LINAC UPGRADES FOR FERMI@ELETTRA

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Abstract

To fulfill the stringent requirements expected from the FERMI@ELETTRA project, the existing linac needs some modifications in the layout and an upgrading of the present plants. Moreover, for the next two years, until the new injection system, now under construction, is fully commissioned, the linac has to be kept in operation as injector for the ELETTRA Storage Ring. Therefore most of the planned activities have to be carried out without interfering with the normal operation of the machine. Details on the new linac layout and related activities are discussed.

INTRODUCTION

The FERMI@ELETTRA project [1] is an initiative among Sincrotrone Trieste, INFM and other Italian Institutes, to construct a single-pass FEL user facility located next to the third generation Synchrotron Light Source ELETTRA, utilizing the existing 1.0 GeV linac. The spectral range of the laser will go from 100 nm to 10 nm with two undulator beamlines implemented on the machine in two different phases:

- Phase 1 (FEL-1) will aim to cover 100-40 nm.
- Phase 2 (FEL-2) will extend the FEL wavelength up to 10 nm.

The first proposal of the FERMI project [2] was submitted to Italian Ministry of Education, University and Scientific Research in February 2002, in response to the Italian Government's call for proposals for a multipurpose pulsed laser X-ray source. In July 2004 the project was funded.

Ongoing activities are now evolving from a conceptual design phase to an early stage of a detailed technical design. Table 1 summarizes the main beam parameters for the two phases of the project.

Table 1: Electron beam parameters for phase 1 and 2

	FEL-1		FEL-2		
Wavelength	100	40	40	10	nm
Beam energy	0.7		0.55	1.0	GeV
Bunch charge	1.0		1.0		nC
Peak current	0.8		2.5		kA
Bunch duration	500		160		fs
Energy spread	0.7		1.0		MeV
Emittance	1.5		1.5		10^{-6} m
Repetition rate	50		50		Hz

To produce a beam with the required beam characteristics the existing linac needs some layout modifications, an upgrading of the RF plants, the implementation of a new synchronization system as well as a review of the whole beam optics, including the installation of two bunch compressors.

Figure 1 shows the present layout of the machine (a), the proposed FEL schemes with the two beamlines and the main modifications to be implemented on the existing machine (b) [2], and the new layout to guarantee the injection in the storage ring (c). At present the linac is operated less than 2 hours a day as the ELETTRA injector, the time remaining is completely available for all the activities connected to the FEL development. Therefore, with careful planning, most of the foreseen upgradings could be already activated.

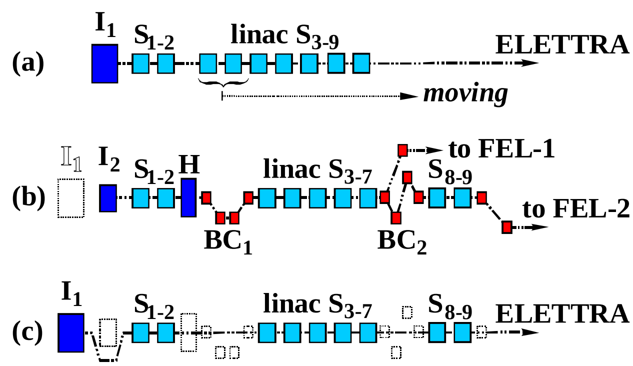

Figure 1: Linac layouts.

Labels meaning:

- I_1: present injector, thermionic gun and bunching sections, beam energy at exit 4.5 MeV.
- I_2: high brightness photoinjector.
- $S_{1\text{-}2}$: 3.2 m long accelerating sections, $2/3\pi$ forward TW, iris diameter 16-22 mm, without sled.
- H: 3rd harmonic cavity.
- BC_1 and BC_2: magnetic bunch compressors.
- $S_{3\text{-}9}$: 6.1 m long accelerating sections, $4/5\pi$ backward TW, each equipped with its own sled system.

LINAC MODIFICATIONS

Figure 2 gives a schematic overview of the linac building complex with the layout modifications and the expected installations.

Concerning the civil engineering, the present tunnel of the machine is adequate in length to house all the required modifications: roughly 40 m of free space are available at the end of the present accelerator for the relocation of two 6.1 m accelerating sections and the installation of the second bunch compressor as indicated in the FEL layout. The 3rd harmonic cavity, the first bunch compressor and the new diagnostics will be taken up in the space left free from the two moved sections. Additional space, roughly 15 m, is needed for the klystron gallery to relocate two RF plants.

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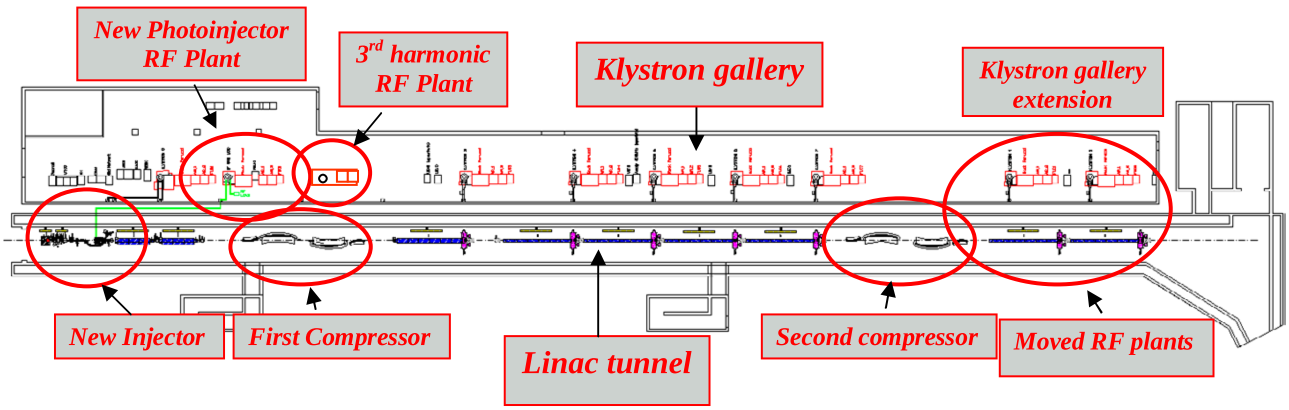

Figure 2: Overview of the linac building complex with the new installation.

Photocathode and New Injection Scheme

At present the linac does not match the beam requirement especially in terms of normalized brightness ($B_n=I_{pk}/4\pi\varepsilon_n^2$). To overcome this problem the actual thermionic electron source will be replaced with a high brightness photocathode. At the same time, at least for the next two years, the original gun must remain operational, to guarantee injection into the storage ring. To fulfil both requirements a new injection layout has been proposed with the new electron source in place of the old thermionic one, which will be relocated 3 m upstream. The scheme shown in figure 3 fits the space available in the present tunnel and all the modifications will be implemented in order to achieve a fast switching between the two modes of operation.

For the RF Gun three different options have been considered: a 1.6-cell developed by BNL/SLAC/UCLA for LCLS [3], scaled to 2998 MHz, a 2.6-cell gun developed at the TUE [4], and a 1-cell higher order mode (HOM) gun developed by Lewellen at the APS [5].

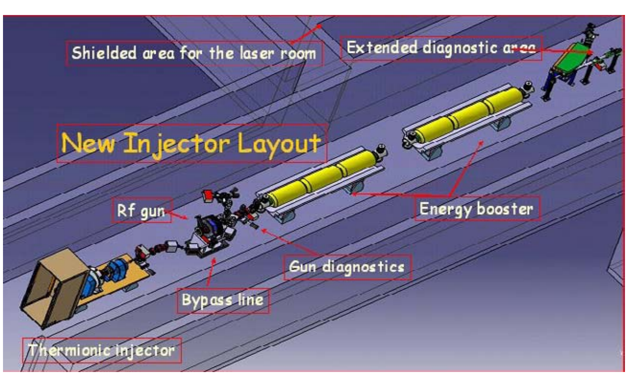

Figure 3: New injection layout.

Preliminary beam dynamics simulations have been performed with ASTRA [6] only for the first two options. We have considered the whole system photoinjector-booster linac up to 120 MeV utilizing the first two SLAC type accelerating sections of the present machine, $S_{1\text{-}2}$, both fed by the same klystron and embedded in their own solenoid with a maximum field up to 0.25 T, which is of great importance to control the beam envelope and the emittance oscillations. For the LCLS gun we have considered two values of the peak electric field at the cathode 120 MV/m and 140 MV/m. Table 2 summarizes the obtained results that are in a good agreement with the required parameters.

Table 2: Output beam characteristics and gun parameters

	LCLS	LCLS	TUE	
Gun field	140	120	100	MV/m
Beam energy	119	111	123	MeV
Norm. emit. (rms)	0.57	0.63	0.57	μm
Energy spread (rms)	0.21	0.27	0.36	%
Bunch length (rms)	0.90	0.93	1.0	mm
Peak current	104	102	93	A
RF peak power	11.1	8.2	8.2	MW
Heat flux @4μs, 10Hz	1.56	1.14	0.77	W/cm^2
Solenoid field	3.02	2.64	4.01	KG
S_1 average gradient	16.5	14.3	18	MV/m
S_1 focusing field	0.6	0.6	0.7	KG
S_2 average gradient	22	22	22	MV/m

In particular the TUE gun seems to be very interesting for the lower gradient of operation and a better performance in terms of heat production/dissipation. The same gun seems to be very promising also for its ideal rotational symmetry due to the axial coupling with the the RF generator. Nevertheless, at present the 1.6 cell LCLS choice seems the most appropriate for reasons of reliability and for the great experience matured on it in many laboratories during the last ten years.

Once the present injector will be relocated 3 m upstream and the transfer line for the storage ring injection commissioned (activities to be scheduled during a long shutdown period), it will be possible to install and test the new photoinjector as a stand-alone set-up before the definitive connection to the main linac.

The diagnostic section in the drift between the gun and the booster linac will provide the control over the main beam parameters and the space available will fit that required for the emittance compensation. More details on the new injection system can be found in [7,8].

Laser System

The laser system will be placed in an existing shielded area located on one side of the linac tunnel, only few meters away from the gun. We plan to assemble a system based on a commercially available Ti:Sapphire laser and amplifier modules upgraded with additional units and control loops. The main requirements of the laser system for a copper cathode based photoinjector are well established and limit the choice to a 10-20 mJ range Ti:Sapphire system based on consecutive regenerative multi-pass amplifier stages. Although the application of a purely diode pumped systems would be preferable for reducing the pulse-to-pulse energy fluctuations (and amplifier induced timing jitter), at the present status of these systems the use of one lamp-pumped multi-pass amplifier end stage seems unavoidable. Temporal pulse shaping for obtaining the necessary 10 ps range 'flat-top' low energy infrared pulses can be done by different methods, however the obtaining of high energy UV pulses with such shape is a serious challenge. We are now examining different possible solutions, including also shaping in the UV region, which would avoid problems with pulse deformations during amplification and frequency conversion.

RF Plant Modifications

At present the RF plants are operated with a repetition rate of 10 Hz. To increase the beam average power we are considering to extend the pulse repetition rate up to 50 Hz, compatible with the klystron TH2132A and some of the components already mounted on our plants, i.e. accelerating sections, sled cavities, thyratrons, etc. On the other hand, to deal with the 50 Hz average power increasing, many other components installed on the pulsed modulators need to be modified or completely substituted, i.e. the HV power supply, the PFN (Pulse Forming Network), etc.

Moreover, since FEL operation calls for an overall improvement of the stability of the machine, many other sub-assemblies have to be checked, modified or completely replaced. In particular:

- it will be necessary to improve the pulse to pulse stability of the HV modulators as well the ripple of the klystron anodic pulses to avoid unwanted phase rotation in the emitted RF;
- all the wave guides and the power distribution systems from klystrons to accelerating sections need to be modified and temperature stabilized;
- the RF low level system, the klystron drivers, etc. have to be replaced with high stability equipments with control loops and feedbacks supplied;
- the accuracy and stability of the water cooling system of the accelerating sections have to be improved to limit the phase errors between adjacent cells.

Concerning the layout modifications it will be necessary to relocate the first two 6 m accelerating sections S_3 and S_4 with their RF plants at the end of the tunnel leaving the space for the installation of the first bunch compressor and the 3rd harmonic cavity. Two more RF plants have to be installed in the klystron gallery: one for the 3rd harmonic cavity, the other for the photoinjector and eventually an RF deflecting structure for bunch length measurements. Most of the activities above described can be gradually implemented on the plants during normal shutdown periods, without interfering with ELETTRA operation. The modularity of the RF plants and in particular the layout of the present accelerating systems (one HV modulator with its own klystron feeds only one accelerating section) guarantees minimal disruption to machine operation since plants can be selected and upgraded one at a time.

Timing System

Timing and synchronization between different sub-systems will be a fundamental issue. The present timing system will be completely revised in terms of global stability and a frequency reference will be properly distributed around the machine allowing the implementation of local phase control loops. Several options are now under investigation for the reference distribution (coax, optical fiber, etc). We have also started a sub-ps jitter analysis and a study on phase measurement that will be crucial subjects for achieving the beam parameters required by the laser.

CONCLUSIONS

A brief overview of the main modifications and upgradings required from the Trieste linac to fulfil the expected performances required for FERMI has been given. Moreover, for each of the above mentioned activities, it will be necessary to carry out a detailed technical design and an accurate time schedule for its implementation according to operational needs of ELETTRA.

REFERENCES

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