INJECTOR FOR LISA

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Abstract

The injector of the LNF project LISA (LInear Superconducting Accelerator) is a room temperature system, consisting of a transport line for the beam at 100 KeV, of a capture section (a graded-β 2.5 GHz structure) which accelerates the beam to 1 MeV, and of an isochronous and achromatic transport line which injects the beam into the SC-Linac after a π-bending.

The 100 keV beam delivered by the gun is composed of 1ms long macropulses. It is then chopped by a system of double choppers (50 and 500 MHz) which selects about 1% of the total beam, and bunched by a 500 MHz prebuncher which squeezes the bunch length to about 2 mm in order to obtain the peak current required by the FEL.

Introduction

The superconducting (SC) electron linac LISA[1], in construction at Frascati INFN Laboratories, is a 25 to 49 MeV test-bench machine aimed at studying the larger SC linacs for colliders or CW machines for nuclear physics and at implementing a high efficiency FEL in the infrared wavelength region. In addition to the acquisition of the general techniques related to superconducting acceleration, LISA will allow to study such interesting topics as low emittance electron guns, beam recirculation and beam break-up that are fundamental in such machines.

The layout of the machine is shown in Fig.1. Its parameters, which are mainly defined by the FEL application[1], are given in Table I: average values are over the macropulse duration, while peak values correspond to the single bucket. The electron beam is generated in a thermionic gun, chopped, prebunched and then accelerated to 1MeV in a room temperature capture section. It is then bent through 180° and injected in the SC part of the linac. The electron beam, after extraction from the SC linac, can follow two alternative paths: either through the undulator or back to the linac entrance. In the latter case, depending on its phase with respect to the linac electromagnetic field, it can be either further accelerated to 49 MeV and used to generate shorter wavelength radiation in the FEL or decelerated to give back most of its energy to the SC cavities and increase the effective FEL efficiency.

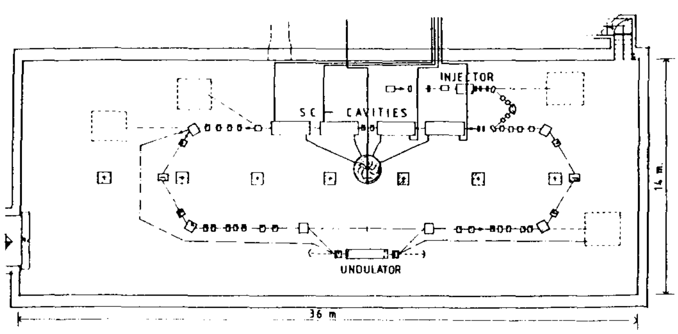

Fig.1 - LISA layout

TABLE I - *Beam Characteristics*

Nominal energy	MeV	25
Energy with recirculation	MeV	49
Peak current	A	5
Average current	mA	2
Duty cycle		< 10%
Invariant emittance	π m rad	10^{-5}
Energy dispersion		$2*10^{-3}$

Injector Description

The injector[2] consists of the following major parts:

- A 100 keV gun.
- Two choppers: one at 50 MHz and another at 500 MHz.
- A 500 MHz prebuncher.
- A 1 MeV, 2.5 GHz capture section.
- An achromatic and isochronous transport line between the capture section and the SC Linac.

The other elements of the injector are: solenoidal focusing lenses, steering coils, collimators, current monitors and fluorescent screens. All RF elements in the injector are normal conducting, to insure that the beam in the SC cavities is almost relativistic. The block diagram of the 100 keV part of the injector is shown in Fig.2.

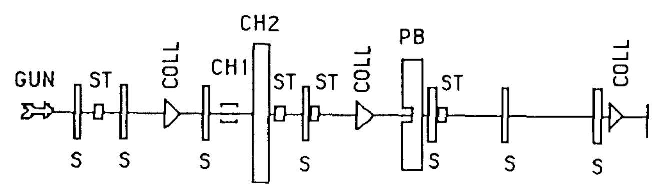

Fig.2 - Sketch of the injector line at 100keV. S *- Solenoidal lenses;* ST *- Steerings;* COLL *- Collimator;* CH1 *- Chopper 1 (50MHz);* CH2 *- Chopper 2 (500MHz);* PB *- Prebuncher (500MHz).*

<u>The gun</u>[3] is a Pierce-geometry thermionic triode. Its main characteristics are listed in Table II. The gun geometry is shown in Fig.3, together with the beam envelope computed using the Hermansfeldt code[4]. The spherically shaped cathode is of the dispenser type with a current density J=10 A/cm^2.

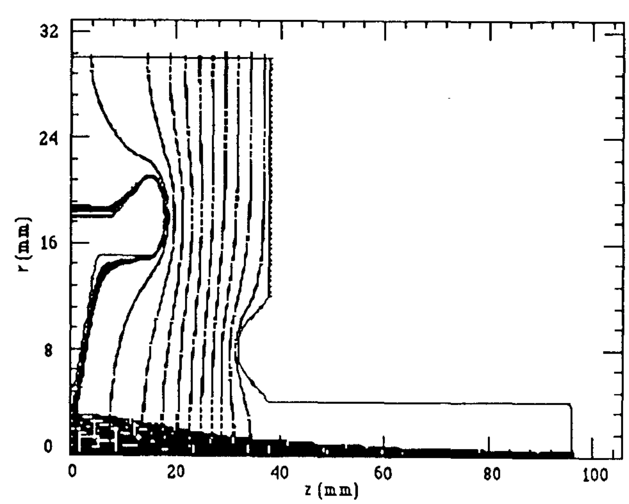

Fig.3 - Gun geometry, beam envelope and equipotential lines. The waist of the beam with r_{min}=0.3mm is at ~90mm from the cathode.

TABLE II - *Gun parameters*

Type	Pierce, triode
Current	$I > 0.2A$
Energy	$W = 100keV$
Energy dispersion	$\Delta W/W = 10^{-3}$
Emittance (invariant π m rad)	$\varepsilon < 10^{-5}$
Cathode radius	$R_k = 40$ mm
Cathode height	$2r_k = 6.4$ mm
Grid radius	$R_g = 39$ mm
Radius of focusing electrode	$R_{fe} = 15$ mm
Curvature radius of foc. electrode	$r_{fe} = 3$ mm
Length of focusing electrode	$L_{fe} = 18$ mm
Anode radius	$R_a = 2$mm
Anode hole diameter	$\Phi_a = 8$ mm

The chopper system[5] is composed of two choppers, CH1 and CH2, working in cascade. CH1 operates at the subharmonic frequency $f_1 = 50$ MHz and consists of a pair of deflecting electrodes. CH2 is a RF copper cavity oscillating at f = 500 MHz in the deflecting TE_{102} mode, with superimposed magnetic field on the beam axis.

Insertion of the additional chopper CH1 has permitted to operate with lower average current without diminishing the peak current, relaxing so the shielding requirements. In fact without CH1 the current would be composed of a succession of micropulses at the frequency of 500 MHz. With CH1 present the frequency is only 50 MHz; one starts from the cathode with a current of 200mA and arrives at the end of the capture section with the peak current of about 5A and average current of 2mA.

The prebuncher is a klystron type microwave cavity oscillating in TM_{010} mode at the same frequency of the superconducting cavities, followed by the corresponding drift space D. The main parameters of the prebuncher are given in Table III below.

TABLE III - *Prebuncher parameters*

Frequency	f = 500 MHz
Gap length	L = 6 cm
Voltage	$V_{PB} = (10\text{-}20)$ kV
Drift space (inversely prop. to V_{PB})	$D = (1.5\text{-} 0.75)$ m
Bunching parameter	$BP = (1.35\text{-}1.5)$
Phase compression	$\Delta\phi_{inp}/\Delta\phi_{out} > 50$

The bunching parameter is defined by

$$BP = \pi * D * V_{PB}/V_g * \lambda * \beta_g$$

where V_g is the gun voltage, λ the wavelength in the prebuncher, and β_g the relative velocity corresponding to V_g.

The capture section[6] is a normal conducting S-Band, standing wave, biperiodic $\pi/2$ graded β accelerator, working at the fifth harmonic of the basic frequency, $f_{cs} = 2500$ MHz. It prepares the injection of the electron bunches into the SC Linac , which has a constant $\beta = 1$ structure, with sufficiently large $\beta \approx 0.94$, small phase bunch length $\Delta\phi \approx 1°\text{-}2°$ (@500MHz), and small energy dispersion $\Delta W/W \approx$ 1-2%. An axial magnetic field produced by superimposed solenoids counterbalances the radial defocusing forces due to either the space charge or to the radial component of the accelerating field. The capture section is designed to work in principle in CW mode with the power dissipation of the order of 20 kW/m. The main parameters of the section are given in Table IV.

Table IV - *Capture section parameters*

Type of the structure: SW, biperiodic $\pi/2$, graded β

Frequency	$f_{cs} = 2500$ MHz
Average axial electric field	$E \approx 1$ MV/m
Input β	$\beta_{inp} = 0.54$
Output β	$\beta_{out} = 0.94$
Length	$L \approx 1.1$ m
Number of cells	N = 23
Power input (CW)	$P \approx 20$ kW

The transport line[2] between the capture section and the SC linac is achromatic to avoid dispersion in the horizontal phase plane and isochronous to avoid bunch lengthening. Since electrons are not fully relativistic at the injection energy, the spread in arrival time due to the energy spread has been taken into account and properly compensated with the trajectory length dependence on the dispersion function.

The injector chain results parallel to the SC linac; the transport line consists of one quadrupole triplet which matches the betatron functions corresponding to the capture section output to the following arc and an arc of 180°; the arc contains three dipoles (45°, 90°, and 45°), and two symmetric quadrupole doublets which adjust the dispersion function to the isochronism condition. Two quadrupoles are positioned on the axis of the SC Linac to match the beam to the linac itself. The layout of the transport line is depicted in Fig.4.

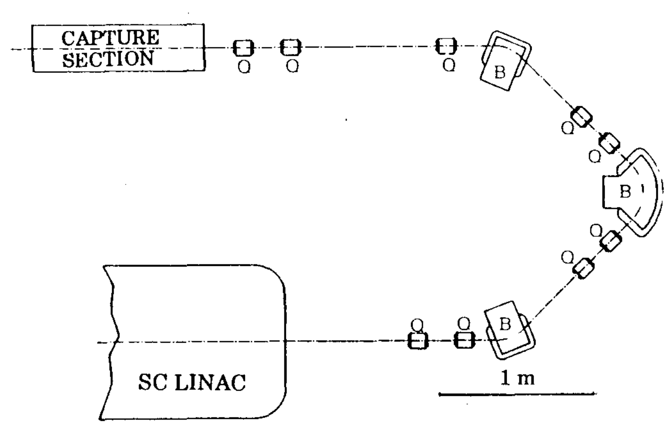

Fig.4 - Layout of the transport line capture section - SC Linac

Particle dynamics

Tracking of particles along the injector has been carried out with a modified version of the program PARMELA[7] simulating different currents, in order to determine the acceptance of the system in the different working conditions. The transverse emittance and dimensions of the beam in the gun focus have been taken as: $\varepsilon_{x,y} = 10^{-5}\,\pi$ m rad; $e_x = e_y = 0.5$mm.

The extremely high quality required for the beam asks for a careful adjustement of all the components of the line from the very beginning. In fact space charge problems influence the bunch transverse dimensions and the longitudinal phase space all along the transport. The maximum average current of 2mA in the Linac can be obtained using an extracted beam from the gun of 200mA and a chopping angle of CH2, $\Delta\phi_{ch}$, of 36°, or otherwise it is possible to decrease the initial current and to increase correspondingly the chopping angle in order to counteract space charge effects. In fact the longitudinal space charge prevents the squeezing of the bunch to very short lengths at the input of the capture section. If the bunch length after the chopper sistem is longer the space charge effects are weaker for the same total current; furthermore decreasing the current intensity along the distance between the gun and the choppers the emittance growth due to transverse space charge can be avoided. So I_{gun} = 120 mA and $\Delta\phi_{ch} = 60°$ have been chosen.

The increase of the beam emittance at low energies can be further reduced if the bunch length is not led to its possible minimum at the input of the capture section keeping the current density below critical values. The high peak current at higher energies can be obtained using the appropriate phase in the capture section, so that in the first cells of the section the beam is still under the bunching process. In this way a final peak current of the order of 5A can be obtained, while the emittance growth is kept under a factor ~2 for the interesting currents. The transverse beam envelopes along the 100keV injector line are plotted for the different currents in Fig.5 and the emittances in Fig.6.

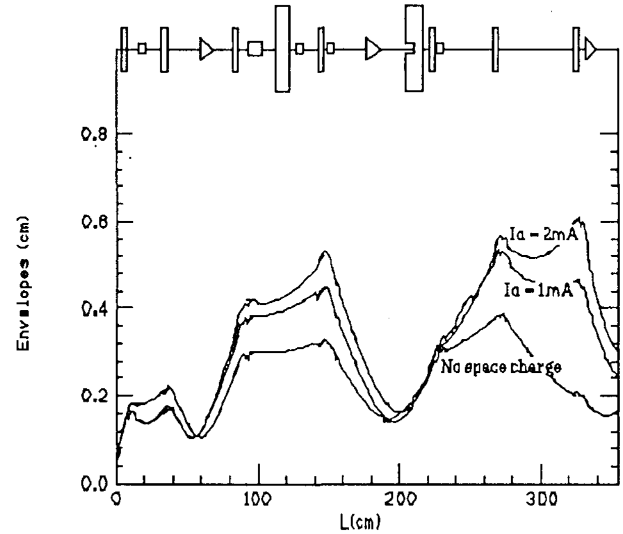

Fig.5 - Transverse beam envelopes along the 100keV injector line

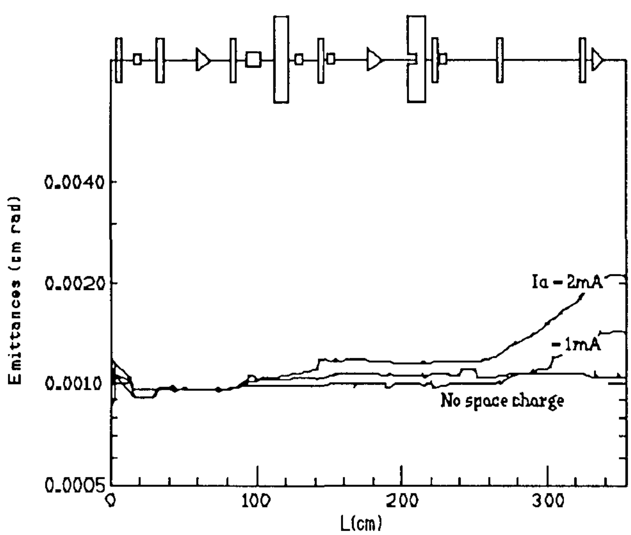

Fig.6 - Transverse emittance along the 100keV injector line.

In the transport line between the capture section and the SC Linac the condition of isochronism depends on the total length of the transport line and on the energy of the beam. If acceleration in the capture section is not on the crest of the rf-wave the output longitudinal phase plane is correlated in energy and phase, and the dispersion function must be changed accordingly acting on the arc quadrupole doublets. If space charge were not present the conditions of achromaticity and isochronism would be well defined, but the space charge introduce an emittance growth and moreover a rearrangement of the particle distribution which cannot be completely cancelled with the quadrupole doublets. Fortunately in the arc the beam has an energy at which the charge in the bunches (~40pC) is not any more strong enough as to disturb excessively the good performance of the line. Fig.7 shows the transverse envelopes between the capture section and the SC Linac. The beam characteristics in the interesting points of the injector are given in Table V for the average beam current of 2mA.

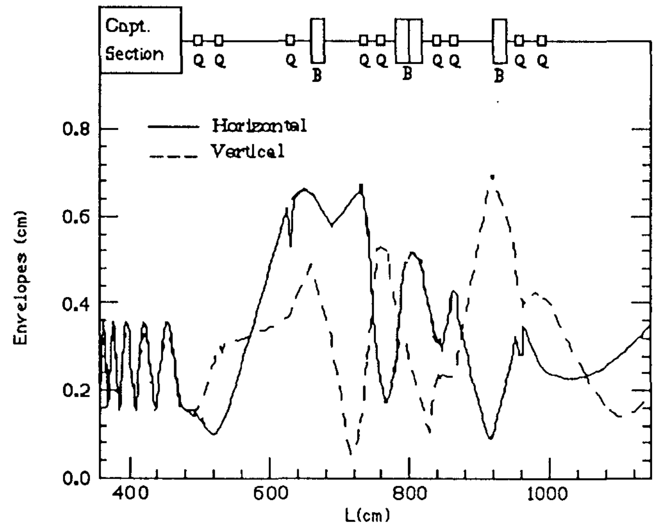

Fig.7 - Transverse envelopes along the transport line capture section - SC Linac.

TABLE V - *Beam parameters along the injector*

	GUN OUTPUT	C.SECTION INPUT	C.SECTION OUTPUT	SCLINAC INPUT
σ_x (mm)	0.5	2.9	3.0	3.5
σ_y (mm)	0.5	2.9	3.0	1.9
$\varepsilon_{x,y}$(π m rad)	1. 10^{-5}	2.10^{-5}	6.10^{-6}	7.10^{-6}
σ_l (mm)	CW	3.5	1.0	1.1
W (MeV)	0.1	0.1	1.1	1.1
ΔW/W	1.10^{-3}	1.10^{-1}	1.8 10^{-2}	1.8 10^{-2}

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