DOUBLE STAGE SEEDED FEL WITH FRESH BUNCH INJECTION TECHNIQUE AT FERMI@ELETTRA

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Abstract

During the month of October 2012 the commissioning of the light source FEL-2 at FERMI reached an important milestone. Fermi FEL-2 is the a seeded FEL operating with a double stage cascade in the "fresh bunch injection" mode [1]. The two stages are two high gain harmonic generation FELs where the first stage is seeded by the 3rd harmonic of a Ti:Sa laser system, which is up converted to the 4th-12th harmonic. The output of the first stage is then used to seed the second stage. A final wavelength of 10.8 nm was obtained as the 24th harmonic (and eventually 48th) of the seed wavelength at the end of the two frequency conversion processes, demonstrating that the FEL is capable of producing single mode narrow bandwidth pulses with energy of several tens of micro Joules. We report on the experimental characterisation of the FEL performances in this configuration.

INTRODUCTION

FERMI@Elettra free electron laser (FEL) is a fourth generation light source at the research centre Elettra – Sincrotrone Trieste, Italy that will function as a user facility producing photons in the ultraviolet and soft X-ray wavelength regions. The scientific case, based on three experimental programs, namely *Diffraction and Projection Imaging* (DiProI), *Elastic and Inelastic Scattering* (EIS), *Low Density Matter* (LDM), calls for stable, high peak brightness, nearly fully coherent, narrow bandwidth photon pulses, together with wavelength tunability and variable polarization [1, 2].

FERMI is driven by a single-bunch, S-band high brightness electron linac. The present final energy of 1.2 GeV will soon be upgraded to 1.5 GeV in order to extend the lowest wavelength range down to ~4 nm. The present 10 Hz repetition rate will also be upgraded to 50 Hz r. Two undulator lines cover the different parts of the total wavelength range. FEL-1, based on a single stage, High Gain Harmonic Generation (HGHG) configuration seeded by an external UV laser (~ 260 nm), covers the range from 80 to 20 nm. To access the 20 to 4 nm region, while still starting from an external seed laser in the UV range, a two stage, harmonic upshift cascade is adopted for FEL-2. A delay line chicane between the two stage improves the FEL performance by using a *fresh part* of the electron bunch in the second stage of the cascade [3]. The facility overview and status report is described in [4]. Recently achieved performance parameters are listed in Table 1.

Table 1: Present FEL-1 and FEL-2 Parameters

Parameter	FEL-1	FEL-2
Electron bunch energy	1.2 GeV	1.0 – 1.2 GeV
Bunch charge	500 pC	500 pC
Bunch Peak current	400 – 600 A	300 - 500 A
Wavelength	80 – 20 nm	20 – 8.3 nm
Energy per pulse*	90 to 320 μJ	up to 100 μJ
Photons per pulse**	10^{13} @ 20 nm 10^{14} @ 52 nm	10^{12} @ 8.3 nm
Relative bandwidth	~10^{-4}	< 10^{-3}
Intensity stability, rms	15%	~50%
Central wavelength stability, rms	~10^{-4}	~ 10^{-4}
Bandwidth stability	< 3%	~ 10%
Repetition Rate	10 Hz	10 Hz

** average, depending on wavelength*
*** max achieved*

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COMMISSIONING OF FEL-2 HGHG – FIRST STAGE

The schematic layout of FEL-2 undulator line is shown in Fig.1. Undulators were installed during April 2012. Commissioning of the first stage of the cascaded HGHG scheme was accomplished by the end of 2012.

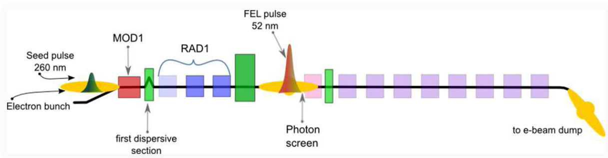

Figure 1: Schematic of FERMI FEL-2 undulator line.

In order to attain the required synchronization between the electrons and the seed laser, a similar procedure to that used for FEL-1 commissioning [5] has been followed. Transverse spatial overlap between electrons and the seed laser is ensured by aligning electrons and photons on two diagnostic screens placed before and after the modulator (MOD1). With the undulator resonance tuned at the seed laser wavelength, the electrons energy distribution appears to be modified with the spectrometer at the end of the undulator [6, 7]. The electrons and seed laser spatial and temporal overlap led to the detection of coherent signal on the photon screens downstream the first stage radiators, tuned at the 5th harmonic of the seed laser. Such coherent emission was used as a probe for the alignment check of a number of diagnostic stations placed in between the second stage radiators. Finally, the photon beam was visible on the screen at the entrance of the experimental hall, 55m away from the emitting radiators.

COMMISSIONING OF FEL-2 IN FRESH BUNCH MODE

Commissioning of the entire FEL-2 line was accomplished with main electron beam parameters listed in Table 1. The Seed laser was the third harmonic of a Titanium:Sapphire laser with a duration of ~180 fs (FWHM) and up to 20 μJ energy per pulse. The transverse size of the seed laser in the modulator was made larger than the electron beam size to ensure as uniform as possible the electron beam energy modulation.

An optical parametric amplifier allows the seed laser central wavelength to be tuned continuously in the range 230–260nm. At the same time, APPLE-II type radiators, namely undulator segments with remotely controllable gap and phase, allow rapid tunability of the output FEL central wavelength and polarization [8]. The first stage is operated in a low gain, nearly constant bunching regime.

FEL-2 first stage is followed by a magnetic chicane that delays the electron bunch respect to the co-propagating photon pulse. Typical time delays are in the range 100 – 300 fs; the corresponding momentum compaction destroys nearly all residual bunching from the first stage,. The second stage with 6 radiator segments is configured in a true HGHG regime, with the FEL power growing exponentially along the second half of the undulator line.

FEL-2 output photon pulse spectrum is essentially made of the radiation emitted from the first stage, at the n^{th} harmonic of the seed laser wavelength, and by radiation emitted from the second stage, at the m^{th} harmonic of the first stage. These two spectral components approximately overlap both in time and space. Their energy per pulse and spectrum was measured by two independent systems, on a shot-by-shot basis.

Commissioning of FEL-2 in fresh bunch mode was accomplished by investigating several harmonic jumps, in both stages. As an example, the second stage was tuned at harmonic number m = 2, 3, 4 or 6, depending on the harmonic number in the first stage, to eventually reach the 18^{th} and the 24^{th} harmonic of the seed laser. A first campaign of studies was carried out at 1.0 GeV to reach 10 nm fundamental wavelength. Later, the beam energy was increased to 1.2 GeV to access to shorter wavelengths, such as $n = 8$, $m = 6$, so the 48^{th} harmonic of the seed laser, namely 5 nm.

All measurements revealed good spectral stability. Purity of the second stage spectra was sensitive to the initial seed laser power. During optimization of the entire system, the first stage output energy was set at few μJ level. Higher energy could have been achieved with a more intense seed laser pulse, but at the expense of the final spectral purity. The second stage output could be as large as tens of μJ.

FUTURE PLANS

By Spring 2013 the linac energy will increase to 1.5 GeV, by full activation of the SLED cavities, in order to reach 4 nm, i.e. the lower wavelength limit for FEL-2. At the same time, the repetition rate of the facility will also be upgraded from 10 Hz up to 50 Hz upon the installation of the new photocathode gun and the completion of the upgrade program of the linac modulators. An intense development program of the beamlines is also ongoing, including, among others, the construction of the second EIS beamline, TIMER, and the setting into operation of the user laser for pump and probe experiments.

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