SURF: an IR FEL with the SC linac LISA

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Abstract

The status of the IR FEL project SURF is reported. The experiment will exploit the 25 MeV beam of the SC linac LISA to produce a high peak power, high efficiency FEL operating at 16 μm.

The expected performances and the experimental program are presented.

1. INTRODUCTION

Superconducting (SC) linacs are probably the best accelerators for Free Electron Laser (FEL) owing to high beam quality and long macropulse. Moreover, the smallness of RF power losses in the SC cavities allows high efficiency configurations exploiting multiple passage in the accelerator for energy doubling and/or energy recovery.

The stringent requirements for FEL operation (high peak current, low emittance and low energy spread, close preservation of beam quality along the transport line) are of concern also for linear collider operation. Therefore an FEL experiment on a SC linac provides a valuable know-how in a field of growing interest for high energy physics research.

The LISA project was approved by INFN in 1987 to provide a test bench with SC accelerators [1]. The design parameters were optimized for FEL operation. The experiment SURF was funded in 1989, in the framework of a collaboration with the ENEA-CRE Frascati and the participation of INFN section of Naples [2].

The most relevant parameters of the accelerator and FEL experiment are listed in table 1.

Table 1 - Parameter list of the LISA accelerator and FEL.

Energy	25	MeV
Bunch length	2.5	mm
Peak current	5	A
Duty cycle	<2	%
Average macropulse current	2	mA
Invariant emittance	10^{-5}	πm rad
Energy spread (@25 MeV)	$2\ 10^{-3}$	
Micropulse frequency	50	MHz
Macropulse frequency	10	Hz
Undulator periods N	50	
Undulator wavelength λ_u	4.4	cm
Undulator r.m.s parameter K	0.5÷1.0	
Radiation wavelength @ 25 MeV	11÷18	μm
Linewidth @ 15 μm	0.5	%
Small signal gain @ 15 μm	9.7	%
Small signal gain @ 5 μm (3[rd] harm.)	2.5	%

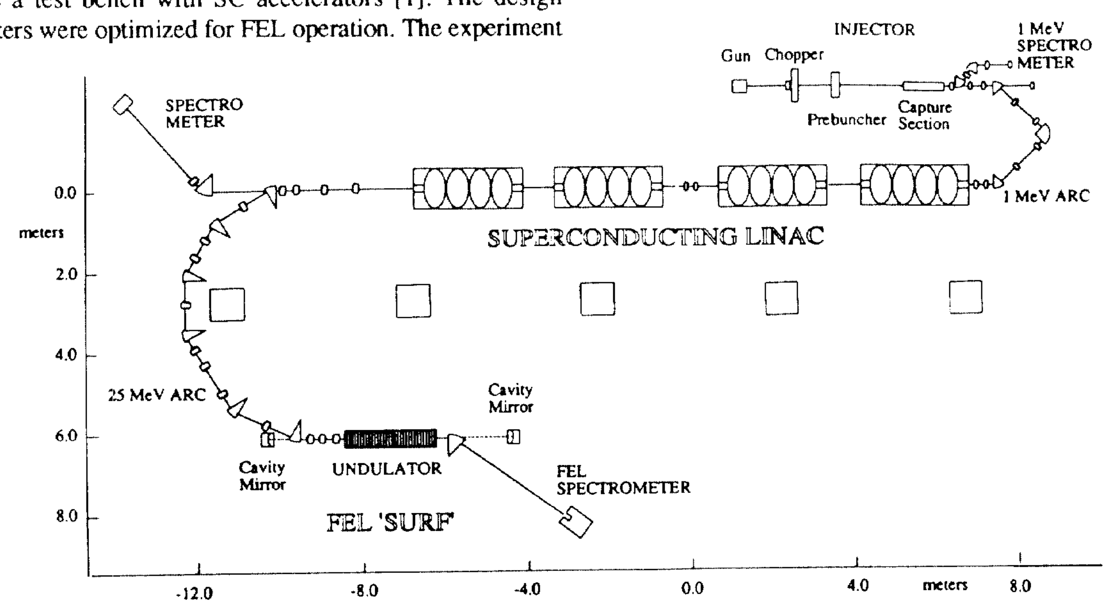

Figure 1. Layout of the complex LISA-SURF

2. THE ACCELERATOR

The schematic layout of the LISA-SURF complex is shown in fig. 1. The accelerator has been assembled up to the exit of the SC cavities. The commissioning of the injector, composed of a 100 kV thermionic gun, a double chopper at 50 and 500 MHz, a 500 MHz prebuncher and a 1.1 MeV β-graded 2500 MHzr capture section, is under way [3]. The first in-site cool-down of the SC cavities has been successfully accomplished in March. The installation of the transport line to the undulator will start after completing the commissioning of the injector.

2.1 The SC linac

The 500 MHz SC linac is composed of four independent cryostats housing a 4-cell cavity. The design energy at the linac exit, assuming an average accelerating field of 5 MeV/m, is 25 MeV . The factory-measured Q_0 of the cavities is lower than the design specifications, altough no quenching has been observed up to ~ 6 MeV/m [4]. CW operation will be prevented by the capability of the refrigerator, but this limitation does not affect pulsed FEL operation. Some improvements are also expected after RF conditioning.

2.2 The beam diagnostics

The 25 MeV beam at the linac exit can be switched between the spectrometer line or injected in the arc toward the undulator. In the straight section before the bifurcation the optical functions and the beam position can be measured and shaped to optimize both the spectrometer performances and the transport efficiency. The visual diagnostic is now accomplished with fluorescent targets (made of ceramic or anodized aluminium) viewed by CCD camera. A frame grabber system allows to store the beam picture for off-line analysis. The development of other diagnostic devices, based on the emission of optical transition radiation and synchrotron radiation, is under way. These have no persistence lag allowing also the measurement of some beam parameters (size, position, emittance) on faster time scale.

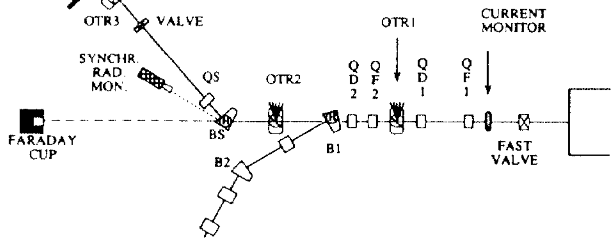

Figure 2. Diagnostics set-up at the linac exit.

The resolution in the focal plane of the spectrometer is 4 10^{-4} at the nominal emittance which gives a beam size σ_h=0.4 mm. A secondary emission wire-grid detector is planned to upgrading the spectrometer time response. These improvements will provide a measurement of the stability along the macropulse. Another spectrometer with similar performances will be placed after the undulator to study the energy spread induced by the FEL interaction.

The layout of the diagnostic devices at the linac exit is shown in fig. 2.

2.3 The transport line

The transport line at the linac exit has been designed taking into account the requirement for the afore-mentioned expansion of both FEL activity and SC accelerator physics. This implied a more articulate layout and some flexibility of the transport line characteristics exceeding the minimal requirement for FEL operation, mainly concerning emittance and peak current preservation. The SC accelerator is immediately followed by a four-quadrupole matching section set to provide optical functions suited for both spectrometer operation and injection in the arc. The arc is composed of three achromatic doublets joined by dispersion-free straight sections. This allows to easily control the beam envelope without affecting the dispersion inside the doublets. The overall lengthening is therefore simply given by

$$\Delta l = 6\rho\Delta E/E(\phi\text{-}\sin\phi)$$

At the nominal energy spread $\Delta E/E$ =0.2 % this gives Δl ~ 140 μm, i.e. no more than 5% of initial bunch length.

The second-order effects causing emittance degradation have been estimated and found negligible; moreover, it must be pointed out that a substantial emittance increase will not affect in serious manner the FEL gain, at least in first harmonic operation.

3 THE FEL EXPERIMENT

3.1 The undulator

The undulator is a 2.2 m long 50-periods hybrid-type device. NdFeB permanent magnets have been used , achieving the maximum undulator parameter K_{rms} = 1.0 at the minimum gap of 20 mm. The field uniformity proper of hybrid device was farther improved by magnet sorting, providing rms field error ~0.3 % without pole-stub tuning. It has been built by Ansaldo Ricerche, in collaboration with ENEA.

The vertical focusing effect of the undulator has been taken into account assuming a null sextupolar component. The quadrupole triplet at the undulator entry ensures easy matching in the real case.

3.2 The optical cavity

The cavity length must be multiple of 3 m to synchronise the stored optical pulse with the 20 ns spaced electron bunch. The bending magnets at the undulator ends and the matching triplet limit the mirror separation to distance d ≥ 6 m. The customary FEL cavity design realizes a confocal optical mode on the undulator length, i.e. it is assumed that the Rayleigh length L_R is half the undulator length $N\lambda_U$. This choice provides the best trade-off between a well focused and a constant mode section along the interaction zone; however, when mirror separation increases the cavity representative point in the Boyd stability plot moves from stable confocal configuration toward a more critical concentric configuration. The design parameters of the cavity for SURF are listed in table 2.

Table 2 - Parameter list of the optical cavity.

Length L_c	6	m
Rayleigh length Zo	1.1	m
Mirror radius R	3.40	m
λ 1st harmonic	15	μm
Waist w_0	2.3	mm
Spot size on mirrors	6.7	mm
Cavity losses	1	%
Output coupling	1	%
Peak power	1.2	MW
Macropulse averaged power	500	W
Average power	50	W
λ 3rd harmonic	5	μm
Waist w_0	1.3	mm
Spot size on mirrors	3.8	mm

The required accuracy will be obtained with a double actuator system, using dc-motor driven micrometric screws for rough positioning and preliminary alignment, and piezoelectric pushers for final tuning; the latter ensures fine tilting range of ±115 μrad for mirrors, corresponding to optical axis tilt of ±980 μrad and displacement of ±0.4 mm with step resolution ~1/1000 full range.

3.3 The expected performances

The wavelength range will be 11 ÷ 18 μm while K varies between 0.5 and 1.0, according to the well known relation

$$\lambda_o=\frac{\lambda_U}{2\gamma_o^2}(1+K^2)$$

In the first stage the operation will consist of spontaneous emission measurements to define the aligment axis, and will be carried on at 15 μm @ 25 MeV, corresponding to K=0.794. The setting for maximum small-signal gain, as derived in FEL theory, requires a slightly higher energy, defined by the detuning parameter

$$\nu=4\,N\,\pi\frac{\gamma-\gamma_o}{\gamma_o}\sim 2.5$$

An ideal beam would drive this FEL with a gain ~ 17%. Some reducing factors have to be applied to take into account the real beam parameter [7] The most relevant are caused by the slippage, i.e. sliding overlapping between photon and electron pulse due to their different longitudinal velocity, and by the energy spread. The relative gain curves obtained assuming the energy spread ranging from 0.05% to 0.2% are shown in fig. 3.

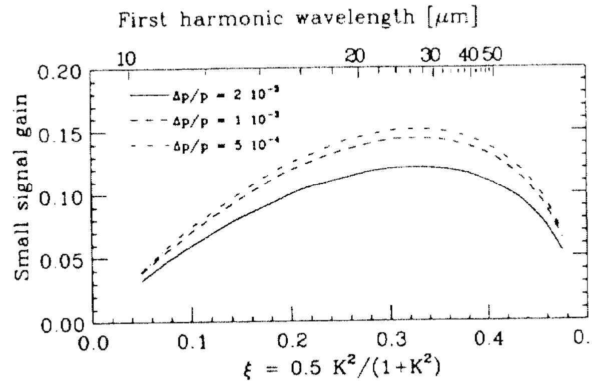

Figure 3. Gain vs ξ at different energy spread.

A peculiarity of FEL operation on SC linac is the long macropulse duration. A modified FEL parameter set will be tested with LISA, operating at higher ν; this implies lower gain and longer start-up time, but gives higher extraction efficiency when a strong laser field is trapped in the cavity, as shown in fig. 4.

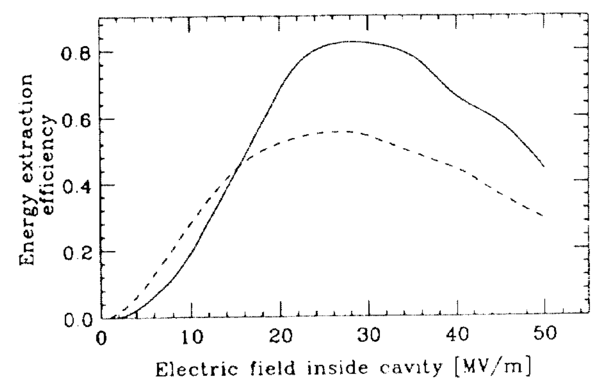

Figure 4. Energy extraction efficiency vs. inside cavity laser field at ν=2.5 (dashed line) and ν=5 (continuos line).

4. REFERENCES

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