# STATUS REPORT ON FERMI@ELETTRA PROJECT*

F. Parmigiani, M. Svandrlik and D.Zangrando on behalf of the FERMI@Elettra team,
ELETTRA, Basovizza, 34149 Trieste, Italy.

*Abstract*

FERMI@Elettra, a single-pass FEL user-facility covering the wavelength range from 100 nm (12 eV) to 4 nm (310 eV) located next to the third-generation synchrotron radiation facility Elettra (see figure 1) in Trieste, Italy is currently under completion and will start user operation next year. The first seeded lasing was observed in December 2010 and the first tests of the experimental stations have started this year. In this paper an overview of the machine and beamlines systems will be given as well as a detailed insight into operation and future upgrade.

## INTRODUCTION

The first proposal for a FEL facility was presented in the beginning of 2002. In January 2007, the conceptual design report [1] was completed with the contribution of many EU and USA synchrotron radiation laboratories.

The sixth framework EU program EUROFEL and then IRVUX collaboration strongly contributed to the design and construction of this facility. The financial support for the construction of this "User Facility" was given by the Italian National and Regional Governments as well as by a project-financing supported loan from the European Investment Bank.

FERMI@Elettra has been designed to be a user facility and so to guarantee high beam quality and stability, light tunability, possibility to vary continuously the FEL light from linear to circular polarization and femtosecond timing precision for the synchronization of the experimental beamlines. In order to satisfy these requirements the FEL process was based on High Gain Harmonic Generation (HGHG) scheme, making use of an external laser to seed the radiation.

This FEL facility will operate two FEL lines, namely FEL-1 and FEL-2. FEL-1, which will cover the wavelength range 100 - 20 nm, is now in commissioning phase to be be completed by the end of this year. FEL-2, located parallel to FEL-1, at a distance of 1 m, will cover the range 20 – 4 nm and will be based on a double cascade of HGHG. Table 1 reports the main parameters for FEL-1 and FEL-2.

The experimental program foresees three stations: Diffraction and Projection Imaging (DiProI), Low Density Matter (LDM) and Elastic and Inelastic Scattering for a total of four beamlines, since EIS includes two lines: TIMEX and TIMER.

## FERMI@ELETTRA OVERVIEW

### *Buildings*

The FEL buildings, experimental hall included, extends for a length of about 360 m. The underground linac tunnel has a length of about 200 m. It is followed by the Undulator Hall that has a length of about 100 m (11 m wide) and by the experimental hall, 60 m long and 27 m wide. Civil works were carried out in about 4 years and were completed in September 2010.

The construction was carried out in such a way that it did not impact the regular operation of the Elettra storage ring, positioned very closely to the excavation activities (fig. 1). Co-occupancy permitted the machine installation in parallel with the construction of the buildings and plants: actually the commissioning of the first part of the machine (photoinjector) started in April 2009.

Table 1: Photons and electron beam parameters

| Parameter | FEL-1 | FEL-2 |
|---|---|---|
| Fundamental wavelength range | 100-20 nm | 20-4 nm |
| Photon Peak Power | 1 – 5 GW | > 0.3 GW |
| Photons per pulse | $> 10^{13}$ | $>10^{12}$ |
| Repetition Rate | 10 Hz | 50 Hz |
| Electron Energy | 1.2 GeV | 1.5 GeV |
| Peak Current | 800 A | 800 A |
| Bunch Length (fwhm) | 0.7 ps | 1.2 ps |
| Slice Norm. Emittance | 1.5 mm mrad | 1 mm mrad |
| Energy Jitter (rms) | < 0.1% | < 0.1% |
| Arrival Time Jitter (rms) | < 200 fs | < 150 fs |

### *Linac*

The free-electron laser FERMI@Elettra accelerator comprises a low emittance RF photo-injector [2] presently operating at 10 Hz, followed by a normal conducting 3 GHz Linac (S-Band), made up of two RF sections (L0, 2 sections), followed by seven CERN, LIL–type, acceleration structures (L1, L2; 4+3 sections) and other seven Elettra-type structures (L3, L4; 2+5 sections) [3]. Fourteen high power RF generators (45 MW peak power) positioned at ground level (Klystron Gallery) feed the acceleration sections plus the photodiode gun and three RF deflectors, all located in the Linac Tunnel situated about 5 m below the ground level. There are 2 RF distribution schemes. In the first one, a single RF plant feeds a single high gradient Elettra-type accelerating cavity via a SLED RF compression system. In the second one, a single RF plant powers two low gradient accelerating sections. Figure 2 shows the Linac Tunnel: the Elettra-type acceleration sections and the SLED cavities installed on top of them are visible.

*Work supported in part by the Italian Ministry of University and Research under grants FIRB-RBAP045JF2 and FIRB-RBAP06AWK3

Figure 1: Sincrotrone Trieste Lab: FERMI@Elettra (FEL - linear accelerator) and ELETTRA storage ring.

The electron beam energy for FEL-1 is 1.2 GeV.

A Laser Heater Chicane, located after L0 (100 MeV beam energy) and containing a 0.5 m long undulator takes care of the microbunching instabilities. It was installed in November 2009. Two (identical) bunch compressors (see fig. 3) developed in house and having a length of 8 m were installed; the first one in April 2010 and located after L1 (300 MeV), the second one, in May 2011, after L3 (700 MeV). They permit a continuously tunable compression of the bunch (the nominal compression factor is 10).

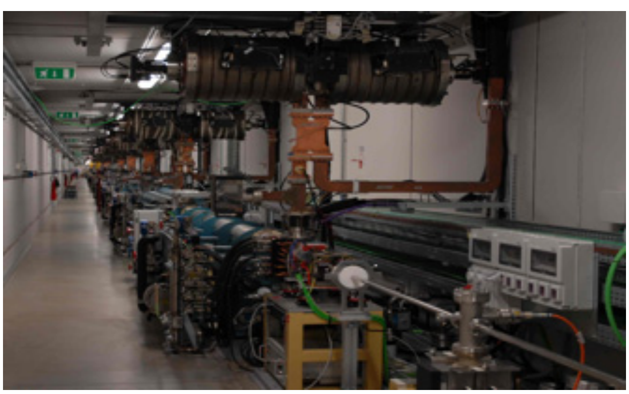

Figure 2: Linac Tunnel

Next October, a 12 GHz (X-band) harmonic cavity for the linearization of the beam longitudinal phase space will be installed after the first two sections of L1 [4]. Three RF deflectors are foreseen for diagnostic purpose, one after the first bunch compression at low electron beam energy and two at the end of the linac. Only the first one is in operation, the other two have not yet been delivered having met some production problems.

### *FEL-1 and FEL-2*

A 30 m transfer line is dedicated to transport the electron beam from the Linac to the selected FEL line (FEL-1 or FEL-2). The seed laser, tunable down to 200 nm and with a peak power of about 100 MW, is installed in this region [5]. The optical timing system synchronizes the seed laser to the electron beam at femtosecond level [6]. The installation of all foreseen FEL-1 electron and photon beam diagnostic components, as well as 4 geometric and 3 energy collimators, have been completed and are now in full operation.

FEL-1 line installation was completed in August 2010. The commissioning of the FEL-1 beam transport to the main beam dump (in common with FEL-2) was successfully completed in October 2010. Immediately after, having minimized the risk of radiation damage of the permanent magnets, we installed the foreseen seven undulators (1 planar plus 6 APPLE-II devices) (see figure 4) and the six phase shifters.

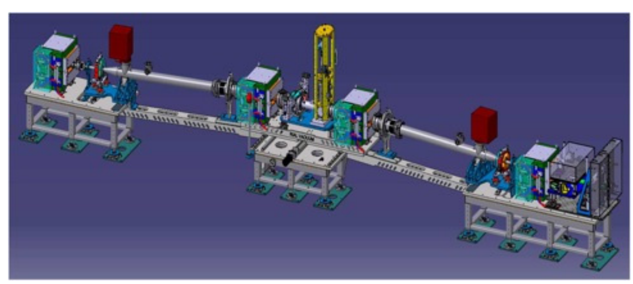

Figure 3: Bunch Compressor System

FEL-2 assembly started during the shutdown of April 2011 with the installation and alignment of the low gap undulator vacuum chambers. It had been continuing throughout August's shutdown, with the installation and alignment of the remaining vacuum chambers and diagnostic components. However the FEL-2 line will be fully operative only at beginning of next year since our effort is now focused on FEL-1 optimization. Consequently the FEL-2 undulators will be installed next year as well.

### *Experimental Hall*

The PADReS (Photon Analysis, Delivery and Reduction System) photon beam transport line delivers both the FEL-1 and FEL-2 light to the experimental stations [7]. In the first commissioning phase, a temporary simplified solution was adopted to characterize FEL-1 photons, sufficient to demonstrate the first FEL-1 coherent light production in December 2010 and to carry out the preliminary commissioning of the TIMEX, LDM, DiProI experimental stations located in temporary positions. The Experimental Hall is shown in figure 5.

## INSTALLATION STATUS

The Linac is completed except for the two high energy RF deflectors (installation not yet scheduled) and the X-band cavity that will be installed next October 2011. The FEL-1 line is at present fully operative while PADReS and the experimental stations installation in their final positions will be completed by the end of 2011.

The installation program for next year foresees the FEL-2 line and the dedicated PADReS line completion as well as the new photonjector system and the upgrade of the repetition rate from the present 10 Hz to 50 Hz.

Small upgrade and tuning of the complex photon and electron beam diagnostic system are continuously ongoing often driven by the commissioning requests.

Figure 4: Undulator Hall

## COMMISSIONING RESULTS

The first evidence of coherent light from FEL-1 was observed in December 2010. The observed pulsed light was emitted at 43 nm with an intensity of about $10^9$ photons/pulse. Many efforts were dedicated to improve the FEL-1 performances. During the last run, in July 2011 we increased the flux, for this wavelength, up to $10^{13}$ photons/pulse. We also extended the observed coherent emission in the range from 52 nm down to 20 nm, where we measured about $10^{12}$ photons/pulse and which is the specified FEL-1 lower wavelength limit.

Many efforts have also been dedicated to evaluate the spatial coherence of the emitted light: preliminary analysis is indicating a very good level of degree of spatial coherence.

The FEL-1 coherent emission in circular polarization at 52 nm was also demonstrated as well as a light tuning of 1 nm around this wavelength.

The seeding process could be implemented quite easily and the general operability of the machine, when delivering photons to the experimental stations, is fairly smooth and reliable.

A detailed status on the commissioning results is reported in [8].

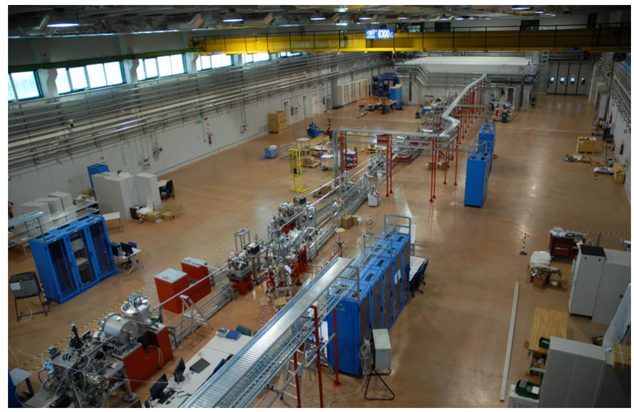

Figure 5: Experimental Hall

## ACKNOWLEDGEMENTS

We would like to thank the whole Elettra team, all consultants and guests for their help, assistance and significant contribution to the success of FERMI@Elettra.

## REFERENCES

[1] C.J.Bocchetta et al., “Conceptual Design Report (CDR) for the FERMI@Elettra Project”, Sincrotrone Trieste (2007).
[2] M.Trovo et al., Status of the FERMI@Elettra Photoinjector, EPAC 2008, Genoa. Italy.
[3] A.Fabris et al., FERMI@Elettra: Installation and Commissioning of the S-band RF System, LINAC 2010, Tsukuba, Japan.
[4] G.D’Auria et al., The X-Band system for the FERMI@Elettra FEL Project, IPAC 2010, Kyoto, Japan.
[5] M.Danailov et al., Laser Systems for Next Generation Light Sources, PAC 2009, Vancouver, Canada.
[6] M.Ferianis et al., The Copper Free FERMI Timing System: Implementation and Results, BIW 2010, Santa Fe, New Mexico, US.
[7] M.Zangrando and D.Cocco, Non-Invasive Diagnostics on FEL Photon Beams General Remarks and the Case of FERMI@Elettra, FEL 2010, Malmö Sweden.
[8] S.Di Mitri, Commissioning and Initial Operation of FERMI@Elettra, this conference, ID 1269 - TUZA01.