STATUS OF THE FERMI@ELETTRA PROJECT

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Abstract

FERMI@Elettra, located next to the third-generation synchrotron light source Elettra in Trieste, Italy, is a seeded FEL user-facility covering the wavelength range from 100 nm (12 eV) to 4 nm (310 eV) [1]. The facility uses normal conducting linac and the wavelength range is covered with two lines, FEL-1 and FEL-2. Three beamlines will transport the FEL photons to the experimental stations, using proper tailoring optics and beam diagnostics to meet the research requirements. Beneficial occupancy of the new undulator and experimental hall was given at the end of summer 2010 when all auxiliary systems were also made available. The installation of the machine is now almost completed; commissioning of the linac has started in parallel to the installation activities and the commissioning of FEL-1 is in a well-advanced state. The first seeded lasing from FEL-1 was observed in December 2010 and the first experiments are starting in 2011. This paper gives an overview of the facility, as well as the general status of installation and commissioning, and a perspective into future developments and user programs.

OVERVIEW OF THE FACILITY

FERMI@Elettra is a 350 meter-long straight machine hosted in three main buildings, close to the Elettra storage ring. Figure 1 shows the site with Elettra (E) and other supporting buildings, where in the bottom part from right to left one can see the 200 m Linac building (1), the 100 m Undulator Hall (2) and the 60 m Experimental Hall (3). The building (4) hosts the technological plants.

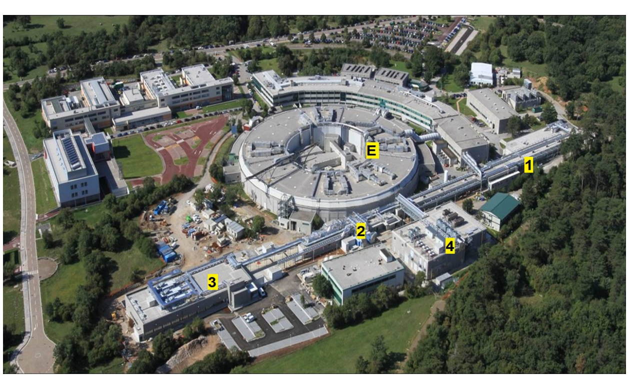

Figure 1: FERMI@Elettra located close to Elettra.

Civil works, carried out in 2007-2010 needed the use of low vibration techniques in the excavation activities, in order to minimize the disturbance of the regular Elettra operation. The main construction phase, devoted to Undulator and Experimental Halls and to the technological plants, started in 2009 and the beneficial occupancy was handed over the end of September 2010. Early co-occupancy allowed starting the installation of machine sections in parallel to the buildings.

The normal conducting 3 GHz linac is equipped with 14 RF transmitters of 45 MW peak power, feeding 16 accelerating sections, the photocathode gun and three RF deflectors. Two main power distribution schemes are present: the first with a single transmitter, feeding two accelerating sections, and the second with a single transmitter feeding a single high gradient accelerating section, via a SLED cavity. The nominal energy is 1.2 GeV for FEL-1 and 1.5 GeV for FEL-2. Repetition rate is presently 10 Hz, but it will be upgraded to 50 Hz in 2012. At 100 MeV a Laser Heater chicane with an undulator is provided to cure microbunching instabilities. Two bunch compressors at 300 MeV and 700 MeV are installed, They are designed for a bunch compression factor up to 10 and the expected compressed bunch length is 0.7 ps. A harmonic cavity at 12 GHz (X-band) will be set into operation for linear time compression in the fall of 2011. In addition, 3 RF deflectors, one in the first bunch compression region [2] and two at the end of the linac, are foreseen for diagnostic purposes, in particular to minimize the effect of the wakefields on the beam emittance in the high gradient cavities of the high energy region of the linac.

A transfer line transports the electrons from the end of the linac to the undulators in the Undulator Hall. The transfer line is about 30 meter long and allows switching between the FEL-1 and FEL-2 lines. It also includes collimation devices, diagnostic facilities and the seed laser insertion point. The seed laser specifications are set by the High Gain Harmonic Generation (HGHG) FEL scheme adopted; in particular the seed laser shall be tunable down to 200 nm, with a peak power above 100 MW over the tunability range [3]. Synchronization in the femtosecond range between the seed laser and the electron beam, as well as along the whole facility, is provided by an all optical timing distribution system [4].

The FEL-1 line consists of a planar undulator (the "modulator") and six APPLE-II undulators (the "radiators"). The wavelength of the FEL radiation can be varied thanks to the variable undulator gap, down to 10 mm. The FEL-1 nominal wavelength ranges from 100 nm to 20 nm. Furthermore, the use of APPLE II undulators allows control of the FEL polarization that can be varied from linear to circular [5].

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Table 1: FERMI@ Elettra Specifications

Parameter	FEL-1	FEL-2
Output λ (fundamental)	100-20 nm	20-4 nm
Peak Power	1 – 5 GW	> 0.3 GW
Repetition Rate	10 Hz	50 Hz
e^- 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
Slice Energy Spread	0.20 MeV	0.15 MeV

The FEL-2 line runs parallel to the FEL-1 line at a distance of 1 meter. An HGHG double cascade scheme is adopted for FEL-2, thus there is a first stage with one modulator and two radiators followed by a second stage with one modulator and six radiators. The final radiators permanent magnets periodicity is lower than in FEL-1, all other specifications are similar. The FEL-2 wavelength range, in the first harmonic is from 20 nm to 4 nm.

At the end of the two FEL lines the electrons are recombined and dumped to a common beam dump, while the photons are transported to the different experimental stations, first passing PADReS, the *Photon Analysis, Delivery and Reduction System*, and then tailored by the optical elements in the beamlines, dedicated to three experimental programs: *Diffraction and Projection Imaging* (DiProI), *Low Density Matter* (LDM) and *Elastic and Inelastic Scattering* (EIS). The EIS foresees hosting two experimental stations - the already built *TIMEX*, and *TIMER*, to be completed in 2012.

INSTALLATION

Installation has been carried out in different phases, to allow parallel commissioning of the available machine parts. It started in April 2009, with the photocathode gun, and it is still ongoing, to complete the linac and the beamlines and to assemble the FEL-2 line.

Linac

The photocathode gun and the 100 MeV section of the linac were built up during the first installation phase in 2009. The largest part of the accelerator was assembled in various steps, to allow parallel progress in the commissioning with beam.

The first Bunch Compressor was placed in May 2010 and after his performance was validated with beam the second compressor was produced and installed in May 2011.

The X-band system and the two high energy RF deflectors are the components still missing in the linac. The X-band cavity production is almost completed and its installation is scheduled for October 2011. It has turned out that the fabrication of the high energy RF deflectors is particularly challenging and is still going on.

FEL-1

The installation of FEL-1 involved two important steps. From February to August 2010, the transport line from the linac to the beam dump were placed, including the aluminium low gap vacuum vessels at the undulator locations. After two months of commissioning, the electron beam transport was optimized and the induced radiation level minimized. This allowed installation of seven undulators of FEL-1 with a reduced risk for radiation damage of the permanent magnets (see Fig. 2) at the end of October 2010.

Figure 2: The FEL-1 radiators.

FEL-2

The FEL-2 line is being assembled during this summer shutdown. Transport of the electron beam along the FEL-2 line through the beam dump is however scheduled with a lower priority than the commissioning of FEL-1 to the nominal performance, hence it will follow most likely in 2012. The production of the FEL-2 undulators is at a fairly advanced stage and they will be installed in 2012, starting with the first stage of the cascade.

Photon Transport and Beamlines

Assembly of the photon transport started end of 2010 and is still running. Due to lack of some beam tailoring and focusing components, temporary solutions were implemented for the characterization of machine performance, using the available beamline diagnostic systems. This opportunity was of crucial importance to evidence the first lasing in December 2010 and to start the commissioning of the experimental stations in March-April and in July 2011.

The final assembly of the DiProI and TIMEX beamlines and commissioning of the performance of the optical layout using the experimental stations will be completed before the end of 2011. The LDM beamline will also be completed by the end of the year, along with the permanent experimental station.

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COMMISSIONING

The commissioning of the 100 MeV linac started in summer 2009. This was the first step of the machine commissioning which is still going on. The first important goal was reached at the end of 2010 when first evidence of coherent signal in the range from 60 to 20 nm was demonstrated.

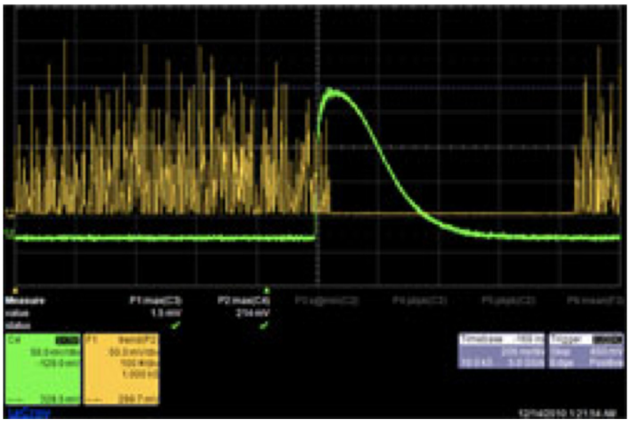

Figure 3: First lasing on 13 December 2010.

Figure 3 shows the first seeded coherent emission from FEL-1, measured using a fast photodiode with undulators tuned at 65 nm. The green trace shows the time profile of a single pulse with the photodiode in saturation. The yellow trace shows a series of seeded FEL pulses, being turned on (left) and off (center-right) by changing the superposition between the seed laser pulses and the electron bunch.

During 2011 the FEL-1 performance has improved gradually [6]. At 43 nm the measured photon flux increased from less than $1*10^9$ photons per pulse in December 2010 to more than $1*10^{13}$ photons per pulse in July 2011. Similar flux intensities are measured at 52 nm and 32.5 nm (spectrum shown in figure 4). However, the most important result is that we can also reach the lower limit of the FEL-1 wavelength range, 20 nm, where the achieved photon flux is $1*10^{12}$ per pulse.

While the benefit of using external seeding in terms of bandwidth and photon energy stability was evident since the very first day of FEL operation, with a typical $\Delta E_{FWHM}/E$ of $1.2*10^{-3}$, there are other important recent achievements. Namely, after the FEL-1 has been optimized on the TEM00 Gaussian mode, there is clear evidence of FEL exponential gain. In the same mode we could diffract the unfocused FEL through periodic structures, acquiring several images whose preliminary analysis shows a very good degree of spatial coherence.

The seeding process results to be quite straightforward and smooth. Once the FEL is on, its stability is quite good, after successfully solving an RF phase jitter issue.

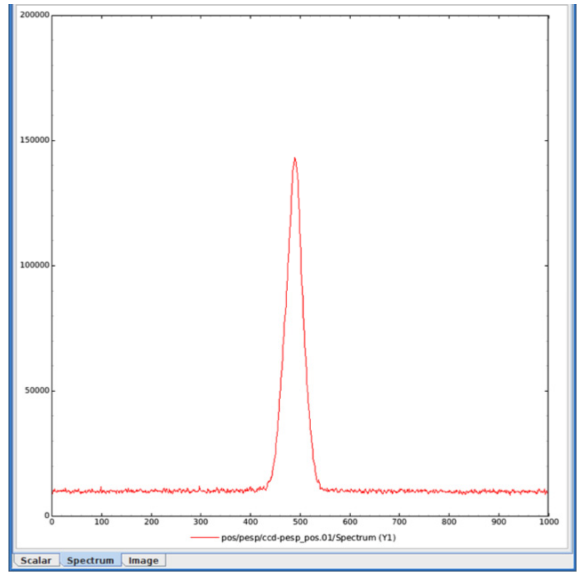

Figure 4: FEL spectrum at 43 nm, July 2011.

FEL light was provided to the experimental stations for beamline and end station commissioning already in March 2011. During that period, while operating for LDM, the FEL polarization was varied for the first time from linear to circular. In July 2011, all three experimental stations were tested with photons and, during the LDM beamtime, a FEL tuning over a small range around 52 nm has been achieved by changing the seed laser wavelength by approximately 1 nm (0.4%).

CONCLUSION

The FERMI@Elettra user facility is close to start operation. Commissioning of the first FEL line (FEL-1) is at a fairly advanced stage and the nominal performance is expected to be attained by the end of 2011.

The commissioning of the second FEL line (FEL-2) will start in 2012, in parallel to the user experimental program which will be launched on FEL-1.

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