STATUS AND UPGRADE PROGRAM OF THE FERMI@ELETTRA LINAC*

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Abstract

FERMI@ELETTRA is a seeded FEL user facility under construction at Sincrotrone Trieste, Italy. It will use the existing normal conducting S-band linac and, with the installation of seven accelerating sections received from CERN after the LIL decommissioning, will be operated at 1.2 GeV.

After the successful commissioning of the new 2.5 GeV Booster injector system of ELETTRA, the linac has been disconnected from the storage ring and is now being revised and upgraded with the installation of major new subsystems, i.e. a new photoinjector, bunch compressors, laser heater, additional accelerating structures, etc.

Here we describe the upgrade program as well as the ongoing activities of the main sub-assemblies of the machine and their status.

INTRODUCTION

For an overall picture of the FERMI@ELETTRA project and a detailed description of the machine layout see [1,2]. Besides the new e-source (a 1.6-cell photo-injector gun) and the main accelerating structures (16 in total), the layout of the machine includes a laser heater (LH), an x-band longitudinal linearizing structure (XB), two bunch compressors (BC1-BC2) and three transverse deflectors (BD1, BD2 and BD3) for bunch length measurements. The first deflector, a 0.5-m long standing wave structure is located after BC1. The other deflectors, two identical travelling wave structures 2.5-m long, will be installed at the end of the linac.

To improve performance and make efficient use of RF power, several modifications to the layout of the main linac were investigated last year. These were:

- installation of an additional RF plant at the end of the linac to feed the two high energy deflecting cavities for bunch length measurements;
- acquisition and installation of two new accelerating sections for the machine to make better use of the available RF power.

With these modifications the total number of accelerating structures will increase from 16 up to 18 with a total of 16 RF plants. This will bring the linac operating energy (on crest) close to 1.4 GeV. In addition we are also considering moving the existing sections S0A and S0B, out of the space-charge dominated regime and replacing them with the two accelerating sections we plan to acquire. The latter will be designed with appropriate RF couplers (i.e. dual feed race-track design) to avoid transverse kicks along the bunch and emittance degradation in the low energy part of the linac. At present we are evaluating in detail the FERMI emittance specification and the tolerance of multipole fields. A decision will be made soon.

GENERAL STATUS

Decommissioning of the "old linac"

In late February 2008, the "old linac" was decommissioned. All the RF plants and the wave guide systems (WG) were dismounted and stored in protective envelopes before storage in a warehouse. Many of them (i.e. HV power supplies) will be re-used in the 10 Hz first phase of the FERMI. Others (i.e. Sled WG's) will be upgraded for 50 Hz operation. The accelerating sections and the Sled cavities have been left on one side of the machine tunnel, locked and protected in a strong case. This will allow the installation of the new technical plants (cooling systems, electrical plants, etc.).

Photoinjector gun

An upgraded version of the 1.6-cell photo-cathode (PC) gun was developed in collaboration with UCLA [3] and delivered to Trieste last March. Since the new building for the PC gun is not yet complete, we took this opportunity to install the PC gun system at MAX-lab in Lund, Sweden, for high power and beam tests. This is being done in the framework of a collaboration between Sincrotrone Trieste, MAX-lab and UCLA.

The accelerating structure was quickly conditioned at the end of May, reaching 10 MW RF peak power (120 MV/m) in less than one week. The first beam tests where performed and the first extracted beam was seen on May 29th, see Fig. 1. For more details on the PC gun tests see [4].

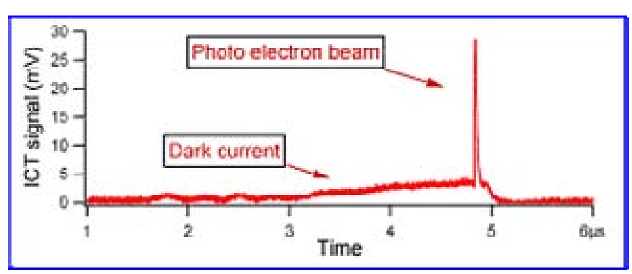

Figure 1: First electron beam extracted from the PC gun.

HV modulators

The klystron modulators for the FERMI linac, with 320 kV and 350 A. will power the TH2132 klystrons. The

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pulse width is 4.5 μs at a pulse repetition frequency of 50 Hz. The goal of the modulator R&D program, started two years ago, was to assembly two 50 Hz prototypes: a conventional line-type modulator (PFN+thyratron) and a solid state one (SSM) based on IGBT switches, to evaluate the performance of both technologies before the final choice.

The 50-Hz upgrade of an existing PFN modulator was completed at the end of February, and the modulator was in full-power testing up to the end of April when the klystron gallery was no longer available because of civil construction. A new HV test area will be available at the end of June.

The SSM modulator is an inductive adder-type design, using Insulated Gate Bi-polar Transistors (IGBTs) as the switching elements [5]. There will be eight induction cells, each driven by two parallel IGBTs. A single secondary turn passes through the aperture of the cores inductively adding the voltages. This voltage is further boosted by a conventional pulse transformer to reach 320 kV. Table 1 summarize the main parameters of the SSM.

The design of the SSM is complete and most parts are in house. Testing of individual components has begun, as well as assembly of the prototype.

Table 1: SSM parameters

Peak Voltage	320 kV
Peak Current	350 A
Pulse Width	4.5 μs
PRF (pulse rep. freq.)	50 Hz
Rise/Fall Time	<0.5 μs
Flat Top	±0.5 % V_{peak}
Pulse Ripple	±0.1 % V_{peak}
Number of Modulators	14 + 1 spare
Number of Cells	8
Number of IGBTs/Cell	2
HV 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
# of Cores/Cell	3

Figure 2 shows the IGBT and gate voltages, and the load current from testing a single induction cell at full peak power. Each cell is comprised of three Vitrovac 7600Z cores measuring 135×430×25.4 mm. All the cores were tested and it was found that they saturate at between 8.5 and 10.5 mVolt-seconds, surpassing the requirements.

A major concern is to protect the IGBTs during a fault. The worst case fault condition is if a core saturates during the pulse. This requires a method to limit the IGBT peak current to a tolerable level as well as to turn off the device quick enough to prevent destruction of the IGBT. Both of these functions can be accomplished with a careful gate driver design. A circuit is used to respond to the de-saturation of the IGBTs, quickly shutting off the devices when a fault occurs [6]. Figure 3 shows the results of fault testing where a core is intentionally saturated. The trigger pulse, load current, and IGBT voltage are shown, demonstrating that the pulse is truncated when the load is shorted.

The first SSM prototype is expected to be completed in July and tested in August.

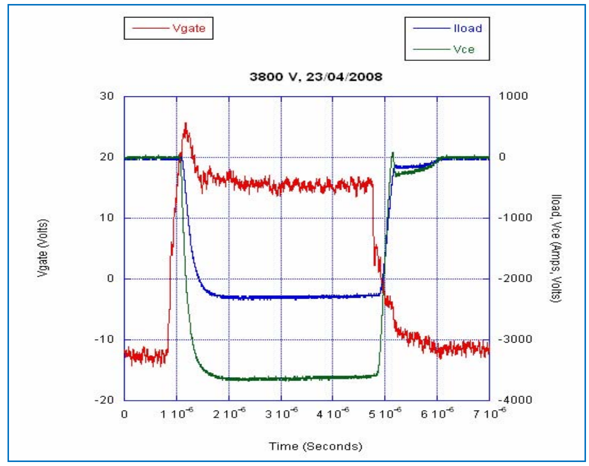

Figure 2: Full peak power testing of single induction cell.

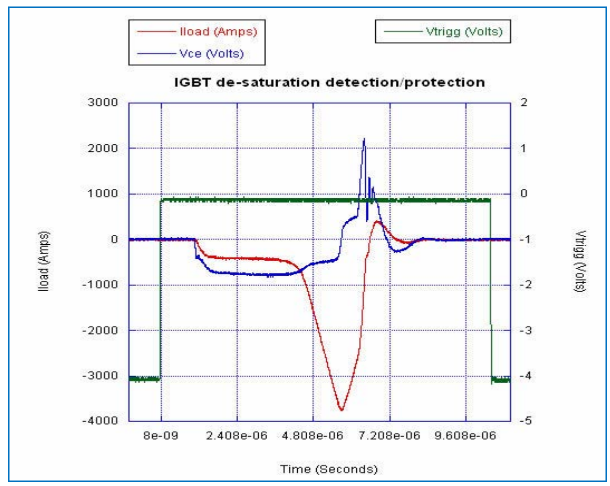

Figure 3: IGBT fault protection.

RF system

The proposed Low-Level RF (LLRF) control system for FERMI [7] is in the prototype stage. In order to meet stringent phase and amplitude stability requirements (0.1% amplitude, 0.1 phase at S-band) novel schemes and architectures have been adopted. The LLRF control is an all-digital system composed of two PC boards, a RF front-end board and a Analog/Digital processing board.

The RF board has 5 RF input channels, 2 RF output channels, as well as various trigger, diagnostic, and base-band I/O. The RF board is mainly used for frequency conversion between RF and IF signals. It houses all of the frequency dependent components such as filters, mixers, and amplifiers. It uses a standard multi-pin connector for all DC and base-band signals, SMA connectors for the RF and IF signals and requires only a single 5-V supply.

This standardization allows similar applications at different frequencies to use the same processing board while changing only the RF front-end electronics.
A diagnam of the RF front-end PCB is shown in Figure 4.

All control, diagnostics, and external communication is performed in a single, large, FPGA. The control systems along the accelerator are connected through high-speed fiber serial links to a central controller in development at CERN/LANL called 'The Matrix'. This allows for FPGA to FPGA, low-latency, time-deterministic, communication between controllers opening the prospect of accelerator-wide control with a bandwidth in the 10's of kHz. Furthermore, linking the systems in this manner permits for coherent clock and data transmission with a temporal resolution on the order of 20 ps [8].

The whole system is now under development in collaboration with LBNL Berkeley and the first prototype should be ready in 12 months with a production system ready 6 months later.

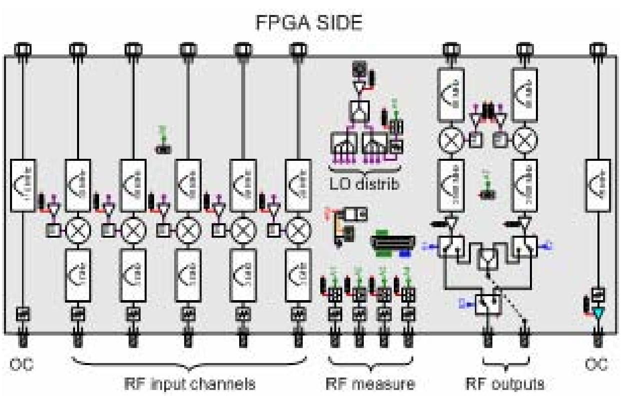

Figure 4: RF front-end PCB.

The waveguide distribution system includes new circuits (for nine klystrons) and old circuits to be upgraded to 50-Hz operation (for seven klystrons with Sled). Most of the new circuits have been designed and technical specifications are ready, we must now to launch the call for tender for selecting the manufacturers.

The circuits for the X-band klystron and that for the high-energy deflectors are still to be completed.

Laser heater and bunch compressors

A laser heater system [9] will be installed after the second accelerating section of the linac, at 100 MeV beam energy. It will give a controlled increase of the uncorrelated energy spread of the beam (5-20 KeV) avoiding the growth of micro-bunch instabilities. It consists of an undulator inserted in a small magnetic chicane and an external laser for beam seeding.

The short laser heater undulator [10] is now under construction at KYMA s.r.l and will be completed next August. The whole magnetic chicane and all the diagnostics beyond the laser heater undulator is a subject of a Broad Area Announcements (BAA) through which Sincrotrone Trieste intends to select a partner for the development effort. The laser beam will be split from the photo-injector laser.

The two bunch compressors required by the FERMI project (two symmetric magnetic chicane) are now being developed in house. For each compressor the present design includes four identical dipoles powered in series, two trim quadrupoles for fine tuning the dispersion function and two sextupoles for linearization of the longitudinal phase space. The chicane also includes a beam position monitor (BPM), with an absolute accuracy of 20 μm rms in single shot and within a 0.1-1.0 nC charge range, and a screen to measure the beam transverse profile, size, and position with a resolution of 20 μm rms.

The intra-section design, Fig. 5, includes one quadrupole, two steering magnets (H-V) as well as beam diagnostics elements, BPM, current monitor and screen, is close to be completion.

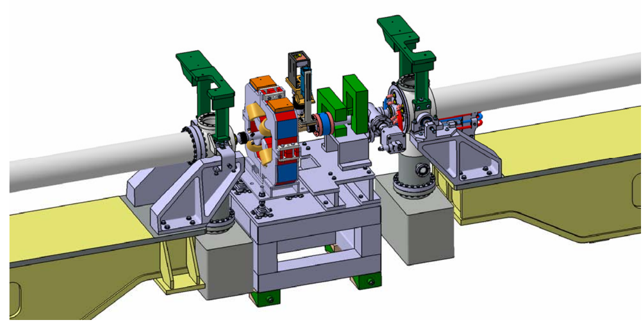

Figure 5: Linac intra-section layout.

CONCLUSIONS AND ACKNOWLEDGEMENTS

The ongoing activities for the upgrading of the FERMI@ELETTRA linac have been reported. Significant progress has been achieved in different areas of the project. In particular the preliminary results obtained with the commissioning of the PC gun are very promising in view of its future implementation on the FERMI linac.

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