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THE INJECTOR OF THE SUPERCONDUCTING LINAC LISA

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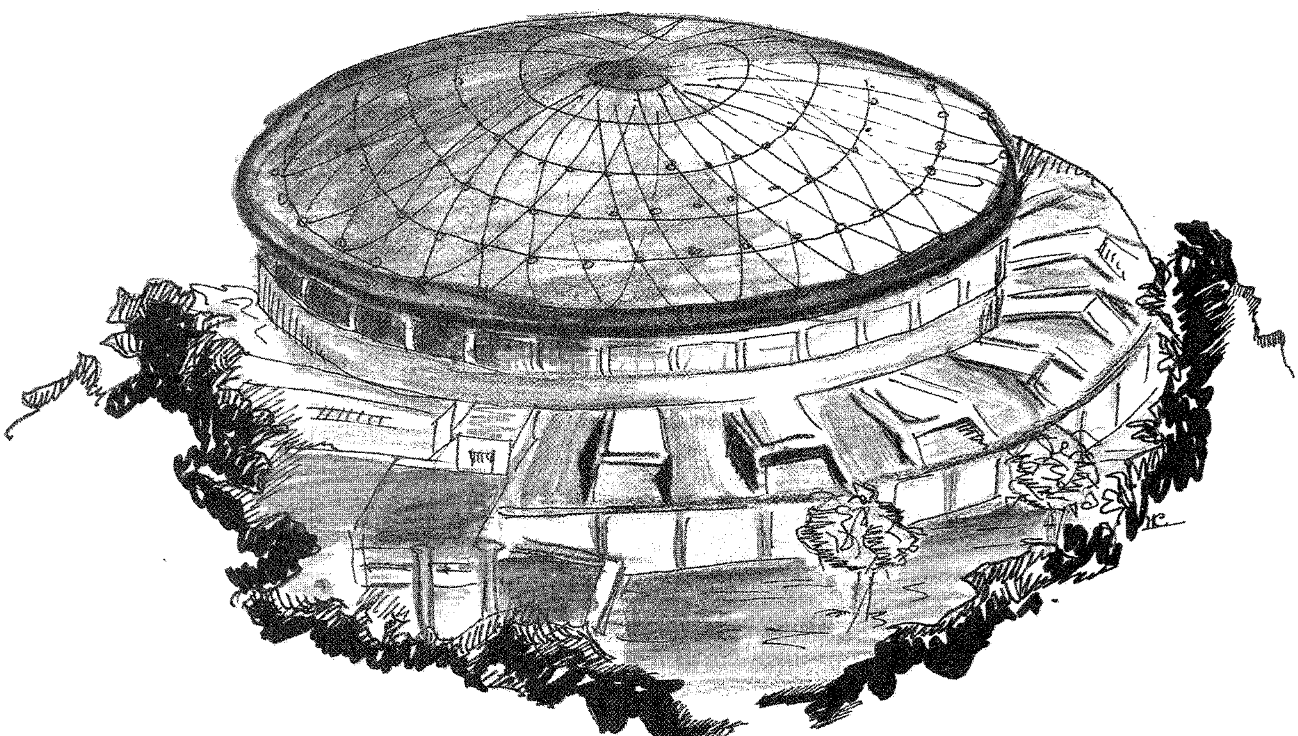

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THE INJECTOR OF THE SUPERCONDUCTING LINAC LISA

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ABSTRACT

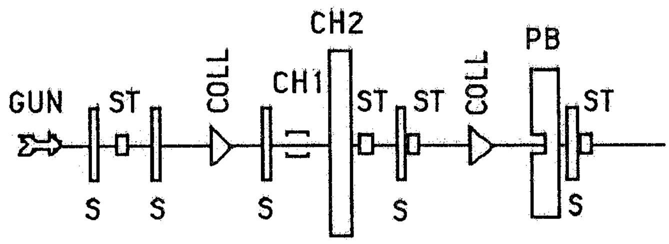
The injector of the LNF project LISA (LInear Superconducting Accelerator) is a room temperature system, consisting of a 100 keV gun, a transport line with chopper and prebuncher systems, a capture section (a graded-β 2.5 GHz structure) which accelerates the beam to 1.1 MeV, and an isochronous and achromatic transport line which injects the beam into the SC-Linac after a π-bending. The status of the project is presented.

INTRODUCTION

The superconducting (SC) electron linac LISA[1], in construction at Frascati INFN Laboratories, is a 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.

In the first step of the project the beam parameters are mainly defined by the FEL application, which will require a 25 MeV beam and 5 A peak current. The bunch compression required to obtain this peak current from the 2 mA average current is performed in the injection system.

INJECTOR DESCRIPTION



S - Solenoidal lenses; ST - Steerings; COLL - Collimator; CH1 - Chopper 1 (50MHz); CH2 - Chopper 2 (500MHz); PB - Prebuncher (500MHz)

FIG.1 - Sketch of the injector line at 100 keV.

The injector[2,3] consists of the following major parts:

- 100 keV thermionic gun;
- Double chopping system;
- 500 MHz prebuncher.;
- 1 MeV, 2.5 GHz capture section;
- Spectrometer channel;
- 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, fluorescent screens.

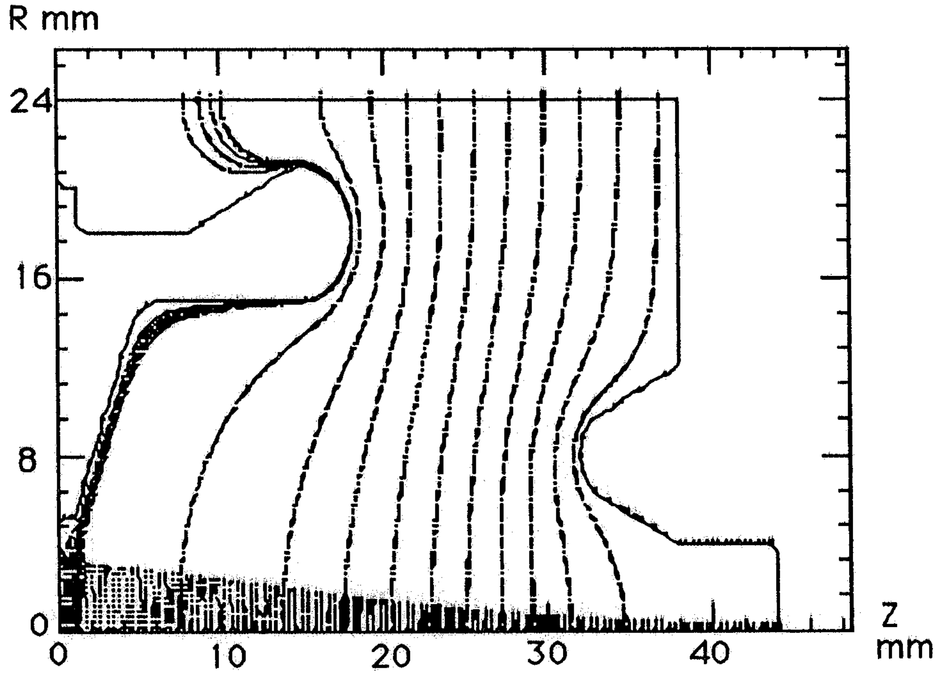
All RF elements in the injector have been constructed and successfully tested[4].

The block diagram of the 100 keV part of the injector is shown in Fig. 1.

THE GUN

As an injector of a SC Linac, the low energy line has been designed for working in a cw mode, but to keep the mean beam power within the limit posed by the Radiation Security Service (1 kW maximum), we decided to work in a pulsed mode. Thus the gun is a Pierce-geometry thermionic triode which nominally delivers 1 ms macropulses at a repetition rate of 10Hz, although macropulse length and frequency can be freely changed keeping the duty cycle constant.

The gun has been designed in our laboratory[5] using the Hermannsfeldt code SLAC-GUN and constructed by the Italian firm PROEL. The design parameters are: current $I \geq 200$ mA, normalized emittance $\varepsilon_n < 10^{-5}$ m rad, energy W = 100 keV, energy dispersion $\Delta W/W = 10^{-3}$.



A sketch of the LISA gun together with electron rays and equipotential lines. Main gun parameters: V_a = 100 kV, V_g = 350 V, I = 0.2 A,calculated emittance (inv.) $\varepsilon = 1* 10^{-6}$ mrad at the distance of 40mm from the cathode. cathode diameter (height) D_k=6.4mm, cathode (spherical) radius R_k = 40mm.

The gun is presently under test, as we want to measure its performances before the final installation on the LISA injector.

A dedicated channel has been constructed, composed of a solenoid lens, magnetic steering coils, a toroidal current monitor and a ceramic fluorescent screen seen by a high resolution CCD camera, as shown in Fig. 2.

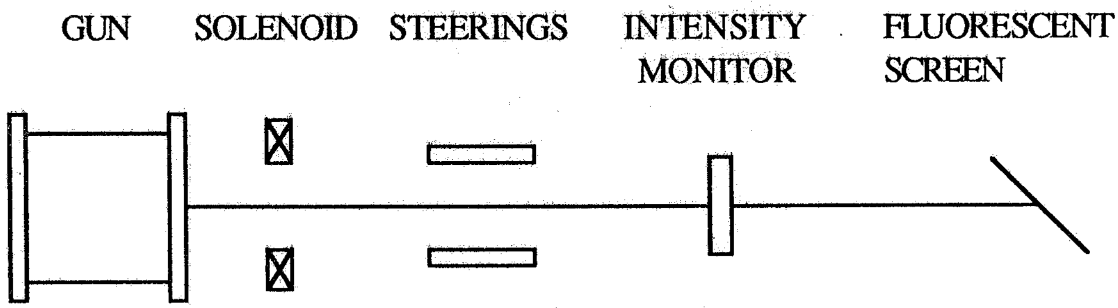


FIG. 2 - Test channel scheme.

The current vs grid voltage characteristics of the gun have been measured as function of the anode potential. A sample of the experimental data is shown in Fig. 3.

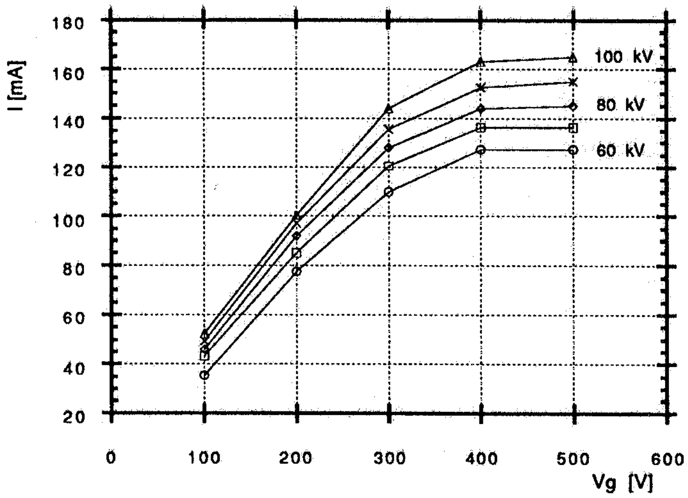


FIG. 3 - Gun current vs grid voltage as a function of the accelerating potential.

The maximum current value of 160 mA is lower than the 200 mA project value because the filament power supply resulted insufficient to heat the cathode up to the right temperature of 1020 °C.

The current vs anode voltage at the fixed grid value of 500 V, shown in Fig. 4, has been fitted with the formula

$$I = G\left(500\ \frac{V}{\mu}\right)^{1.5}$$

giving $\mu = 350$ and $G = 6.\ 10^{-6}$, in good agreement with the design values.

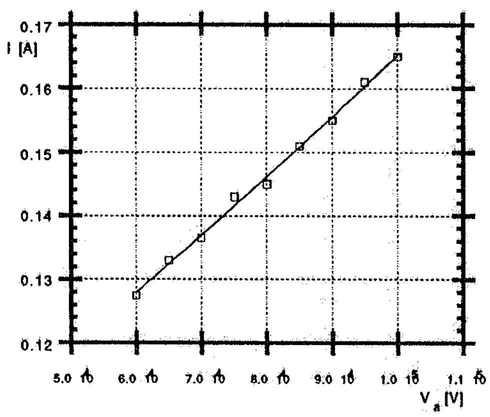


FIG. 4 - Gun current vs anode voltage at 500 V grid potential.

The beam transverse emittance can be evaluated measuring the spot dimension on the screen as function of the solenoid strength. The equations derived by the transport matrices of the beam envelope for at least three different solenoid current values can be inverted giving the optical functions and the emittance in each transverse plane if the space charge effects can be neglected.

In our preliminary measurements the beam dynamics suffered from two different drawbacks: the low current caused an early focussing in the gun, and consequently a large beam in the transport channel, sensitive to nonlinearities in solenoid and steering coil fields. The diffuse field of two small ion pumps positioned very near the gun output, that were required to lower the vacuum in the gun itself, clearly influenced in a nonlinear way the beam trajectory.

In these conditions the emittance measurements must be evaluated with great caution and considered only as very preliminary results.

Applying the described technique, with an accelerating field of 90 kV and a transported current of 100 mA, we obtain a normalized rms emittance of .9 10^{-5} m rad in the vertical plane and of 1.2 10^{-5} m rad in the horizontal one.

CHOPPING AND PREBUNCHING SYSTEMS

A double chopping system has been chosen in order to operate with lower average current without diminishing the peak current, relaxing so the shielding requirements. The first chopper CH1 operates at the subharmonic frequency $f_1 = 50$ MHz and consists of a pair of deflecting electrodes. It selects 10% of the total current so that the beam afterwards is composed of a succession of micropulses at the frequency of 50 MHz. The second chopper CH2 is a RF rectangular copper cavity oscillating at f = 500 MHz in the deflecting TE_{102} mode. It selects a phase spread $\Delta\Phi_{ch}$ ranging between 36° and 60° over the wavelength according to the accelerated percentage of the total current. Both choppers act deflecting vertically the beam; a pair of steerings corrects this deflection so that only the selected ~1% of the current passes through a collimator whose walls absorb the ~99% of the beam power.

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 (D=1.44m). The gap length is one tenth of the wavelength; the voltage is of the order of 10 kV.

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 with sufficiently large $\beta \approx 0.94$, small phase bunch length $\Delta\phi \sim 1°\text{-}2°$ (@500MHz), and small energy dispersion $\Delta W/W$ ∩ 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 transport line 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 bending is obtained with three dipoles (45°, 90°, 45°) and two symmetric quadrupole doublets which adjust the dispersion function to the isochronism condition at the midpoint of the central dipole. Two triplets in front and after the arc take care of the matching between the linacs and the arc itself.

THE SPECTROMETER

In the matching line between the capture section and the arc, a pulsed magnet deviates the beam to the spectrometer; the pulse timing is such that a single macropulse can be extracted, or the whole beam derived to the spectrometer arm. The spectrometer consists of two 60° sector bending magnets and two quadrupoles. The beam dimensions are analyzed on a fluorescent screen.

A bunch length measurement[7] is foreseen exploiting the spectrometer line: a vertically deflecting 2.5 GHz cavity, positioned before the pulsed magnet, gives an angular kick to the electrons depending on their position along the bunch, causing a vertical widening of the beam spot on the screen proportional to the bunch length. To increase the sensitivity of the measurement a different set of quadrupole gradients will be used in this configuration which will give the optimum vertical phase advance between the cavity and the screen, so that while the energy measurement will be on-line this last diagnostic tool will be used off-line.

PARTICLE DYNAMICS

Tracking of particles along the injector has been carried out with a modified version of the program PARMELA[8] simulating different currents, in order to determine the acceptance of the system in different working conditions.

The extremely high beam quality required asks for a careful adjustment 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 nominal average current of 2 mA in the Linac can be obtained using an extracted beam from the gun of 200mA and a chopping angle of CH2, $\Delta\phi_{ch} = 36°$, or otherwise it is possible to decrease the initial current and to increase correspondingly $\Delta\phi_{ch}$. 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 system is longer the space charge effects are weaker for the same bunch charge; furthermore decreasing the beam current intensity 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. The longitudinal magnetic field produced by the solenoid around the section has been measured for different values of the current in the windings; the analytical expression obtained with a polynomial fit of the measured values has been introduced in the program PARMELA and used for particle tracking[6].

TOLERANCES

Tolerances of the line up to the capture section have been checked with PARMELA simulations: 10% errors in the field intensities of magnetic lenses do not change appreciably the line transmission, while 1% precision in the field of the capture section solenoid is needed. The prebuncher voltage must be fixed up to 0.5%. Element alignment precision of 0.5 mm are needed.

The quadrupole gradients along the line must be optimized depending on the optical functions at the capture section exit, which will be measured using the spectrometer line. Errors in the measurements of even 50% in the initial optical functions have been simulated and tracked with PARMELA resulting in an emittance degradation of the same order as in the case with no errors, a little more significant in the horizontal plane; the degradation of course is higher for lower initial emittances. The beam envelopes are perturbed but not in a significant way; the final betatron functions can still be matched to the SC Linac transport. The final bunch length is almost independent on the initial transverse conditions: only differences of some tenths of millimetres have been observed.

Errors of the order of 1% in the initial energy measurements have been also simulated and they do not affect much the final bunch length nor the transverse behaviour.

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