SwissFEL STATUS REPORT

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Abstract

SwissFEL is a 5.8-GeV linac which sends electron bunches at 100 Hz into a 60-m long in-vacuum undulator line to produce hard X-rays between 0.1 nm and 0.7 nm (Aramis line). The SwissFEL machine design is based on a low emittance beam with tight tolerances on RF phase stability. The first lasing of SwissFEL is planned for early 2017 and two end-stations should then be brought into operation in the same year. The delivery of the SwissFEL building to PSI is planned for fall this year, but some rooms are already completed and currently in use for component assembly. The production of the C-band RF accelerating structures has now reached the nominal rate of 5 structures/month. Two different RF solid-state modulator prototypes have demonstrated voltage pulse stability lower than 20 ppm but reliability tests are still ongoing. The undulator assembly and measurement sequences have started and 13 undulators are planned to be ready in the tunnel by October 2016. Large series of components like magnets, vacuum systems and mechanical supports are already in house and undergoing assembly. Photonics components for beamlines and for two end stations are ordered and planned to be ready for 2017. The next important milestone is the commissioning of the injector, the first 120 meters, in Spring 2016.

INTRODUCTION

The overall layout of SwissFEL is shown in Fig. 1. In order to tune the FEL wavelength of Aramis between 1 and 7 Angström, the electron beam energy can be varied between 2.1 and 5.8 GeV. This is achieved with Linac 3 which either accelerates or decelerates the beam. This enables the energy at the extraction point towards Athos (end of Linac 2) to stay always constant and equal to 3 GeV. Genesis simulations, assuming a slice emittance of 0.2 µm, lead to a pulse energy as high as 1.4 mJ at 1 Å in the case of long pulses with 200-pC charge (Fig. 2). At the end of the undulator line, electrons are deviated vertically down towards a 240-ton shielded beam dump [1]. The SwissFEL injector will produce two bunches separated by 28 ns at a repetition rate of 100 Hz. The second bunch is deflected after Linac 2 in the transfer line (Fig. 1) towards the soft X-ray Athos line.

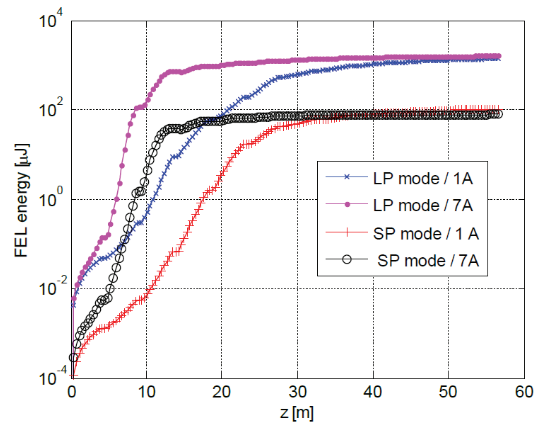

Figure 2: Genesis simulation of FEL pulse energy growth for two bunch charges, 200-pC long pulses (LP) and 10-pC short pulses (SP), and for two wavelengths: 1 and 7 Angström (graph from [2]).

STATUS OF BUILDING AND INFRASTRUCTURE

SwissFEL is a two-storey building from cathode source (z = 0 m) to the end of last linac (z ~ 460 m). All the RF power plants as well as the rest of the infrastructure are situated on the top floor. As a consequence, all the cabling and cooling lines come down from the ceiling as can be seen in the pictures of Fig. 3.

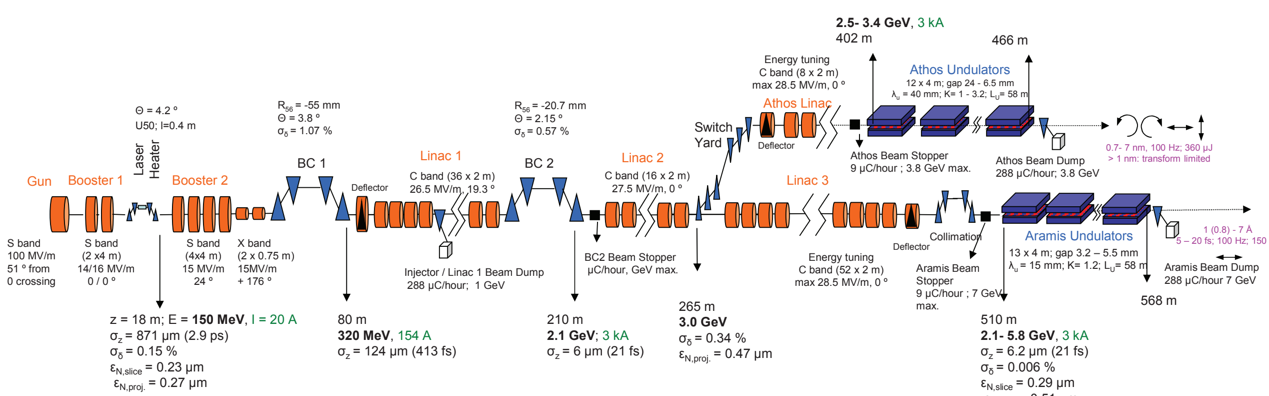

Figure 1: SwissFEL layout with the hard X-ray FEL line Aramis and the future Athos line to be built after 2018 (some parameters are merely indicative and only valid for a specific mode of operation).

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The raw construction of the building is completed as illustrated in Fig. 3. Electrical and water infrastructure is currently being installed until Fall 2015. The Aramis undulator line is located in a single floor building and most of the electronic infrastructure is situated in the gallery beside the tunnel.

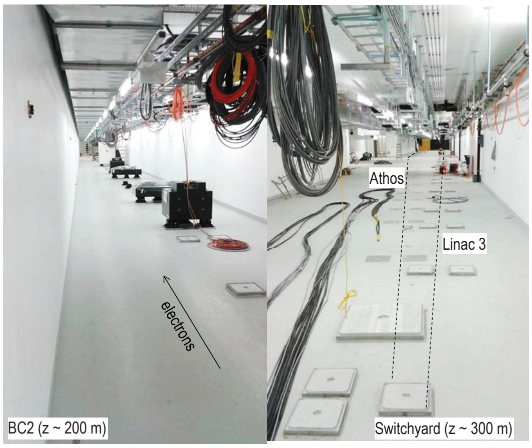

Figure 3: Pictures of the SwissFEL beam tunnel at z = 200 m (distance from cathode), near BC2, and at z = 300m, near switchyard.

The hard X-ray optical components are located in the optical hutch downstream of the front end wall of the Aramis undulator line (Fig. 3). The FEL pulses are then distributed over three end stations: A, B and C. The completion of the building is planned for Fall 2015, but some areas are already used by PSI for the assembly of components such as the injector part of the tunnel or the undulator preparation laboratory.

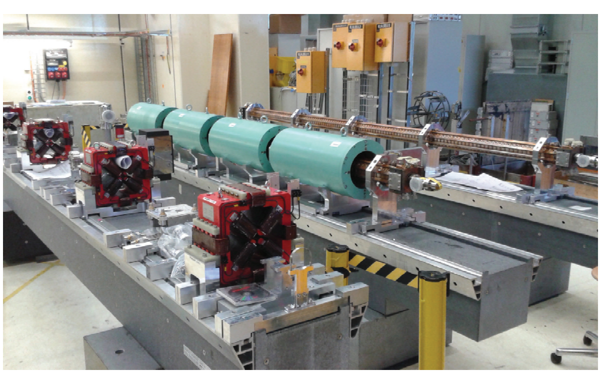

Figure 4: Injector girders assembled with new S band structures in the SITF building.

STATUS COMPONENTS

The SwissFEL injector test facility (SITF) was shut down in October 2014 after four years of operation. Many components will be re-used for the SwissFEL injector and the pre-assembly of girders has started in the SITF building (Fig. 4). The S-band RF structures are new, with a constant gradient RF design and dual-feed racetrack couplers. The C-band structure production has now reached a nominal rate of five structures per month (Fig. 5). In July 2015, 46 units out of 104 were already brazed and ready for conditioning at SwissFEL. One of the structures was conditioned up to 52 MV/m and showed a negligible breakdown rate at the nominal gradient of 28 MV/m. The BOC cavities are produced and brazed in house and 16 BOCs out of 27 are now ready for installation.

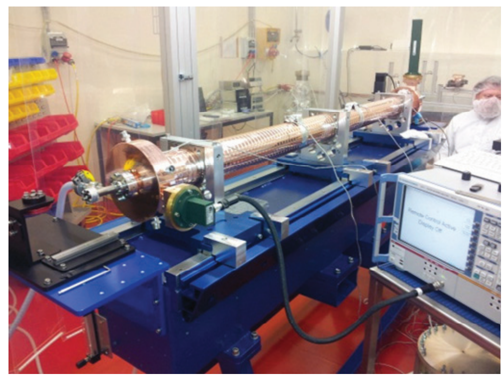

Figure 5: Picture of a newly produced C-band structure under RF frequency check after brazing.

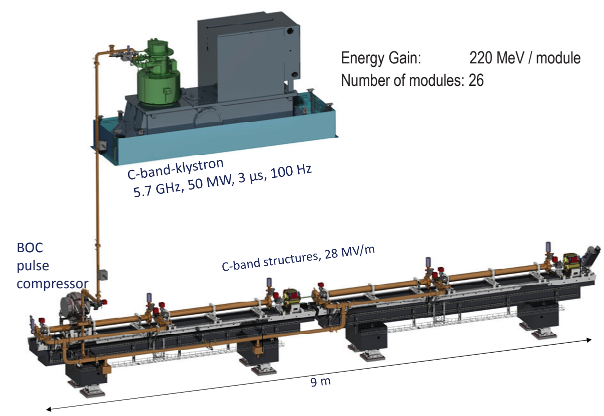

Figure 6: 3D Drawing of an RF module with the klystron–modulator assembly powering four C–band structures of 2-m length each.

There are twenty six C-band RF modules distributed over three linacs in order to accelerate the electron beam from 0.35 GeV to 5.8 GeV. Each module (Fig. 6) consists of four structures of 2-m length [3]. The RF power is generated by a solid state modulator coupled to a C-band klystron producing 3-microsecond-long pulses at 100 Hz with 50 MW of power. These pulses are then compressed to 300 MW thanks to an RF pulse compressor; the so-called barrel open cavity (BOC) [4]. This peak power allows a gradient of 28 MV/m (with 10% margin) leading to an energy gain of 220 MeV per module.

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The solid-state RF modulator is a key component for SwissFEL since the accelerator design for a low emittance beam requires a very good stability level of the RF phase which means a modulator voltage pulse-to-pulse stability around 20 ppm rms [3]. Such stability levels have been demonstrated at PSI with two commercial modulator prototypes. Further reliability tests are however still required before launching a series production.

The Aramis line consists of 13 undulator modules each of 4-m length. These in-vacuum undulators have a variable rms *K* value ranging between 1 and 1.8. In order to adjust the gap, both magnet arrays are attached to wedges which change the gap by sub-micron steps when moved longitudinally (Fig. 7). The robust mechanical frame gives the stability and reproducibility of the magnetic field map. The magnet array is a hybrid lattice with a period of 15 mm with NdFeB(Dy) magnets and Permendur poles [5]. The whole undulator sits on eccentric cam-shaft movers giving five degrees of freedom (x, y, pitch, yaw and roll) for the alignment of the 4-m-long undulator with respect to the electron beam axis.

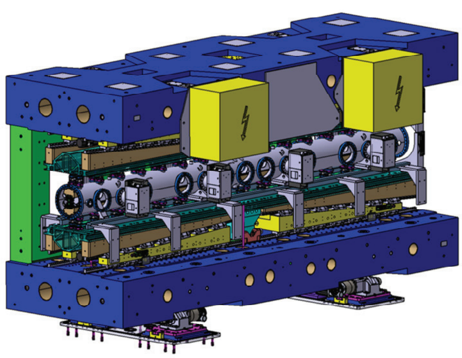

Figure 7: Cut-away view of the Aramis in-vacuum undulator revealing the wedges (in yellow) which open or close the gap.

Nine undulator frames together with 4 magnet arrays out of a total of 13 units have been delivered. The magnet array assembly in the undulator frame (Fig. 8) is done at PSI within the SwissFEL building. The magnet arrays are attached to the undulator frame thanks to adjustable columns (Fig. 9). These columns are then used to correct for the phase error of the magnet lattice. The local magnetic field amplitude errors are corrected by adjusting the height of each individual pole/magnet set via an automatic screw driver. An rms phase error below 2 degrees, along with a trajectory straightness within 2 µm, has been achieved with this method on a prototype [6]. The first undulator of the series is currently under magnetic optimisation and will be installed in the SwissFEL tunnel in October 2015. The rest of the series will then follow at a rate of one per month.

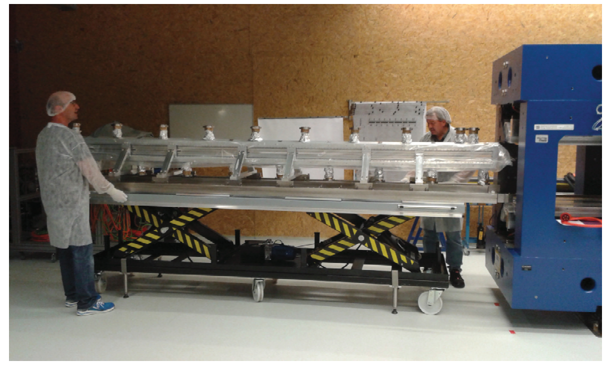

Figure 8: Insertion of the magnet arrays within the undulator frame for the first round of magnetic optimisation (without the vacuum chamber).

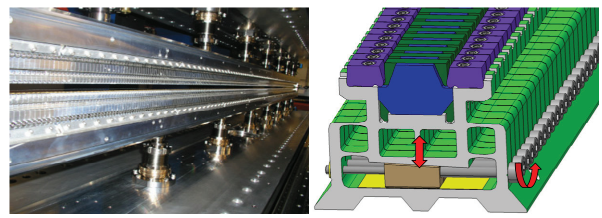

Figure 9: Magnet arrays attached to the undulator frame with adjustable columns prior to the vacuum tank installation (left). Individual magnet/pole sets are sitting on flexible supports (right).

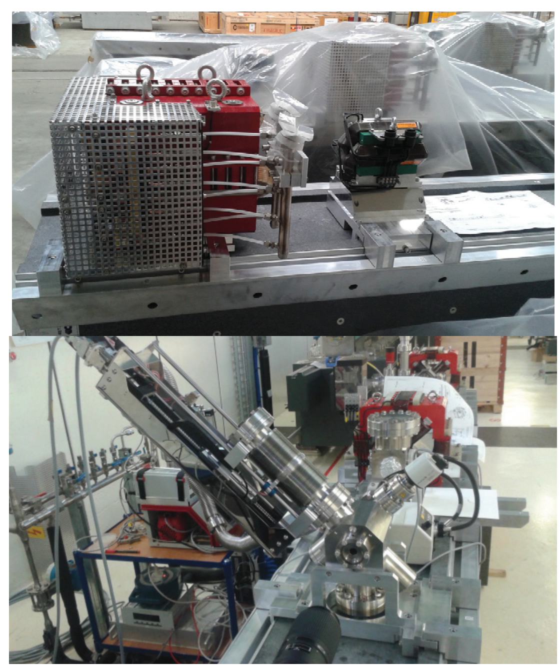

Figure 10: Quadrupole and steering magnets positioned on a girder before vacuum pipe installation (top). Prototype of the PSI wire scanner mounted on the girder for the site acceptance test of the linear feed-through (bottom).

Many components are already produced and tested such as, for example, the power supplies and magnets. About 450 magnets (steerers, dipoles, quadrupoles, etc.) have been produced and measured at PSI. These are currently being installed on girders (Fig. 10). Several electron diagnostic component prototypes have been successfully tested (OTR screens, BPMs, etc.) and series production is currently under way. SwissFEL will be equipped with Wire-scanners (WSCs) for emittance measurements and transverse profile monitoring during FEL operations (Fig. 10). WSC in-vacuum hardware and beam-loss-monitors (scintillator fiber) have been tested at the 250-MeV SITF and at the GeV energy scale in FERMI [7,8]. The gun laser system (Table 1) which will illuminate the photocathode and drive the laser heater is in production and should be delivered by the end of 2015.

Table 1: Summary of Gun Laser Specifications

Wavelength	1040 nm
Pulse energy at 260 nm before shaping	800 µJ
Energy stability	0.5% rms
Minimum pulse duration (Gaussian)	500 fs FWHM

In addition, the first photonics components have arrived at PSI. The X-ray pulse energy and position monitor has been provided by DESY and was recently delivered to PSI (Fig. 11).

Figure 11: X ray pulse energy and position monitor in the SwissFEL building.

The designs of the two end stations (ESA & ESB) which will be operated in the first phase of SwissFEL are completed. End station A is dedicated to ultrafast photochemistry and photobiology, and End Station B will focus more on pump-probe crystallography. Key components (diffractometer, heavy load goniometer, pump lasers, etc.) are now in the procurement phase. Some special components like the 2D detector "Jungfrau" are developed directly in house at PSI. The two end stations should be ready for Fall 2017 in time for the first pilot experiments.

Figure 12: 3D drawings of the End Station A (top) and End station B (bottom).

CONCLUSION

Despite a few months of delay in the delivery of the building infrastructure the preparation of key components like the RF modules and the undulators are progressing according to the schedule. The procurement of the RF modulator is the critical path item of the project but recently pulse to pulse voltage stability tolerances could be demonstrated with two different prototypes. The injector test facility has been shut down in order to prepare the new version of the injector. The next important milestone will be the commissioning start of this injector in March 2016.

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