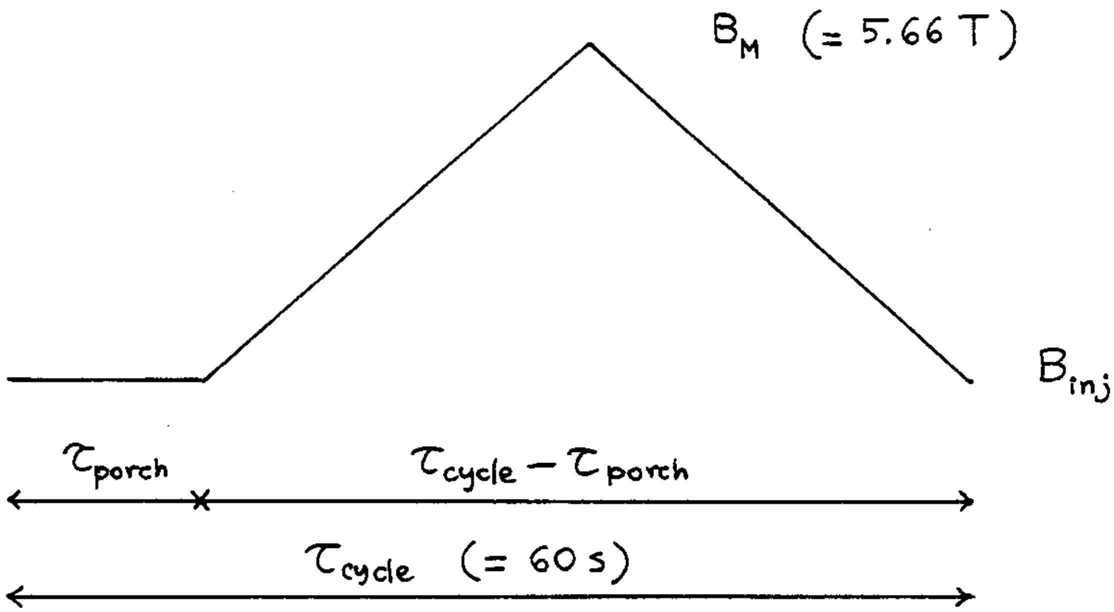


Fig. 2