Progress on the Femto-Slicing Project at the Synchrotron SOLEIL

P Prigent, Ph Hollander, M Labat, M E Couprie, J L Marlats, C Laulhé, J Luning, T Moreno, P Morin, A Nadji, F Polack, S Ravy, M Silly, F Sirotti
Synchrotron SOLEIL, L’Orme des Merisiers - Saint-Aubin - BP 48 – 91192 GIF S/YVETTE Cedex, FRANCE

E-mail: pascale.prigent@synchrotron-soleil.fr

Abstract. The aim of the Femto-Slicing project at SOLEIL is to generate 100 fs X-rays pulses on two beamlines, CRISTAL and TEMPO, for pump-probe experiments in the hard and soft X-rays regions. Two fs lasers are currently in operation on TEMPO and CRISTAL for pump-probe experiments on the ps time scale enabling time resolved photoemission and photodiffraction studies. The Femto-Slicing project is based on the fs laser of the CRISTAL beamline, which can be adjusted to deliver 3 mJ pulses of 30 fs duration at 2.5 kHz. The laser beam will be separated in three branches: one delivering about 2 mJ to the modulator Wiggler and the other ones delivering the remaining energy to the TEMPO and CRISTAL experiments. This layout will yield natural synchronization between IR laser pump and X-ray probe pulses, only affected by jitter associated with beam transport. In this paper, we present the current status of the Femto-Slicing project at SOLEIL, with particular emphasis on the expected performance, and the design and construction of the laser beam transport and the diagnostics implementation.

1. Introduction
The goal of the Femto-Slicing project at SOLEIL is to provide 100 fs pulses of soft and hard X-rays for pump-probe experiments on two beamlines, with reasonable flux and with a 1-10 kHz repetition rate. Our first proposition [1] for the project was based on the use of three separate lasers, located at different places: one (4 µJ, 35 fs, 250 kHz) on the TEMPO beamline, another one (500 µJ, 30 fs, 10 kHz) on the CRISTAL beamline and a more powerful femtosecond laser (5 mJ, 30 fs, 10 kHz) near the storage ring. Due to a postponed funding, a less ambitious version in term of laser performance has been retained for starting the project. In this scheme, we are going to share the CRISTAL laser with its characteristics adjusted to 3 mJ, 30 fs, 2.5 kHz, to both create the slicing process and to pump the experiments. In term of synchronization, this scheme is simpler than our first version, since the same laser locked on the RF/4 clock of the machine generates the IR laser pump and X-rays probe pulses. Such configuration used in other facilities [2] [3] [4], has already demonstrated its abilities. Presently, we are studying the optical transport systems to the wiggler and to the experiments. The two lasers on TEMPO and CRISTAL are running and some ps pump-probe experiments have already been carried out.
In this paper, we present the advance in the design concept and implementation of the optical beam transport system.
2. Optical 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 optical beam transport should also be designed to keep a high level of polarized beam for the interaction into the wiggler. Therefore, the optical beam transport system is one of the important components in this project.

2.1. Design requirements

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

| Element                           | Value               |
|-----------------------------------|---------------------|
| Laser energy                      | 2 mJ                |
| Pulse duration                    | 50 fs               |
| Laser Rayleigh overlap            | 0.5 meters          |
| Laser pointing stability          | 10 µrad             |
| Laser waist inside the wiggler    | ~ 400 µm            |
| Electron beam size (2×σ)          | ~20 µm (V) x 400 µm (H) |

The maximum electron energy modulation calculated [5] as a function of the laser energy is shown on figure 1.

Figure 1. Electron energy modulation versus laser energy.

For these parameters, the expected number of photons on the CRISTAL sample at 7 keV is about $10^5$ photons/s and the X-ray pulses duration expected on each beamlines is given in table 2.

| Radiator | Laser | Slippage | Emittance | Energy | Total |
|----------|-------|----------|-----------|--------|-------|
| TEMPO    | 50    | 53       | 47        | 117    | 145   |
| CRISTAL  | 50    | 53       | 54        | 52     | 104   |
2.2. Design concept

The schematic layout of the optical beam transport system is shown on figure 2. The distance between the CRISTAL laser and the wiggler is about 80 m long. The distance between the TEMPO laser and the wiggler is about 120 m long. For the long optical path, delivering 50 fs laser pulse at such distance is quite challenging. The laser used is that of the CRISTAL beamline. At the exit of the laser, the beam is separated into 3 branches. One will deliver about 3 mJ at 2 or 3 kHz to the wiggler, another one about 0.8 mJ to the CRISTAL experiments, and the last one about 0.2 mJ to TEMPO experiments. All the beam transport will be in primary vacuum.

For the delay line necessary to equalize the overall path length between the pump and probe pulses, we take advantages of the distance between the laser source and the X-ray source. One part of the laser beam toward the wiggler is taken and sent back to the experiment acting as the pump for both CRISTAL and TEMPO. This avoids us to put a large multi-pass optical cavity in the constraint area of the laser hutches.

![Figure 2. Layout of the optical laser beam transport system.](image)

2.3. 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 M101-M110, located in five enclosures. First of all, the laser beam is elevated and transported above the ring before entering by the roof. Inside the ring, the laser beam is sent to the tangent port of a dipole chamber through two mirrors M101A –M101B and focused to the center of the wiggler by a 9 meter lens. The lens is located just before the M101A and M101B. A UHV MgF2 window placed before the dipole chamber separates the ultra-high vacuum from the primary.

On the optical path through the wiggler, the returning optical beam transport to the CRISTAL beamline named BT20 (green line in fig.2) is created. A beam splitter M108 placed in an intermediate enclosure ENC104 located on the roof divides the beam in two parts. The reflected part is sent to the wiggler trough mirrors M107-M105 and the transmitted part is returned to the laser hutch through
others mirrors M201- M205. Almost all the mirrors are used in reflection to minimize the energy losses and pulse distortions. The optical mirror configuration in enclosure ENC.104 is shown on figure 3. The figure 4 shows the design of the two following enclosures ENC103 and ENC102 on the wiggler path, located on the roof. In enclosure ENC102, two mirrors M103 and M102 send the laser inside the ring. This enclosure is placed in a shielded box in order to protect personnel against radiation hazard.

![Figure 3. Intermediate enclosure ENC.104](image1)

![Figure 4. Enclosures ENC103 and ENC102 before the laser enters into the ring.](image2)

In figure 5, an overall view of the ring and beam entrance components is shown.

![Figure 3. Overall view of the ring components at the entrance of the laser beam](image3)

The last enclosure ENC105 is currently under design. This enclosure will have three beam entrances and two beam exits. It will comprise several mirrors and diagnostics. In order to achieve good stability, the enclosures ENC104 and ENC105 will be fastened on the concrete wall of the ring. The enclosures ENC103 and ENC102 will be attached on two non-removal concrete dales on the roof. These dales will be glued together to remain stable.

2.4. CRISTAL-TEMPO optical beam transport
Two optical beam transports will be built to send the CRISTAL laser to the TEMPO beamline. One named BT40 will start in enclosure ENC105 from the returning beam BT20 to CRISTAL. The other 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 synchronization between the two laser systems. On the BT40, a beamsplitter M203 located in the enclosure ENC105 on the returning path will split the returning beam into two parts. The transmitted part will be sent to the TEMPO experiments.
2.5. Laser diagnostics

The diagnostic package consists of a centering diagnostic and a pointing diagnostic. Their designs must ensure that their respective field are large enough to capture an initial roughly-aligned system, yet with enough resolution to operate in closed-loop in the future. The pointing diagnostic which image the far-field is located behind the last laser mirror M101B in the ring. The pointing sensor will be a CCD camera on which is focused the beam leak. The mirror 104 on the roof will be motorized to control the pointing in the wiggler. The centering diagnostic is an afocal which relay an image plane of the beam to the desired object space on a CCD camera. This diagnostic is located on a leak behind the mirror 104. A mirror in the laser hutch will be motorized to control the centering.

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

3. IR and THz diagnostics

An IR diagnostic for the initial alignment of the laser with the electron beam will be installed inside the tunnel on the 0° exit of the wiggler. A retractable mirror will collect visible and IR radiation at low electron beam current and send them to CCD camera and photodiodes for optimisation of the laser-electron timing interaction. The coherent THz radiation produced by the “hole” created in the electron bunch by the slicing process will be used to control the interaction laser-electron efficiency. A liquid-He cooled bolometer and photo diodes will detect the THz radiation on the IR AILES beamline.

4. Conclusion

The design of the optical beam transport components is currently under study and some implementations in the ring have already been done. Some detailed plans for enclosure are achieved. We plan to receive the major equipment by the end of 2012 and the beginning of 2013. The installation of the beam transport system is scheduled between January to June 2013. The components of the wiggler are under construction and we expect to install it in August 2013.

5. References

[1] A. Nadji et al., IPAC’10 proceedings, p2499.
[2] A. Zholents and M. Zoloterev, PRL 76 (1996), 912.
[3] R. W. Schoenlein et al. Science 287 (2000), 2237.
[4] G. Ingold et al., PAC’01, Chicago, p. 2656.
[5] J. Zhang, M. Labat, internal report Synchrotron Soleil, January 2012.

Acknowledgments

The authors would like to thank all the SOLEIL beamlines and groups involved in the Femto-Slicing project.