EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN – PS DIVISION

CTF3 Note 2000-016 (Tech.)
(Injector)

The Solenoids in the Bunching Section of the CTF3 Injector

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Abstract

This note describes the layout of the transverse beam focusing in the bunching section of the CTF3 injector in its nominal phase. A sequence of solenoids is used to create an axial magnetic field, which focuses the beam during the bunching process and during acceleration. Nine identical solenoids have to be manufactured according to existing designs and drawings, while eleven solenoids from LIL can be reused.

Geneva, Switzerland
10 November 2000

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This note describes the layout of the transverse beam focusing in the bunching section of the CTF3 injector in its nominal phase. A sequence of solenoids is used to create an axial magnetic field, which focuses the beam during the bunching process and during acceleration. Nine identical solenoids have to be manufactured according to existing designs and drawings, while eleven solenoids from LIL can be reused.

1 INTRODUCTION

During the nominal phase of the CTF3 injector the electrons are extracted from a thermionic gun. The time structure is imposed to the beam in the following bunching section comprising three harmonic bunchers operating at harmonics of 1.5 GHz, one pre-buncher and a buncher [1]. In order to obtain the required beam quality in the longitudinal and transverse phasespace, respectively, the beam is focused by a longitudinal magnetic field. The field is superposed from the exit of the gun to the exit of the last accelerating structure of the injector and will be generated by a sequence of solenoid magnets. The longitudinal magnetic field B_s along the bunching and accelerating section of the CTF3 injector in its nominal phase was chosen in order to cope with the required beam quality [1]. The scenario for the solenoids proposed in this note is a compromise between best reproduction of this field and the efficient reuse of already existing magnets. As shown in [1], a magnetic field strength of 0.1 T along the accelerating structures copes with the required transverse beam emittances. Nevertheless, the PARMELA simulations revealed that the transverse beam emittances at the exit of the injector can be further decreased by means of a higher magnetic field strength along the accelerating structures.
The present note describes the parameters of the solenoids, their position along the beam line and the proposed configuration of power supplies. Special emphasis is put on the efficient reuse of already existing solenoids.
After introduction of the equation used to calculate the field strength, an arrangement of solenoids assuming a short 6-cell buncher of about 150 mm length is proposed in the following section. The second part describes a scenario, which assumes the use of a buncher of about 1000 mm in length. Since the design of the bunching cavities is still under progress, the positions of the solenoids quoted in this note are preliminary and are based on assumptions concerning the dimensions and placement of the cavities. However, the proposed specifications and number of the magnets do not change with the final cavity design.

2 MAGNETIC FIELD ALONG A SOLENOID AXIS

The mechanical lengths of the solenoids which are presently in use at LIL is comparable to their diameters. Accordingly, the calculation of the magnetic field B_s along the solenoid axis cannot exploit approximations for long or short magnets, respectively. Since the considered solenoids have no iron yokes, the exact expression for the field can be derived by the integration of Biot–Savart's Law as

$$B_s(s) \;=\; \frac{\mu_0 NI}{2L(R_o - R_i)}\left[\left(\frac{L}{2} - s\right)\ln\frac{R_o + \sqrt{R_o^2 + (\frac{L}{2} - s)^2}}{R_i + \sqrt{R_i^2 + (\frac{L}{2} - s)^2}} \;-\; \left(\frac{L}{2} + s\right)\ln\frac{R_i + \sqrt{R_i^2 + (\frac{L}{2} + s)^2}}{R_o + \sqrt{R_o^2 + (\frac{L}{2} + s)^2}}\right] \;, \qquad (1)$$

where N is the number of turns, I is the applied current, L is the mechanical length, R_i and R_o are the inner and outer radius of the coil, and s is the distance from the solenoid center. An example for a solenoid presently in operation at LIL and its axial field strength is shown in Fig. 1.

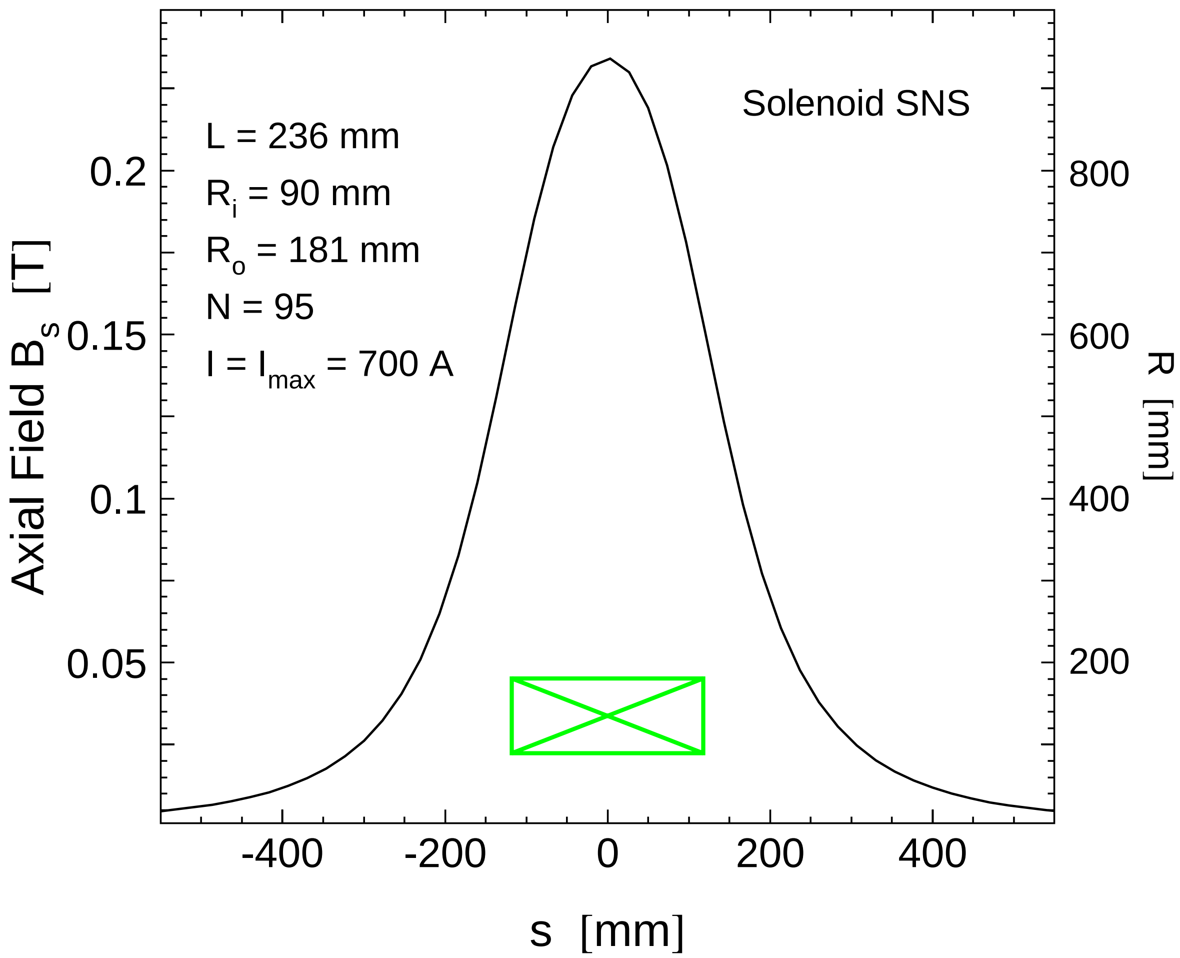

Figure 1: Magnetic field B_s along the axis of a solenoid of type SNS, which is currently installed at LIL. The field is calculated from Eq. 1.

3 SCENARIO FOR A SHORT BUNCHER ($L_B \approx$ 150 MM)

In the PARMELA simulations [1] the length of the 6 cell buncher was assumed to be 150 mm and a magnetic field strength of 0.15 T along the accelerating structure was chosen. Figure 2 shows the proposed arrangement of solenoids for a field strength of 0.2 T, which will result in smaller transverse emittances. To power the solenoids of the buncher and the accelerating structures two supplies from LIL will be used. Their maximum voltage is 300 V and they can provide a maximum current of 785 A. Due to the limited power, the field strength cannot be further increased for the present arrangement. The corresponding positions and specifications of the

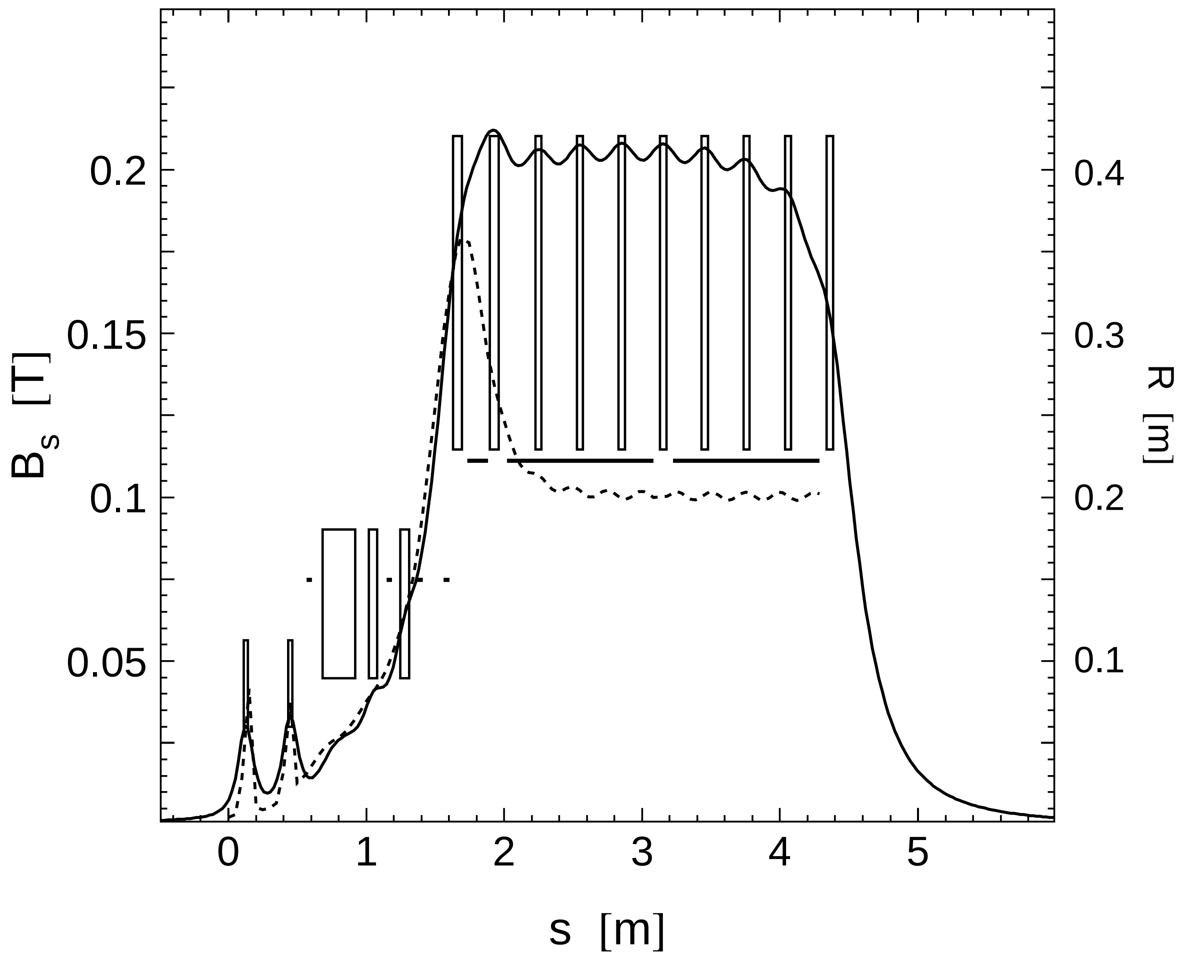

Figure 2: Arrangement of solenoids in the bunching and accelerating section of the CTF3 injector in the nominal phase. Shown is a scheme assuming a short 6-cell buncher ($\approx$ 150 mm) and two accelerating structures. The exit of the gun is placed at $s = 0$. The boxes represent the dimensions of the solenoids and the straight horizontal lines represent the dimensions of the structures. The dotted line indicates the field assumed in the PARMELA simulations [1] and the full line indicates the field generated by the solenoids.

solenoids are listed in Tab. 1, where the exit of the thermionic electron gun is placed at $s = 0$. It should be mentioned that the diameters of the first three harmonic bunchers and the pre-buncher are assumed to be about 300 mm, since their design is still in progress. However, they will not be covered by magnet coils.

According to Fig. 2 the field strength at the exit of the gun is assumed to be zero in the PARMELA simulations and the beam is strongly compressed twice afterwards. The proposed arrangement of solenoids generates a beam compression which is slightly weaker and the field peaks are broader with respect to the field assumed in PARMELA. Due to the enhanced width of the first maximum the field does not vanish at the gun exit. This deviation is due to the finite length of the corresponding solenoid, while in PARMELA the field is created by infinitely flat pancake coils. However, the gun will be built at LAL according to a design made at SLAC. It was proposed that the first two solenoids after the gun will be built in a LAL/SLAC collaboration as well [2]. In this case the specifications of these two solenoids will be different from the specifications quoted in this note! After these two solenoids the beam is transversely compressed while passing the first three harmonic bunchers and the pre-buncher. In order to minimise the number of power circuits the slope of the field used in PARMELA is

s/m	L/mm	D_i/mm	D_o/mm	N	I_{max}/A	I/A	circuit	$R/m\Omega$	P/kW	existing
0.127	33	120	226	185	20	20	A	875	0.350	yes
0.449	33	120	226	185	20	20	A	875	0.350	yes
0.800	236	180	362	95	700	40	B	11.7	0.019	yes
1.050	62	180	362	23	700	150	C	5.65	0.127	yes
1.279	62	180	362	23	700	150	C	5.65	0.127	yes
1.663	66	460	844	108	700	520	D	151	40.9	yes
1.929	66	460	844	108	700	520	D	151	40.9	yes
2.248	45	460	844	72	700	700	E	404	198	yes
2.550	45	460	844	72	700	700	E	404	198	yes
2.852	45	460	844	72	700	700	E	404	198	yes
3.153	45	460	844	72	700	700	E	404	198	yes
3.455	45	460	844	72	700	700	E	404	198	no
3.757	45	460	844	72	700	700	E	404	198	no
4.059	45	460	844	72	700	700	E	404	198	no
4.360	45	460	844	72	700	700	E	404	198	no

Table 1: Positions and specifications of the solenoids for a 6-cell buncher of about 150 mm in length. Listed are the positions s of the geometric centers of the solenoids, the mechanical lengths L, the inner and outer Diameters D, the number of turns N, the maximum and the applied currents I, the corresponding power circuit $\{A...E\}$, the estimated resistances R of the circuits, and the consumed powers P of the circuits. Already existing solenoids and those to be built are indicated.

not reproduced exactly by the proposed scenario but the remaining deviations are small. Moreover, the use of independent power supplies for each of the first five solenoids is presently under discussion [2].

In order to generate the strong slope of the magnetic field strength during beam compression before the buncher, coils with 50% more turns than those used for the accelerating structures are placed in front and behind the buncher, respectively. The solenoid behind the buncher has a mechanical distance of 200 mm from the preceding one in order to facilitate the manufacturing of the buncher cavity [2] and both are powered in series.

After the buncher the beam is focused by a constant magnetic field along the accelerating structures. The centers of the solenoids are arranged in distances of 302 mm from each other thus allowing for a sufficient space of 200 mm for the rf-power couplers at the entry and the exit of each accelerating structure. Towards the end of the structure the magnetic field strength drops by about 50%. Due to the relatively high rigidity of the beam at the end of the structures of more then 20 MeV the resulting increase of the beam size can be neglected.

In the proposed scenario exclusively solenoids of existing design [3] are used. The first eleven magnets are presently used at LIL and will be available for CTF3. The last eight solenoids are of the same type and four of them exist at LIL as well. Since the technical drawings of the remaining four solenoids are available, the manufacturing of these four solenoids can be launched quite soon.

4 SCENARIO FOR A LONG BUNCHER ($L_B \approx$ 1000 MM)

An alternative buncher design foresees to use a cavity with 15–20 cells and lower gradients instead of the 150 mm long 6-cell buncher. Figure 3 shows an arrangement of solenoids, which provides a field strength of 0.15 T along the accelerating structures. The upper field is limited as before by the maximum voltage available from the power supply. In contrast to the option discussed before, which needs four new solenoids,

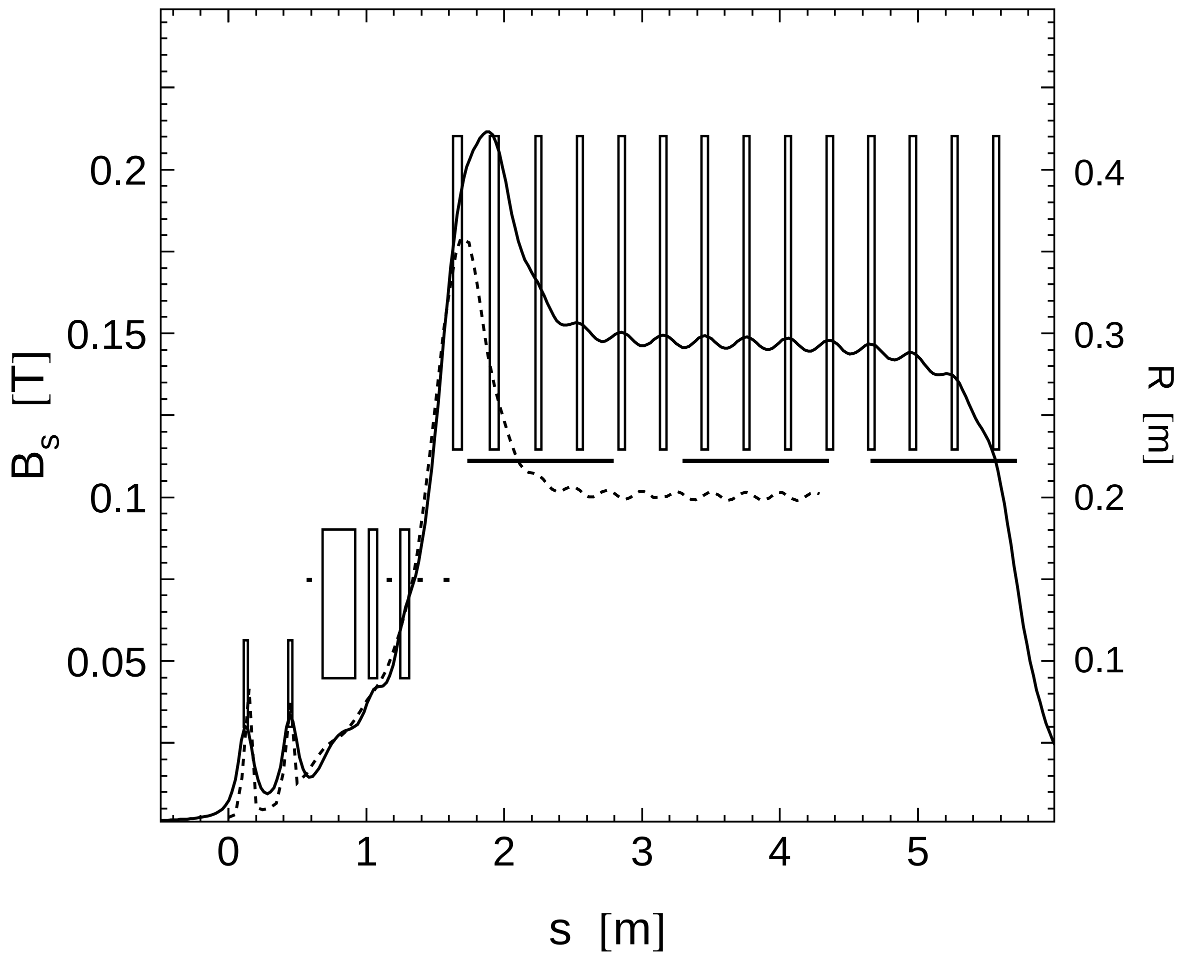

Figure 3: Arrangement of solenoids in the bunching and accelerating section of the CTF3 injector in the nominal phase. Shown is a scheme assuming a long buncher ($\approx$ 1000 mm) and two accelerating structures. The exit of the gun is placed at $s = 0$. The boxes represent the dimensions of the solenoids and the straight horizontal lines represent the dimensions of the structures. The dotted line indicates the field assumed in the PARMELA simulations [1] and the full line indicates the field generated by the solenoids.

eight additional solenoids must be built in order to cope with the increased length of the buncher. However, the positions and specifications of the other magnets are the same as for the case of a short buncher. The electrical parameters of the power circuits are listed in Tab. 2.

5 CONCLUDING REMARKS

For the two scenarios of the buncher of the CTF3 injector, which are currently under discussion, arrangements of solenoids for transverse beam focusing were proposed. In case of a short 6-cell buncher design four solenoids of same type must be built following an existing design. The maximum field strength for this option is 0.2 Tesla. For the option using a long buncher eight solenoids of same type have to be built at minimum. However, it is recommended to provide an additional spare solenoid. The maximum field decreases to 0.15 T due to the limited voltage available from the power supply.

s/m	L/mm	D_i/mm	D_o/mm	N	I_{max}/A	I/A	circuit	$R/m\Omega$	P/kW	existing
0.127	33	120	226	185	20	20	A	875	0.350	yes
0.449	33	120	226	185	20	20	A	875	0.350	yes
0.800	236	180	362	95	700	45	B	11.7	0.024	yes
1.050	62	180	362	23	700	150	C	5.65	0.127	yes
1.279	62	180	362	23	700	150	C	5.65	0.127	yes
1.663	66	460	844	108	700	560	D	151	47.5	yes
1.929	66	460	844	108	700	560	D	151	47.5	yes
2.248	45	460	844	72	700	495	E	605	148	yes
2.550	45	460	844	72	700	495	E	605	148	yes
2.852	45	460	844	72	700	495	E	605	148	yes
3.153	45	460	844	72	700	495	E	605	148	yes
3.455	45	460	844	72	700	495	E	605	148	no
3.757	45	460	844	72	700	495	E	605	148	no
4.059	45	460	844	72	700	495	E	605	148	no
4.360	45	460	844	72	700	495	E	605	148	no
4.662	45	460	844	72	700	495	E	605	148	no
4.964	45	460	844	72	700	495	E	605	148	no
5.266	45	460	844	72	700	495	E	605	148	no
5.567	45	460	844	72	700	495	E	605	148	no

Table 2: Positions and specifications of the solenoids for a buncher length of about 1000 mm. Listed are the positions s of the geometric centers of the solenoids, the mechanical lengths L, the inner and outer Diameters D, the number of turns N, the maximum and the applied currents I, the corresponding power circuit $\{A...E\}$, the estimated resistances R of the circuits, and the consumed powers P of the circuits. Already existing solenoids and those to be built are indicated.

6 REFERENCES

[1] F. Zhou and H.H. Braun, Updated Beam Dynamics for a CTF3 Injector, CTF3 Tech. Note 2000-015 (Injector), (2000).

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[3] D. Blechschmidt and D.J. Warner, Parameters of the LEP Injector Linacs, CERN/PS/88-07 (LPI), (1988).