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FERMI STATUS REPORT

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Abstract

FERMI, the seeded Free Electron Laser (FEL) located at the Elettra laboratory in Trieste, Italy, consists of two FEL lines. The FEL-1 facility, covering the wavelength range between 20 and 100 nm, was officially opened to external users. The shorter wavelength range, between 20 and 4 nm, is covered by the FEL-2 line, a double stage cascade operating in the "fresh bunch injection" mode, which is still under commissioning. We will report on the different FEL-1 operation modes that can be offered for users and assess the performance of the facility. The progress in the commissioning of FEL-2 will then be addressed, in particular reporting the performance attained at the lower wavelength limit; this aspect is of great interest for the user's community of the FERMI seeded FEL since it allows to carry out experiments below the carbon K-edge.

INTRODUCTION

Over the last year various activities have been carried out at FERMI, the Italian seeded FEL in Trieste. The lower energy FEL line, FEL-1, covering the range between 12 and 62 eV [1], is open for users and welcomed scientists from Italy and from all over the world to perform experiments on the three experimental stations so far available, namely the Diffraction Projection Imaging (DiProI) station, the Elastic Inelastic Scattering TIMEX (EIS-TIMEX) station and the Low Density Matter (LDM) station. A part of the infrared seed laser pulses has been successfully transported to the experimental stations, making very low jitter pump-probe experiments possible.

The higher energy FEL line, FEL-2, covering the range between 62 and 310 eV and based on a double stage HGHG cascade, produced the first coherent photons at 14.4 nm in October 2012; that was the first experimental demonstration of a seeded free electron laser configured as a two stages cascade operating in the "fresh bunch injection" mode [2]. Since then three more commissioning runs allowed to explore the performance of FEL-2 on the whole operating range down to 4 nm and beyond. Most recent results at 4 nm will be shown here.

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Along with operation of FEL-1 and commissioning of FEL-2, the construction completion activities and the first upgrades are progressing. Three more beamlines are under construction and will be completed by 2015. First upgrades are concentrated on the linac. The new 50 Hz photocathode gun has been installed and commissioned during 2013. The linac energy finally attained 1.56 GeV. Two more accelerating structures are in construction and will be installed in 2015. This will give operating margin on the nominal energy and is part of an upgrade program which has been launched to get an even more reliable and robust facility for our user's community.

FEL-1 OPERATION FOR USERS

Three calls for proposals of experiment on FERMI have been opened between 2012 and 2013. A total number of 125 proposals were submitted and 50 have been ranked by the FERMI Review Panel (FRP) to get beamtime. In the 3rd call, 50 proposals have been submitted and 16 have been short listed in the FRP meeting of January 2014 for beamtime, that is, with an oversubscription rate of 3.13.

In 2013 the FERMI operation time attained almost 6500 hours, divided between time for linac, FEL-1 and FEL-2 commissioning (55% of total hours) and time for users operation (45% of total). The latter includes machine and beamline preparation time, beamtime for internal scientific groups and beamtime for external users assigned via the FRP. In total, FERMI hosted during 2013 15 experiments peer reviewed by the FRP, pertaining to both the first and second call for proposals, equally divided between DiProI (5), EIS-TIMEX (5) and LDM (5). During 2014 FERMI will host 16 experiments, pertaining to both the second and third call, of which 7 on DiProI, 2 on EIS-TIMEX and 7 on LDM.

The average uptime of the FEL during user beamtime runs achieved 84.3% in 2013, to be compared with the goal set at 80%. Anyway, various actions have been launched to increase the reliability of some of the most critical systems, like the linac RF plants and the seed laser system, along with the aim to reduce the time needed for the optimization and fine tuning of the FEL parameters. For instance, after the installation of a new seed laser oscillator, with reduced phase noise, the seed laser system uptime is equal to 100%, along with a phase noise and jitter reduction by more than a factor of 3. The time for

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optimization and fine tuning strongly depends on the FEL parameters requested by the users. For the standard operating conditions of FEL-1, listed in Table 1, the operability and reliability of the machine is very good and the uptime is close to 90%.

Table 1: FEL-1 Standard Parameters

Parameter	FEL-1
Electron beam energy	1.0 - 1.4 GeV
Bunch charge	500 pC
Bunch Peak Current	400 – 600 A
Wavelength	100 – 20 nm
Energy per pulse*	30 – 200 μJ
Photons per pulse**	10^{13} at 20 nm

**average, depending on wavelength and spectral purity.*
***up to 10^{14} at longer wavelengths.*

However, a more complex set of FEL parameters can be requested by a given experiment. This is the case of the novel two colour FEL scheme, which is possible with a seeded FEL as FERMI [3]. In this configuration, two FEL pulses, pump and probe, are generated by seeding the electron bunch with two laser pulses. Wavelength and intensity ratio between the two pulses, as well as the time delay between them can be controlled; the feature is that the two pump and probe pulses are practically jitter free. Of course this configuration, which is of great interest for the FERMI users' community, demands for longer machine preparation times than the standard configuration and also the uptime may then be lower than 80%, due to longer and more frequent FEL optimization times.

Another way to perform time resolved experiments at FERMI is provided by transporting a portion of the IR seed laser pulse from the seed laser room down 150 m to the experimental stations. Low timing jitter is an intrinsic characteristic of the system, since the FEL is generated by the same seed pulse. Low jitter and high pointing stability along the transport line and in the distribution tables to the experimental stations are then ensured by advanced optical and mechanical design, along with sophisticated feedback loops. Figure 1 shows the signal stability on a semiconductor sample at EIS-TIMEX, with an excellent jitter value of less than 7 fs rms [4].

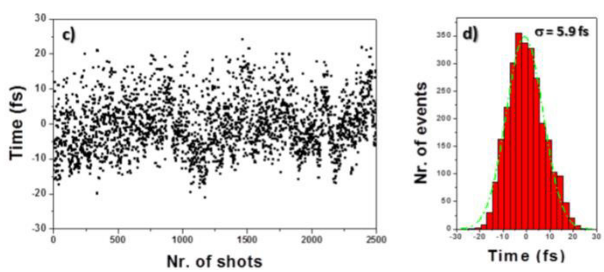

Figure 1: Typical jitter measurement at EIS-TIMEX.

PROGRESS ON FEL-2

FEL-2 is based on a double stage cascaded HGHG scheme; the external seed laser, the third harmonic of a Titanium:Sapphire laser, seeds the first stage, made up of a modulator and a two segments radiator; the photon pulse generated in the first stage seeds the second stage, made up of a modulator and a six segments radiator. A delay line, made by a magnetic chicane after the first stage, allows to delay the electron beam with respect to the photon pulse. At the end of 2013, after three commissioning periods, FEL-2 was characterized at several harmonic transitions, in both stages, and at different electron beam energies, between 1.0 and 1.4 GeV. After first lasing at 14.4 nm in October 2012, later studies were carried out at 10.8 nm, where the energy per pulse achieved up to 100 μJ. Lasing was also observed at 6.5, 5.0 and 4.08 nm, even if at lower intensities. All studies were carried out with 500 pC electron bunch charge. Finally, in May 2014 it was possible to study the FEL-2 behaviour at the nominal electron beam parameters required for FEL-2 at 4 nm, as reported in what follows.

New Photocathode Gun

A new photocathode gun, capable to operate at 50 Hz, was installed in 2013. The cathode aging, expected, at the beginning was quite fast. Laser processing was applied as a first cure, but then in January 2014 the cathode was replaced. Since then the new gun runs with excellent performances. The laser pulse energy required to extract 500 pC from the gun is now as low as 30 μJ, more than a factor 2 less than prior to cathode replacement. This leaves enough margins to increase the charge to 800 pC. The emittance measured at the laser heater, 100 MeV, is 0.7 mm mrad (500 pC) and 1.0 mm mrad (800 pC) and can be quite well preserved along the linac.

Linac Energy Increase

Two periods in May and August 2013 were dedicated to the full activation of the SLED cavities in the high energy section of the linac and the consequent RF conditioning of the 7 backward travelling accelerating sections. Energy gains of 150 MeV per section could be achieved, also thanks to implementing the SLED operation with the phase modulation technique, to reduce the peak field in the cavities for the same gain factor. Eventually in August the energy of 1.56 GeV could be achieved. As shown in Fig. 2, that results in 1.5 GeV working electron beam energy, once the losses for chirp compensation and for linearization by deceleration in the fourth harmonic X-band cavity are taken into account.

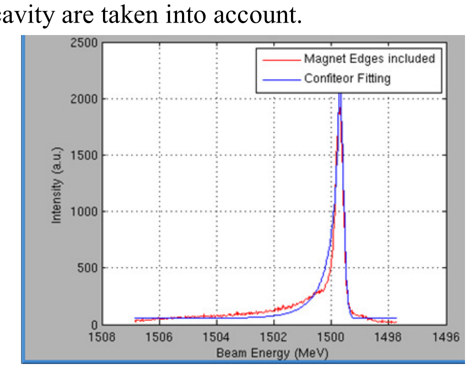

Figure 2: 1.5 GeV electron beam energy.

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FEL-2 Achieves Nominal Intensity at 4 nm

The run number 20 of FERMI started in May 2014. The first 7 weeks of the run are devoted to commission FEL-2 at its shortest wavelength, that is 4 nm (310 eV), with the electron beam parameters set to the nominal foreseen conditions, 1.5 GeV electron beam energy, 800 A peak current (800 pC extracted from the gun) and well controlled emittance and energy spread.

After few weeks of characterization and optimization, in particular of the beam trajectory across FEL-2, on the 6^{th} of June we could produce FEL pulses at 4 nm with the expected average intensity of 10 µJ and some super-shots at 20 µJ. The first stage was tuned at the 13^{th} harmonic of the seed laser, 20 nm, and the second stage at the 5^{th} harmonic of the first stage (harmonic transition 13x5). Electron beam and FEL parameters are summarized in Table 2, while Fig. 3 shows the FEL-2 spot at 4 nm and Fig. 4 the intensity measured on the photodiode.

Table 2: FEL-2 Parameters, May – June 2014

Parameter	**FEL-2**
Electron beam energy	1.5 GeV
Bunch charge	800 pC
Bunch Peak Current	800 A
Wavelength	4 nm
Energy per pulse, average	10 µJ

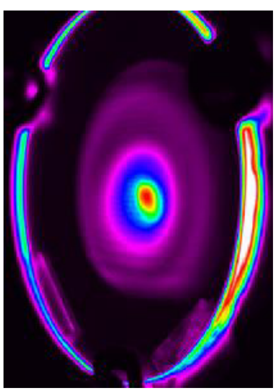
Figure 3: FEL-2 spot at 4 nm.

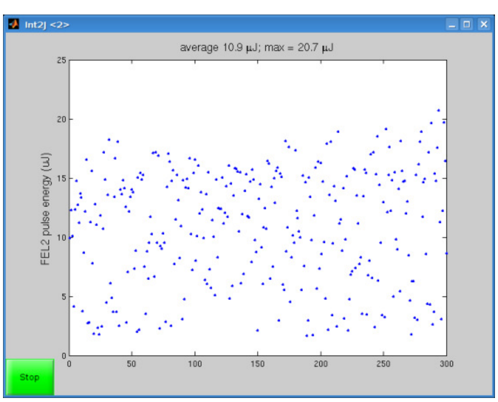

Figure 4: Photodiode intensity versus time, at 4 nm.

This is a remarkable improvement compared to the results obtained in 2013 and opens the perspective to the opening of FEL-2 for users in the f call for proposals, the fourth of the series.

UPGRADE ACTIVITIES AND PLANS

Three more beamlines are presently under construction and will be available for users at the end of 2015. They are EIS-TIMER, a Four-Wave-Mixing instrument, MagneDyn, that will allow to perform time resolved magnetic dynamics studies, and finally TeraFERMI, that will use the spent electron beam in the Main Beam Dump to produce femtosecond, high intensity (MV/cm), broadband (0.1 to 10 THz) TeraHertz pulses.

Meanwhile, the linac will be completed with two additional accelerating sections. The new structures will have minimized phase and amplitude asymmetries in the coupler cells, to reduce the induced kick to the beam; they will gain 50 MeV each. They will replace the first two sections in the 100 MeV injector part, which will then be relocated at higher energy, where free spots in the layout and RF power are already available. This upgrade will allow to increase the maximum linac energy to 1.65 GeV, beneficial both in terms of minimum wavelength achievable and of reliability and uptime. Furthermore, the beam quality at 100 MeV is expected to improve.

There is also a plan to profit of the free spots in the FEL-2 layout to upgrade it; namely there is space available to host a third undulator in the first stage radiator. This would bring advantages in terms of reliability and flexibility of FEL-2 operation.

CONCLUSION

FERMI is routinely operating for users with FEL-1.

FEL-2 has achieved the nominal energy per pulse at 4 nm and will be opened for users in the next call for proposals.

An upgrade program to widen the experimental opportunities and to further increase the reliability, the robustness and the flexibility of the facility is ongoing.

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