THE LINEAR SUPERCONDUCTING ACCELERATOR PROJECT LISA

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Abstract

LISA will be a 25 to 49 MeV superconducting recirculated linac of low emittance and energy spread. It is intended to be a test-bench machine for future colliders and to have an immediate application to the implementation of a FEL in the infrared. The machine is described and the status of the project is presented.

Introduction

The superconducting (SC) electron linac LISA, in construction at the Frascati INFN Laboratories, is a 25 to 49 MeV test-bench machine aimed at studying the problems of larger linacs for colliders or of 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 beam generation, recirculation and beam break-up that are fundamental in such machines.

The layout of the machine is shown in Fig.1 and its main characteristics are given in Table I. The electron beam is generated in a thermoionic gun, chopped, prebunched and then accelerated to 1 MeV in a room temperature capture section. It is then bent through 180° and injected in the SC part of the linac.This solution minimizes the machine hall size and is well suited to the design of an isochronous transport (see further on).

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.

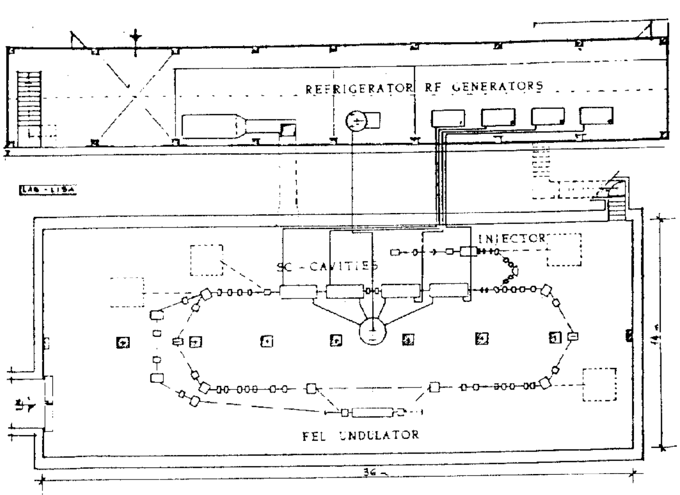

FIG. 1- The layout of the machine

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The parameters of LISA are mainly defined by the FEL application. The beam consists of macropulses with a duration of the order of milliseconds and variable repetition frequency . The duty cycle is kept to less than 10% in order to meet radiation safety requirements. The fine structure of the macropulses is such that only one out of ten buckets of the 500 MHz wave is filled. This is done using a double chopper system, the first one being driven at the SC linac frequency (500 MHz) and the second at the tenth sub-harmonic (50 MHz). Average values quoted in Table I are over the macropulse duration, while peak values correspond to the single bucket.

TABLE I - Beam characteristics

Nominal energy	MeV	25
Energy wih recirculation	MeV	49
Peak current	A	5
Average current	mA	2
Duty cycle		≤ 10%
Invariant emittance	m	$\pi x10^{-5}$
Energy dispersion		$2x10^{-3}$

Description of the machine

Injector [1]

The injector consists of the following major parts:
- A 100 KeV gun.
- Two choppers : a 50 MHz one and and 500 MHZ one.
- A 500 MHZ prebuncher
- A 1 MeV, 2.5 GHz capture section.
- An achromatic and isochronous transport line.

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, so as to insure that the beam in the SC cavities is fully relativistic . The block diagram of the injector is shown in Fig. 2.

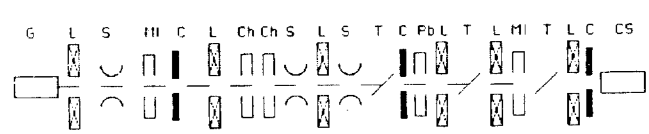

FIG. 2 - The injector

G = gun; L = lens; S = steering; MI =intensity monitor; Ch =chopper; T = target; C = collimator; Pb = prebuncher; CS = capture section.

The gun is a Pierce-geometry, thermoionic 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.

After passing through the two choppers and the prebuncher the 15° phase (@ 2.5 GHz) electron bunches have an energy of 100 KeV and a 10% energy spread ; they are then injected into the capture section. The choppers are two in cascade: the first operates at 50 MHz and consists of a pair of deflecting plates, the second operates at 500 MHz and consists of a cavity oscillating in the TE_{102} deflecting mode.

TABLE II - Gun parameters

Type	Pierce, triode
Current	$I > 0.2$ A
Energy	$W = 100$kV
Energy dispersion	$DW/W = 10^{-3}$
Emittance (invariant m*Rad)	$e < 5*p*10^{-6}$
Cathode radius	$R_k = 40$ mm
Grid radius	$R_g = 39$ mm
Radius of focusing electrode	$R_{fe} = 15$ mm
Curvature of focusing electrode	$r_{fe} = 3$mm
Length of focusing electrode	$L_{fe} = 18$ mm
Anode radius	$R_a = 2$ mm
Anode hole diameter	$F_a = 8$ mm

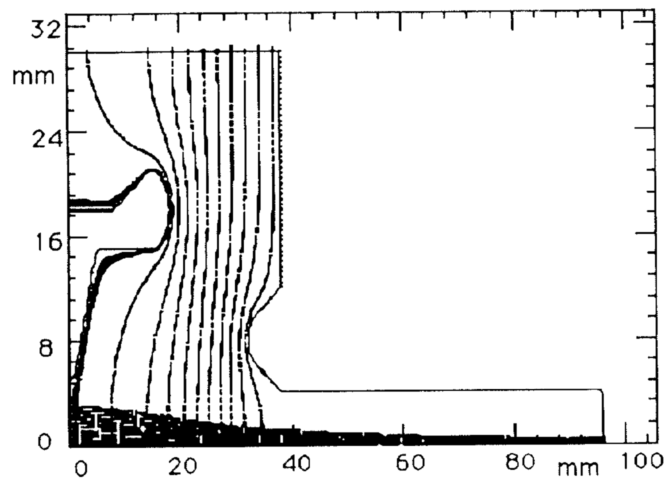

FIG. 3 - The geometry of the gun, electron trajectory and equipotential lines

$U_a = 100$ kV, $U_{grid} = 445$V; Beam current I = 0.7A; Beam emittance $\varepsilon = 2.3*\pi*10^{-6}$ m rad.
The waist of the beam with R = 0.3 mm is at about 90 mm from the cathode.

The harmonic capture section is an S-band (2.5 GHz) graded β (0.55 to 0.94) standing wave structure; at its output the micro-bunches have an energy of 1 MeV, a 15° phase spread and a 2% energy spread. The structure is 1.1 m long and the peak power dissipation is about 20 KW .

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.

TABLE III - Beam parameters

	Input Gun	Output Capture Section	Capture Section
E (MeV)	0.1	0.1	1.0
$\Delta E/E$	1.e-4	10.e-2	2.e-2
$\Delta\Phi°$(@500 MHz)	dc	± 1.1	±1.0
σ_l(mm)	dc	1.1	1.0
σ_x (mm)	0.3	4.0	3.0
σ_y (mm)	0.3	4.0	3.0
$\varepsilon_{x,y}$ (m rad)	1.0e-5	1.3e-5	5.e-6
I_{avg}(mA)	120.	2.0	2.0
I_{peak}(A)	0.12	5.2	5.3

The line elements are a quadrupole triplet that matches the betatron functions at the exit of the capture section to those of the following 180° arc, three dipoles and two symmetric quadrupole doublets used to adjust the dispersion function to fulfill the isochronism condition. The optical functions are shown in Fig. 4.

The beam parameters are given in Table III.

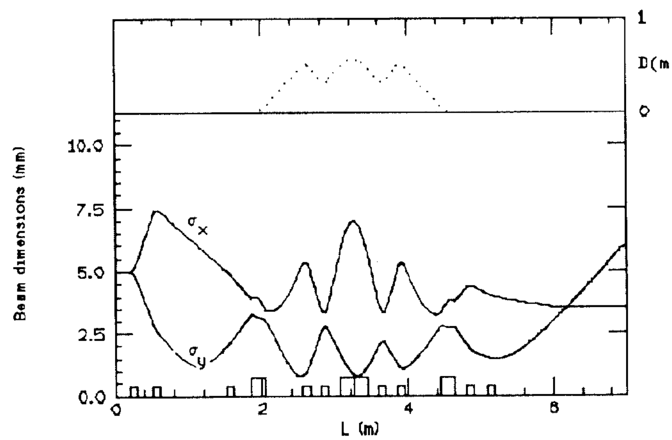

FIG.4 -Transverse beam dimensions in the transport injector-SC linac

SC Linac structure

The main accelerating structure consists of four superconducting cavities made of bulk Niobium. Each cavity is subdivided into four cells and has its own separate cryostat. The main characteristics of the cavities are listed in Table IV. The cavities are supplied by Interatom together with the main RF couplers , the parasitic modes suppressors and a mechanical slow-tuning system. They will be fully tested at the factory.

The RF drive will consist of four independent chains separated from the cavities by circulators. Fast phasing of the chains is foreseen at the low power level inputs.

TABLE IV- Main cavity parameters

Frequency	MHz	500
r/Q_0	Ω/m	380
Number of cells		4
Useful length	m	1.2
Accelerating field	MV/m	5
Number of cavities		4
Voltage /cavity	MV	6
Q_0 @ 4.2 °K		2×10^9
Q_{ext}		6.5×10^6
Average current	mA	2
Power/cavity	KW	12
Bandwidth	Hz	77

Refrigeration system

The refrigeration system consists of a closed-cycle helium refrigerator and of the distribution valve box and transfer lines connecting the refrigerator to the four cryostats. It is designed to handle the following heat loads at 4.2 K°:
a) cryostat static losses ≈ 20 W
b) transfer line and distribution box static losses ≈ 15 W
c) RF heat production within the cavities ≈ 160 W.

In order to shorten the cool-down time and to allow for some extra capacity as a safety factor a 300 W @ 4.5 °K commercial refrigerator, Model TCF 50 by Sulzer, has been purchased. The cryogenic plant also provides the fluid for intermediate temperature cooling at 80°K, to both the cryostat radiation shields and the distribution system. An automatic controller provides remote control and manages the various plant operation modes (cool-down, warm-up, recovery from failure, etc.). It also automatically performs other special operations such as those required in case of emergency.

The control system

The system has been designed so that machine diagnostics, control functions and FEL data acquisition and controls are integrated in a single complex. Distributed intelligence and a highly interactive graphic interface to the human operator are also provided.

The system is built using standard VME electronics and Macintosh II personal computers; the choice was based on good performance/price ratio and on the requirement to fully exploit the advantages of commercial industrial systems, namely low cost, availability and strong software support.

As a software environment the choice fell on the MacSYS system, developed at CERN. From the user's point of view MacSYS offers several advantages such as the possibility of using the MacVEE hardware for simple, memory mapped, access to the VME and the RFT Real Time Fortran compiler. Furthermore a smaller scale laboratory system is easily implemented, thus permitting subsystems to be indipendently developed during the early stages of machine commissioning.

More detailed information on the control system can be found in reference [2].

The recirculation lattice [3]

There are two separate recirculation channels corresponding to beam energy doubling or recovery after interaction with the FEL.

For energy doubling the lattice must be achromatic and isochronous and minimize beam break-up effects. Its layout is shown in Fig. 1., and the corresponding lattice functions in Fig. 5.

The transport channel to the undulator and the following energy recovery arc are still under design. The transport arc requires tuning of the beam cross section to optimize the FEL interaction, while the recovery arc must take into account the energy spread introduced by the FEL.

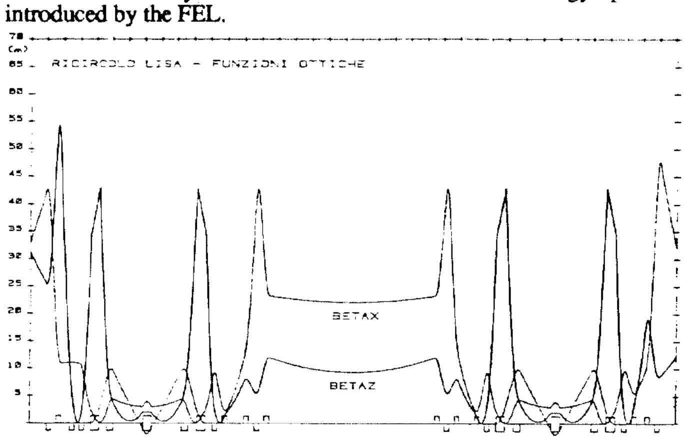

FIG. 5 - Optical functions

The FEL [4]

The beam quality afforded by the SC linac is well suited for use in a high efficiency FEL covering the infrared wavelength region. The wavelength of the radiation obtained in the first harmonic from an undulator with a 5 cm period and a field parameter $0.5 \leq K \leq 1.5$, is shown in Fig. 6. The main FEL parameters are summarized in Table V.

FELs in this wavelength region find applications in biology, chemistry and material science. Using the third harmonic the FEL wavelength can be extended into the visible. Longer wavelengths can instead be obtained by decreasing the electron beam energy.

In a first stage it is planned to use an electro-magnetic undulator. A shorter period hybrid ondulator is foreseen at a second stage of the experiment.

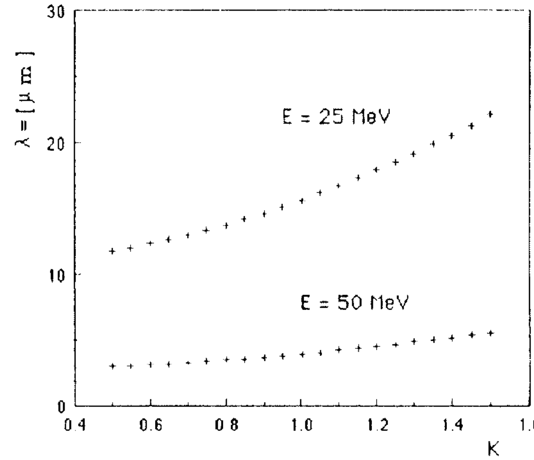

FIG. 6 - FEL: first harmonic wavelength vs. K

TABLE V - FEL Main parameters

Beam energy	MeV	25
Number of undulator periods		50
Undulator wavelength	cm	5
Radiation wavelength	μm	15
Microbunch length	mm	1.3
Microbunch rep. frequency	MHz	50
Optical cavity:		
output coupling		2%
passive losses		5%
power in cavity	KW	6

Buildings, facilities and time schedule

The accelerator hall is placed under ground for radiation safety reasons and is equipped with a closed circuit ventilation system. All power supplies are installed outside the accelerator hall. A cross-section of the buildings is shown in Fig. 7. Construction will start next summer.

The orders for the main parts of the accelerator have been placed and it is foreseen to start testing parts in the spring of 1989 and to start installation in the autumn.

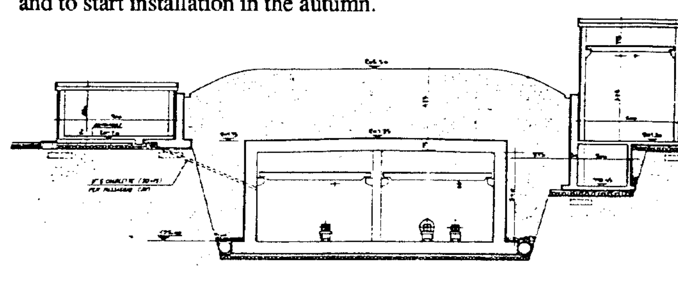

FIG. 7 - Cross-section of the buildings

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