LINAC UPGRADING PROGRAM FOR THE FERMI PROJECT: STATUS AND PERSPECTIVES

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Abstract

FERMI@ELETTRA is a soft X-ray fourth generation light source under development at the ELETTRA laboratory. It will be based on the existing 1.0-GeV linac, revised and upgraded to fulfill the stringent requirements expected from the machine. The overall time schedule of the project is very tight and ambitious, expecting 10 nm photons for users by 2010. Here the machine upgrade program and the ongoing activities are presented and discussed.

INTRODUCTION

FERMI@Elettra is a photon user facility under construction at the Elettra Laboratory. It is based on a single-pass FEL, that uses the existing normal conducting 1.0-GeV linac to deliver photons in the UV to soft X-ray range (100-10 nm). The scheme adopted for the FEL will be based on a double-stage, seeded harmonic cascade, able to provide controlled high-power radiation pulses. To fulfill the stringent requirements imposed by FERMI [1], the present linac will be completely revised and upgraded. The main machine modifications cover the installation of a new high-brightness electron source, a laser heater system for the control of uncorrelated energy spread, a 4th harmonic accelerating section to linearize the bunch charge, and two magnetic bunch compressors to increase the delivered peak current.

Moreover all the machine sub-ps diagnostics will be revised and upgraded as well as the capabilities of the synchronization system that will allow sub-ps timing control. The operating pulse repetition rate of the machine will be extended up to 50 Hz and all the RF power plants will be upgraded to increase their operating power and stability. In terms of energy, the machine capability will be extended up to 1.2 GeV with the installation of seven supplementary accelerating sections received from CERN following the LIL decommissioning. This will provide some margin on the operating gradients of the accelerating structures. Figure 1 shows the machine schematic layout with the main components and operating parameters. The machine is divided into different segments, Linac0 (L0), Linac1 (L1), ..etc, in order to evaluate the stability requirements of each segment in terms of phase and amplitude of the RF accelerating field.

All the components up to the first bunch compressor will be installed in a new 85 m long upstream machine tunnel extension. This new tunnel extension, will be ready for the end of 2007. Figure 2 shows the progress of the civil engineering.

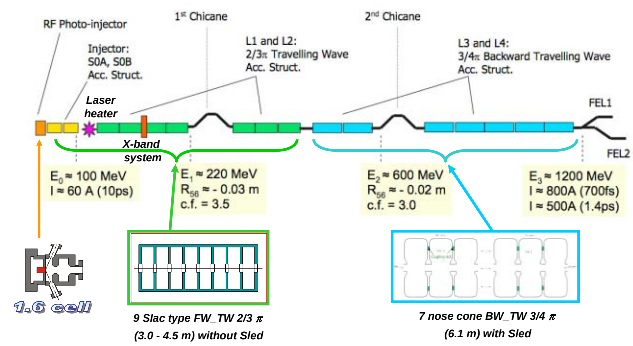

Figure 1. FERMI machine layout

MACHINE LAYOUT

The main linac is roughly 150 m long and accelerates the electron beam from 100 MeV to 1.2 GeV. After the photoinjector and the first two accelerating sections S0A and S0B that boost the beam energy up to 100 MeV, fourteen normal conducting accelerating modules are spaced out by two magnetic chicanes according to two main prescriptions:

i) minimize the geometric transverse and longitudinal wake fields acting in the linac;
ii) guarantee maximum flexibility for the electron bunch manipulation.

In particular, L1 runs off-crest to induce the energy-time correlation required by the bunch compression in the first magnetic chicane (BC1). This requires very tight tolerances for the RF operating parameters, typically below 0.1^{o} S-band for the phase and 0.1% for the amplitude.

Figure 2. On site civil engineering activities

The residual energy chirp is cancelled by the longitudinal wake field in L4 which acts in conjunction with the linearization process provided by the X-band

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cavity located in front of BC1. Working together, this configuration optimizes the compression efficiency. As discussed later, for longitudinal Landau damping of the microbunch instabilities driven by the combination of space charge forces, magnetic compression and Coherent Synchrotron Radiation (CSR), there is a laser heater system beyond LO at 100 MeV. At the linac exit, the beam is brought to the undulator system by a transfer line and a spreader which directs the beam into two FEL lines. Two diagnostic sections equipped with RF deflecting cavities, multi-screen stations and a spectrometer for energy analysis will be installed after BC1 and in the transfer line after the linac for a full characterization of the slice and projected beam properties.

BUNCH COMPRESSION

The FERMI accelerator is equipped with two symmetric magnetic chicanes. This provides us with a large flexibility in terms of electron beam compression scenarios. Two machine configurations have been considered and simulated: one-stage and two-stage magnetic compression. The machine layout is configured for a two-stage compressor, although the one-compressor scheme is preferred [2]. One of the advantages in using a one-stage compression scheme is that of minimizing the impact of the microbunch instability on the final slice energy spread. The one-stage compression has been studied through a reverse tracking technique, in order to achieve the electron bunch quality requested for the production of coherent harmonic generation, i.e. a flat current profile and energy distribution.

THE NEW PHOTOINJECTOR

The RF photocathode gun and the associated systems are meant to reliably produce the extremely high quality beam required by FERMI. An agreement between ELETTRA and UCLA to obtain this technology was discussed and signed, and an upgraded version of an existing 1.6-cell gun, scaled to 2998 MHz plus other design changes, is now under construction at UCLA. The main improvements will include: i) an enhanced 0-π modes separation (13.8 MHz), ii) removal of the RF tuners from the cells, iii) symmetrization of the gun full cell to limit the dipole and quadrupole components of the RF field, iv) improved yoke design of the solenoid magnet to remove steering and skew coupling errors, and v) a higher pumping conductance for better RF and QE performance. Details on the design could be found in [3]. Figure 3 shows the photoinjector layout with the main components. The gun laser system is already in house and we plan to have all the photoinjector components ready for the installation by the end of the year.

LASER HEATER

The laser heater will provide a controlled increase of the uncorrelated energy spread that, according to analytical and numerical studies, will help in suppressing the growth of microbunch instabilities [4]. It consists of an undulator located in a magnetic chicane that allows external laser seeding of the electron beam. The particles interact with the laser in the short undulator, gaining an energy modulation on the scale of the optical wavelength.

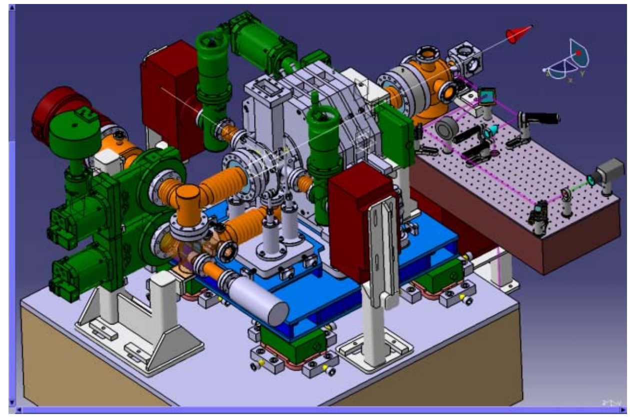

Figure 3. Photoinjector layout

The corresponding electron density modulation is negligible and the energy position correlation is smeared by the transverse motion in the chicane. As a result, the laser-electron interaction leads to an effective heating of the beam. The main laser heater layout is shown in Figure 4 and its main parameters are listed in the table [1].

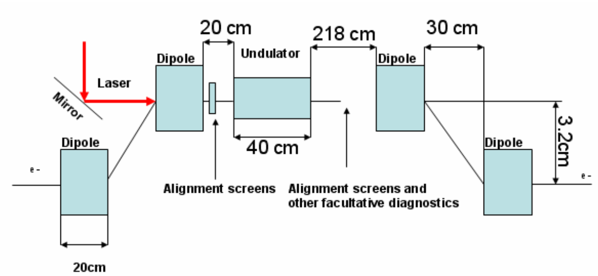

Figure 4. Laser heater layout

The maximum required peak power from the laser is 10 MW [5,6]. A small part of the photoinjector laser will be split off the main pulse prior to the compression section of the infrared amplifier and stretched out to reach a pulse duration of 20 ps. The required energy is less than 1mJ so only a small fraction of the infrared light available before the harmonic conversion (>18mJ) will be used. The energy modulation has been studied analytically and with the ELEGANT and GENESIS codes. A good agreement has been found between all the three methods [7].

Parameter	Value
Undulator period	4 cm
Number of periods	10
Bending angle	3.5 degrees
Bending length	20 cm
Drift between bending	30 cm
Drift before undulator	20 cm
Drift after undulator	218 cm
Total length	418 cm

Table 1. Main laser heater parameters

HV POWER SYSTEM

A detailed description of the requirements for the klystron modulators for FERMI can be found in [8]. Two prototypes of modulators are being assembled: a conventional line type modulator (PFN) and a solid state modulator (SSM). The scope of this program is to have a dedicated test stand for comparing both the technologies in terms of performance and reliability before the final choice. The PFN plant is essentially an upgrade of the existing ELETTRA modulators, modified to operate at 50 Hz and to reach the desired level of reliability and performance. The solid state modulator is an inductive adder type design. It uses eight induction cells, each with three amorphous magnetic cores. Each cell is driven by two 6.5 kV, 600 A Insulated Gate Bi-Polar Transistors (IGBTs) operating in parallel at 3636 V. A pipe is passed through the center of each of the cells, inductively adding the voltages. The output pulse of the modulator is then stepped up by a conventional 1:11 pulse transformer to reach the 320 kV needed for the klystron. An R-L circuit is used to compensate for both the droop from the capacitors and the magnetizing inductances. Table [2] shows the specifications for the solid state modulator. A schematic of the modulator is shown in Figure [5].

Number of Cells	8
Number of IGBTs/Cell	2
Transformer Ratio	11:1
Nominal IGBT Voltage	3636 V
Fault IGBT Voltage	4156 V
IGBT Current	1925 A
Core Dimensions	135×430×25.4 mm
N^{o} of Cores/Cell	3

Table 2. Specification for the solid state modulator

ACCELERATING SECTIONS AND RF DISTRIBUTION

Nine accelerating sections from the decommissioned CERN LIL accelerator have been measured and characterized. Seven sections will be used in the linac expansion for the FERMI project. Two sections will be used in the new booster. The impact of temperature stability of each waveguide component and accelerating section on the energy stability has been analysed. To meet the energy stability of better than 10^{-3} the error budget allocated to temperature stability must be within 0.05 ºC. A prototype of the temperature controller, manufactured by the Italian firm IRS was installed on two accelerating sections of the present linac for a test, shows that this stability is reachable. The design of the layout of the waveguide system is now completed and we are in the process of identifying suitable vendors.

LLRF

The very stringent pulse-to-pulse stability requirements on the RF fields for the Fermi Linac (0.1º S in phase, 0.1% in amplitude) necessitate the design of a new state of the art low level RF control system (FLLRF) [9]. Several key characteristics of this system will be:

- the use of 16-bit, low latency, high speed (130 Msps) input ADCs and output DACs (400 Msps).
- Active pulse to pulse calibration of all input signal lines to compensate for thermal drifts.
- The use of non-IQ sampling to help average the integral nonlinearity (INL) errors of the ADCs.
- Multi Giga-bit serial communication links station to station and station to central controller.

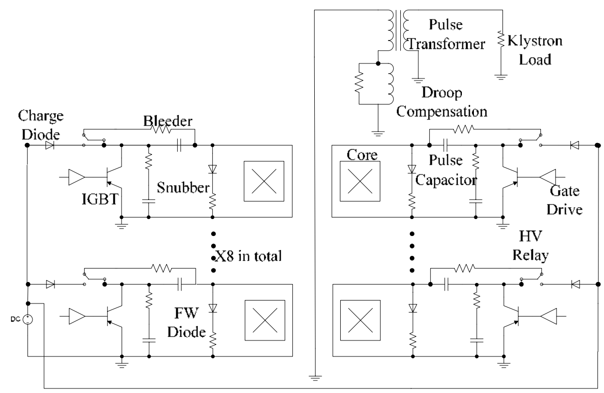

Figure 5. Schematic of solid state modulator.

The control system will have 5 input and 2 output channels. Each input can be used in a low-latency direct feedback configuration or in high accuracy (memory intensive) feed forward application.

CONCLUSIONS

An overview of the FERMI linac upgrading program is reported. The main ongoing activities are focused on the technical design of the components as well as the assembly of prototypes to verify and test their feasibility, capability, and reliability. Installation of the new systems is planned for the beginning of 2008 when the new buildings will be available. The first half of next year will be extensively used for the photoinjector installation, test and beam characterization. During this period the prototype RF power stations will be tested to verify and validate their performance and reliability before making the final choice and then upgrading of all the remaining stations.

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