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COMMISSIONING OF THE LASER BEAM TRANSPORT FOR THE FEMTO-SLICING PROJECT AT THE SYNCHROTRON SOLEIL

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Abstract

The aim of the Femto-Slicing project at SOLEIL is to generate 100 - 200 fs FWHM short X-ray pulses on two beamlines, CRISTAL and TEMPO, for pump-probe experiments in the spectral range of hard and soft X-rays. We note that this capability could be extended in the future to two or three more beamlines. Femtosecond lasers are currently in operation on TEMPO and CRISTAL beamlines, for pump-probe experiments on the ps time scale, enabling time resolved photo-emission and photo-diffraction studies, respectively. The Femto-Slicing project is based on the fs laser of the CRISTAL beamline, which can be adjusted to deliver 3 to 5 mJ pulses of 30 fs duration at 2.5 to 1 kHz, respectively. This laser beam is separated in three branches: one delivering about 2 mJ to the modulator wiggler and the other ones delivering the remaining energy to the experiments on the TEMPO and CRISTAL beamlines. This layout will yield natural synchronisation between Infra-Red (IR) laser pump and X-ray probe pulses, only affected by jitter and drift associated with beam transport.

In this paper, we present the progress in the implementation and commissioning of the laser beam transport system and its characterization.

INTRODUCTION

The first proposition for a Femto-Slicing project at SOLEIL [1] was based on the use of three lasers, located at different places: a powerful fs laser dedicated to the slicing of the electron bunches (5 mJ, 30 fs, 10 kHz), installed in a hutch close to the storage ring, and the pump lasers for the TEMPO (4 µJ, 35 fs, 250 kHz) and the CRISTAL (5 mJ-500 µJ, 30 fs, 1 kHz-10 kHz) beamlines. Due to funding limitations, a reduced version in term of laser performance has been retained to start the project. In this scheme, the CRISTAL laser, with its characteristics adjusted to 5 mJ, 30 fs, 1 kHz, is used for both, delivering the IR laser pump and creating the X-ray probe pulse. In term of synchronization, this scheme is simpler than the first version, since the same laser locked on the machine radio-frequency RF/4 clock generates the 800 nm laser pump and X-rays probe pulses. We note that such a configuration is used also in the other femto-slicing facilities [2] [3] [4].

LASER BEAM TRANSPORT SYSTEM

For the optical beam transport system, the challenge is to transport the compressed femtosecond laser beam over long optical paths, with a minimum loss of energy, minimum distortion of spatial intensity profile and temporal pulse profile. The laser beam transport has also been designed to keep a high degree of polarization as needed for the interaction in the wiggler.

Design Requirements

The requirements for the interaction of the laser beam with the electron bunch are summarized in table 1.

Table 1: Requirements for Laser-Electron Interaction

Parameter	Value
Laser energy	2 mJ
Pulse duration	50 fs
Laser Rayleigh length	0.5 meters
Laser pointing stability	10 µrad
Laser waist inside the wiggler	~ 400 µm
Electron beam size (2xσ)	~20 µm (V) x 400 µm (H)

The maximum electron energy modulation calculated with various codes [5] as a function of the laser pulse energy is shown in figure 1.

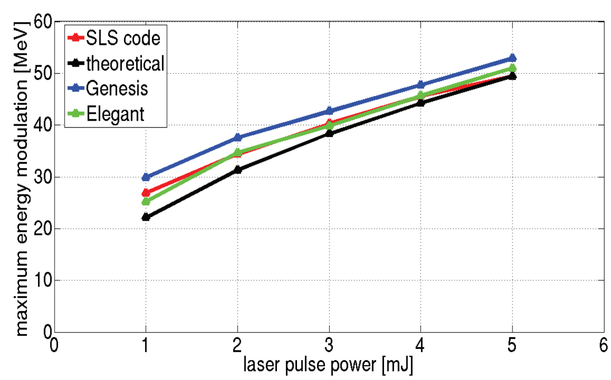

Figure 1: Electron energy modulation versus laser pulse energy.

For these parameters, the expected number of photons are about 5 10^5 photons/s (CRISTAL) and 10^6 photons/s (TEMPO).

Design Concept

The schematic layout of the optical beam transport system is shown in figure 2. The laser used is that of the CRISTAL beamline. At the exit of the laser, the beam is separated into 3 branches. The laser energy on each branch is adjustable by changing beam splitters in the optical enclosures ENC.104 and ENC.105, which are

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located on the roof of the accelerator tunnel. The distance between the CRISTAL laser and the wiggler is about 80 m, while the transport distance between the CRISTAL laser and the TEMPO experiment is about 110 m. For the long optical path, delivering 50 fs laser pulse at such distance is quite challenging. Therefore, the transport is kept in static primary vacuum and the number and thickness of optical windows used on the laser path have been minimized as much as possible to avoid dispersion effects.

For the delay line necessary to equalize the overall path length between the pump and probe pulses, we have taken advantage of the distance between the laser source and the X-ray source. One part of the laser beam sent toward the wiggler, is sent back to the experiment to be employed as the pump pulse for both experiments at the CRISTAL and TEMPO beamlines.

CRISTAL-WIGGLER Optical Beam Transport

The optical beam transport from the CRISTAL laser hutch to the wiggler is named BT10 (blue line in fig.2). The laser beam is transported to the entrance of the wiggler with several in-vacuum mirrors MIR101-MIR110, located in five optical enclosures. First of all, the laser beam is elevated and transported above the ring. Two mirrors MIR103 and MIR102, located in enclosure ENC102, send the laser inside the ring. This enclosure is placed in a shielded box in order to protect personnel against radiation hazard. Inside the ring, the laser beam is sent through the tangent port of a dipole chamber via two mirrors MIR101A –MIR101B and focused to the center of the wiggler by a 9.1 m lens LENS101. This lens is located just before MIR101A and MIR101B. A thin UHV MgF_2 window placed before the dipole chamber separates the ultra-high vacuum from the primary vacuum.

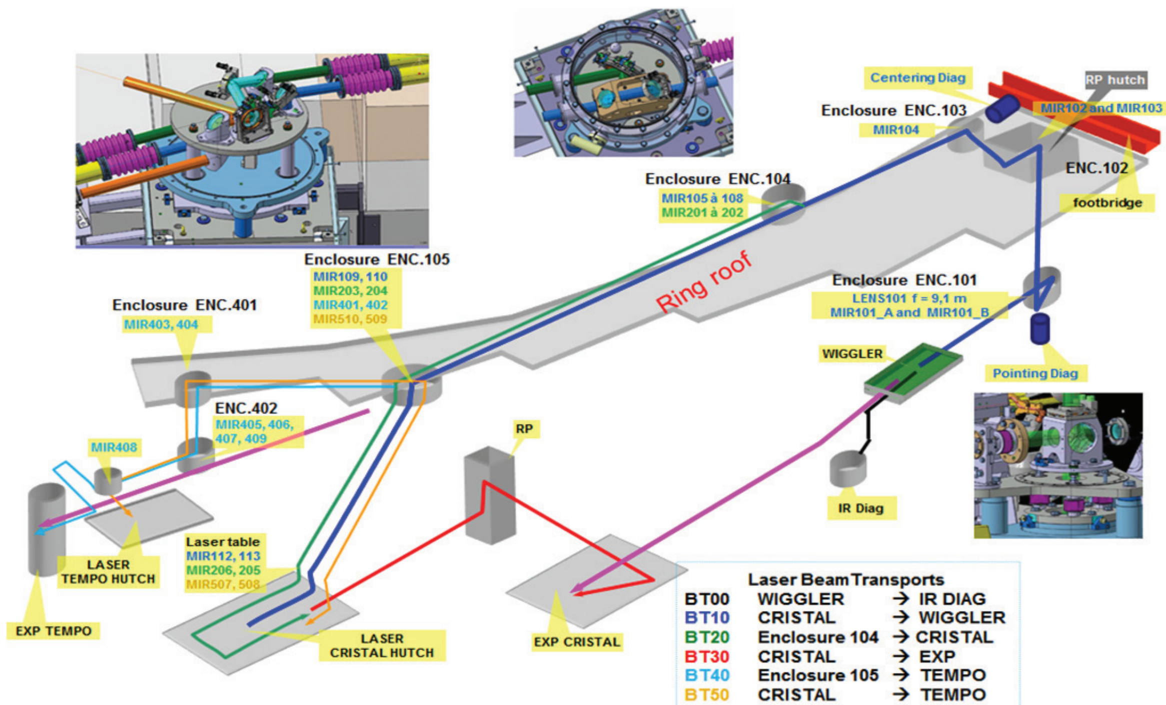

Figure 2: Layout of the optical laser beam transport system.

On the optical path towards the wiggler, the returning optical beam transport to the CRISTAL beamline named BT20 (green line in fig.2) is created with the MIR108 beam splitter. In the enclosure ENC105, another beam splitter MIR203 on the returning path can be placed to distribute the beam between CRISTAL and TEMPO and to create the BT40 laser beam transport. This enclosure has three beam entrances and three beam exits. It comprises several mirrors and a diagnostic.

The figure 3 shows pictures of the enclosures ENC105, ENC104, and ENC103 installed on the ring roof.

CRISTAL-TEMPO Optical Beam Transport

The laser transport system to the TEMPO beamline will be installed by the end of 2014. One branch named BT40 starts from enclosure ENC105. The other one, named BT50, will start directly from the CRISTAL laser hutch and go to the TEMPO laser hutch. We plan to use this last one for making synchronisation between the two laser systems.

Optical enclosures ENC401, ENC402, ENC403 comprising optical mirrors, diagnostics and an additional delay line for TEMPO are under construction.

We note that as part of a future development experiments at the TEMPO beamline will also be able to use the TEMPO laser as pump, which will offer more

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flexibility in pump wavelength and facilitate the transition from ps to fs experiments.

Figure 3: Pictures of ENC105 (left) and ENC104, ENC103 and shielded box (right), installed on the tunnel.

Laser Transport Diagnostics

The centering diagnostics package consists of two diagnostics in the laser hutch and another one before the tunnel entrance. They routinely ensure that the laser is properly transported, i.e. centred on each optics along the path and collimated to about 40 mm (99,99 % enclosed energy) before the focalisation. These diagnostics are made of afocals which relay an image plane of the beam to the desired object space on CCD cameras. For controlling the pointing inside the wiggler, another diagnostic which images the far-field is located behind the last laser mirror MIR101B in the ring. These diagnostics are coupled with motorized mirrors in the laser hutch and in enclosures ENC103, ENC104 and ENC105.

The requirement is to have a pointing precision of 10 µm at 10 m in the wiggler.

Two other important IR imaging and terahertz diagnostics described in [6] are used for finely finding the spatial, temporal and spectral overlap between the laser and the electron bunch at low current, and for controlling the interaction laser-electron efficiency.

COMMISSIONNING

The wiggler and the main part of the laser beam transports and diagnostics were installed during three machine shutdowns between August 2013 and January 2014. The laser transport diagnostics were characterized between January and March 2014. For preliminary alignment, the laser beam profile was observed on a target located at 14 m behind the wiggler, close to the IR imaging station. The beam was propagated with the nominal size of about 40 mm before the focalisation. The figure 4 shows that the laser beam and the synchrotron radiation are aligned on the center of the target. With the nominal laser beam size of 40 mm requires before the lens, the beam after the focalisation spreads as it travels through the diverse vacuum chambers and it is partially clipped by the crotch and slot dipole sections. So, on the target, we observe a beam section of about 15 mm (V) x 22 mm (H) in good agreement with the optical simulations.

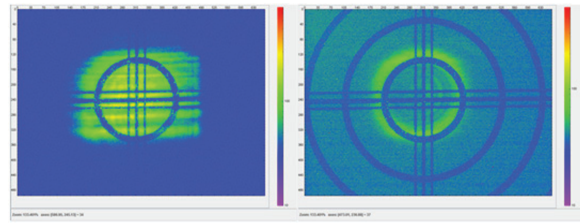

Figure 4: Beam profiles observed on a target at 14 m from the wiggler center. Diameter of the first target ring is 10 mm. (Left) laser profile (laser output: 3 mJ @ 1 kHz, beam diameter at LENS101 ~ 40 mm). (Right) synchrotron radiation (wiggler gap = 19 mm, 2 mA current).

The output laser energy was varied from 0.2 mJ to 3 mJ @ 1 kHz. At the same time, in the laser hutch, the returning beam to CRISTAL was observed and the beam size and profile after the 80 m propagation length were checked and used for alignment. The IR diagnostic for the fine alignment of the laser with the electron beam were installed inside the tunnel on February 2014. Commissioning of the electron-laser overlap has started and tests have been done during some machine beam time. First observations of the electron radiation and laser beam on this diagnostic have been done with first tests of the temporal overlap.

CONCLUSION

The installation of the beam transport system has been carried out. Characterisations of the diagnostics have progressed significantly. Commissioning of the electron-laser interaction is underway.

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