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FEL project in Frascati INFN Laboratories with the linear superconducting accelerator LISA

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ABSTRACT

A program to construct a test superconducting electron linear accelerator (LISA) is in progress at Frascati INFN National Laboratories [1]. The electron beam will be used to realize a FEL in the infrared region 11 - 18 μm in collaboration with a group of ENEA-CRE Frascati. The characteristics of the electron beam, the undulator and the expected performances of the FEL are described. Some future developments - energy doubling, energy recovery, third harmonic operation - are briefly presented. Such improvements aim to realize a high power, high efficiency FEL exploiting the features of a SC linac.

THE ACCELERATOR AND TRANSPORT LINE

The main parameters of the linac are summarized in Table 1. They have been defined to match the requirements of an infrared FEL, that will be illustrated further on. The SC cavity frequency is 500 MHz; an harmonic buncher has been inserted to achieve the high peak current required for FEL operation. The microbunch repetition rate is 50 MHz.

Table 1 - Main parameters of LISA

Energy (MeV)	$25 \div 49$
Bunch length (mm)	2.5
Bunch charge (pC)	40
Peak current (A)	5
Duty cycle	≤ 10%
Average macropulse current (mA)	2
Invariant emittance (π m rad)	10^{-5}
Energy spread (@25 MeV)	$2x10^{-3}$

The expected performance is adequate for FEL operation. The peak current will be further improved in a successive phase by replacing the thermionic gun and prebuncher by an RF injector that is under development.

The layout of the machine in the experimental hall is shown in Fig. 1.

The electron beam is generated in a thermionic gun, chopped at 50 MHz, keeping 10 % of the initial gun current, prebunched and accelerated to 1.1 MeV in a room temperature preaccelerator [2]. It is then injected in the SC linac structure made of four cavities, whose characteristics are shown in Table 2. The accelerating frequency was chosen selecting among existing low frequency cavity designs to get a trade off between wake fields and power consumption, which decrease with frequency, and cost which of course increases when large cavities are used [3]. Furthermore the choice of rather low frequency cavities allows operation with longer electron pulses thus counteracting the gain reduction due to slippage.

The SC cavities are designed to operate at 4.2 K and the expected thermal load, including cryostat losses, is about 200 W.

Table 2- Parameters of the RF cavities

Frequency (MHz)	499.8
r/Q_0 (Ω/m)	380
Useful length (m)	1.2
Overall length (m)	2.5
Number of cells per cavities	4
Accelerating field (MV/m)	5
Q_0 (@ 4.2 K)	$2x10^9$
Q_{ext}	$6.5x10^6$

After leaving the SC linac, the beam can be steered either through the FEL undulator or back to the linac entrance to be further accelerated to 49 MeV. It is also foreseen to recover part of the beam energy after it has passed through the FEL by recirculating it through the linac with such a phase as to be decelerated.

The beam structure is a succession of millisecond macropulses, the duty cycle of the machine being restricted to ≤ 10% for radiation safety reasons. Since the duty cycle is limited by the total beam power dispersed by losses or dissipated in the beam dump, it will be possible to extend the duty cycle when effective energy recovery will be operative.

The transport line from the SC linac to the undulator is shown in Fig. 1. A wide angle achromatic chicane, composed by two 30° magnet deflecting in opposite directions, brings the beam to the undulator, without interfering with the installation of the mirror holders of the 6 m long optical cavity. A quadrupole doublet allows the matching of the electron beam profile to the optical mode inside the cavity.

The 180° bending arc from the linac to the undulator is normally isochronous, but the dispersion integral can be tuned and the line can be made non-isochronous, should the need arise for a pulse compression system.

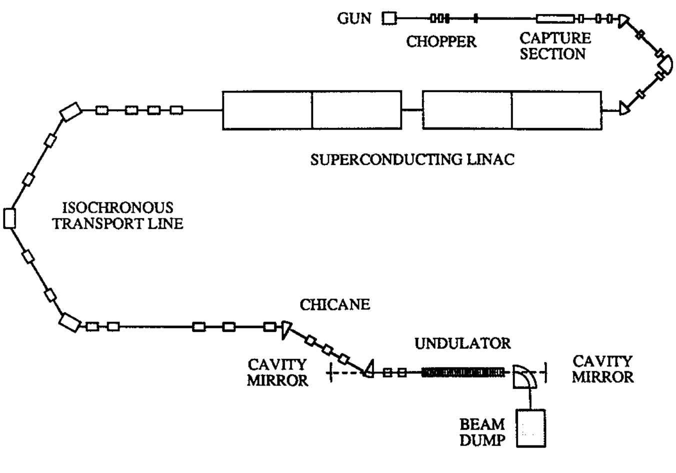

Fig. 1 - Schematic layout of LISA

THE FEL

The beam quality of the SC linac is well suited for operating a high efficiency FEL covering the infrared wavelength region. The first harmonic wavelength obtained from a 4.4 cm period undulator, with a undulator parameter r.m.s. ranging from 0.5 to 1.0 at the design beam energy of 25 MeV, spans the wavelength region from 11 to 18 µm. Shorter wavelengths, extending into the visible, can be covered by doubling the beam energy or working on the third harmonic emission line. Meanwhile the region below 11 µm will be more easily accessible if the accelerating gradient will be improved over the nominal value, conservatively set at 5 MeV/m garanteed by the purchaser, while current achievements approach 7 MeV/m. Of course longer wavelengths are obtainable at lower beam energy.

A NdFeB permanent magnet hybrid undulator with ≈ 4.4 cm period to be built by Ansaldo Ricerche in Genoa in collaboration with the ENEA group will be used [4]. A prototype 8 period long has been realized and is under test. The final choice of the undulator parameters - period and number of poles - will be defined after the completion of the test. The lower limit to the undulator period is given by the requirement of a gap of 2 cm. In the following an undulator of 50 poles of 4.4 cm period is assumed.

The nominal small signal gain is 17.3 % at λ=15 µm; according to parametrization of gain given in [5] to take into account emittance, energy spread and slippage effect the gain on the fundamental harmonic is reduced to 10.0 %. With the same parametrization the gain for third harmonic operation reduces to ≈ 5 % which is sufficient if low losses dielectric mirrors are used for the cavity.

The main parameters of the FEL in its present design are summarized in Table 3.

Table 3 - FEL: Main Parameters

Beam energy (MeV)	25
Number of undulator periods	50
Undulator wavelength (cm)	4.4
Undulator parameter K_{rms}	0.5 ÷ 1.0
Radiation wavelength (µm) @ 25 MeV	11 ÷ 18
Optical cavity length (m)	6
Cavity passive losses (%)	2
Cavity output coupling (%)	3

The gain on fundamental and third harmonic is shown in Fig. 2 for a 25 MeV beam and K_{rms} between 0.5 and 1.0.

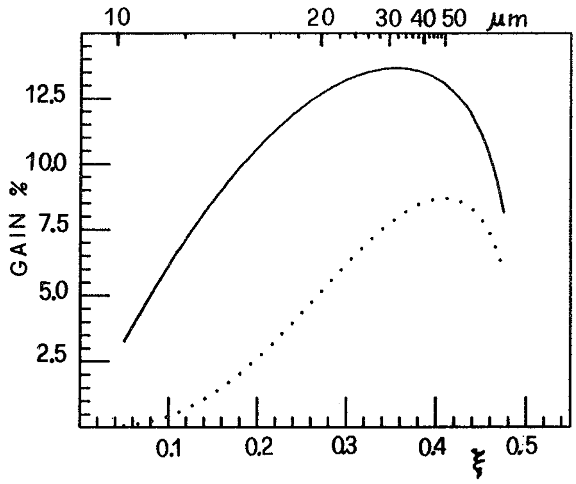

Fig. 2 - Gain vs ξ in fundamental and 3rd harmonic.

The normalized parameter $\xi = K^2/(2(1+K^2))$ is used on abscissa axis and the corresponding first harmonic wavelengths are reported on the top axis; the curves refer to the gain reduced by inhomogeneous broadening and slippage.

The saturation efficiency is ≈ 1% which gives average power of 500 W during macropulses, and peak power of 1.25 MW . The energy recovery will provide a large increase of efficiency in electron to laser energy conversion which will allow longer laser macropulses at constant average power, or higher average power by increasing the electron microbunch repetition rate. The requirement of low emittance prevents a peak power increase with the present injector scheme.

More details concerning the FEL efficiency with energy recovery are given in [6]; the calculation were carried out assuming a 5cm period undulator: altough general considerations still hold, numerical results must be reconsidered. The design of the optical cavity is in progress.

TECHNICAL FACILITIES AND TIME SCHEDULE

The cross section of the building to house LISA and its ancillary equipment is shown in Fig.3. Preliminary experimental activity on the FEL will be carried out in the accelerator hall. Restrictions to access - delay time after beam shut-off, limited working time, access control burocracy - suggest to plan an outside laboratory where the deflected FEL beam is more accessible.

The accelerator hall is underground to save on the concrete shielding. Building activities started in March 89 and are scheduled to be completed by Autumn 89. All the main accelerator components will be delivered by the end of the same year. Commissioning of the machine is foreseen to be performed in the first half of 1990. The undulator is expected to be built within one year from the order; its delivery should closely follow the end of commissioning of the accelerator.

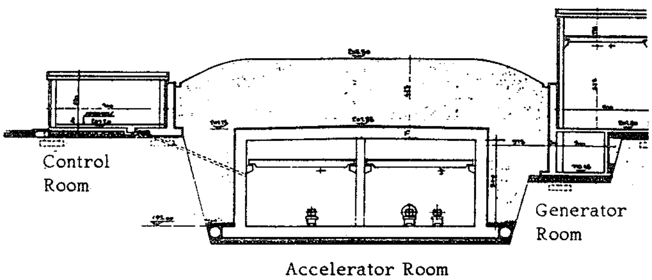

Fig. 3 - Cross section of the buildings for the LISA plants.

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