SWISSFEL, THE X-RAY FREE ELECTRON LASER AT PSI

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Abstract

PSI prepares the construction of an X-ray free-electron laser, SwissFEL, as its next major research facility. The baseline design consists of a 5.8 GeV linear accelerator and two FEL lines covering the wavelength range from 0.1-0.7 nm and 0.7-70 nm, respectively. SwissFEL features a linear accelerator in C-band technology, a novel design of variable gap in-vacuum undulators for the hard X-ray FEL and Apple II undulators with full polarization control for the soft X-ray FEL. The two FELs are operated independently and simultaneously with 100 Hz pulse rate each. In addition to the FEL performance goals SwissFEL aims for low overall energy consumption. Linac parameters as well as the cooling systems are optimized towards this goal. For the whole facility a staged construction is planned, with groundbreaking in spring 2013. The commissioning of the linear accelerator and the hard X-ray FEL will start in 2016. An overview of SwissFEL goals, status, and plans is given and the SwissFEL R&D activities are reviewed.

OVERVIEW

Since the last status reports at FEL conferences [1,2], the SwissFEL design has matured and stabilized towards construction of the facility. Preparation of the building site and procurement of major components has begun, with groundbreaking for the buildings scheduled for early 2013. All key parameters and most modifications have been included in a final update of the design report [3]. The design is driven by the following requirements

- wavelength coverage from 1-70 Å with very good timing resolution and stability in the order of 10 fs for the range of science as described in [4,5]
- a tight overall budget frame
- construction site in the vicinity of PSI with less than 800 m facility length
- constraints for power consumption and power dissipation

Figure 1 shows an overview of the facility and table 1 the project schedule until first operation of the hard X-ray FEL (1-7Å) named “ARAMIS”. The building has all necessary provisions for the second, soft X-ray FEL “ATHOS” with 7-70Å wavelength range. The procurement of ATHOS components will happen in a later budget phase after 2016.

INJECTOR

A test version of the SwissFEL injector consisting of a photocathode RF gun, 4 S-band RF cavities, an X-band harmonic cavity, the first bunch compressor, and a diagnostics section for the characterisation of projected emittance, slice emittances and longitudinal phase space has been set-up at PSI and is used for SwissFEL beam dynamics studies and component development [6]. All components are now operational with the exception of the RF power source for the harmonic cavity [7]. Commissioning of this power source is expected for early autumn this year. Very good emittance figures, compliant with the SwissFEL design, have been measured, covering the two extremes of the SwissFEL bunch charge range [8,9]. A summary of the results is listed in table 2.

A new RF gun capable of running at 100 Hz with improved beam dynamics properties [10] will be installed in the course of 2013. Further plans for the facility include a test of a full fledged undulator prototype with beam.

The injector test facility will be dismantled in late 2014 for reuse of its components in SwissFEL. To mitigate effects of microbunching instability [11], a laser heater will be will be integrated in the final injector configuration for SwissFEL with an undulator designed by ASTeC/Daresbury. Two more S-band and one more X-band structure will be added for a beam energy of 350 MeV in BC1.

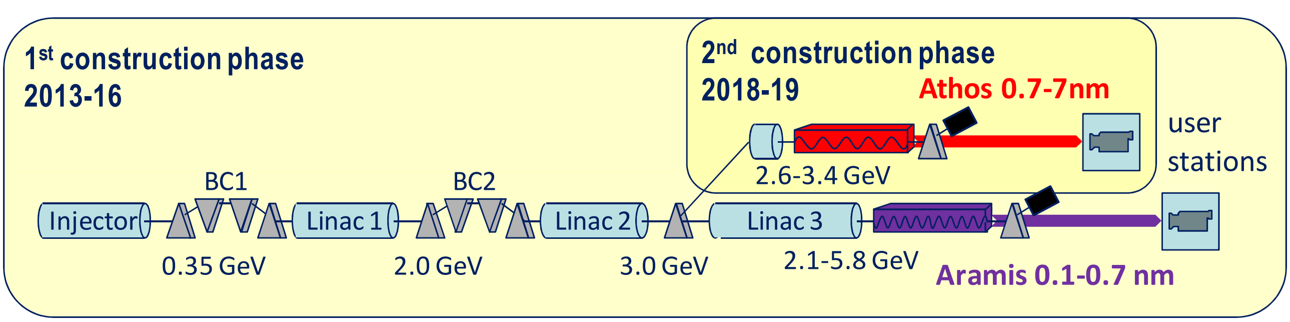

Figure 1: Schematic of SwissFEL.

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Table 1: SwissFEL Schedule Until First User Operation

2012	2013	2014	2015	2016	2017
component procurement accelerator and ARAMIS FEL				preparation ATHOS FEL	
prepatory work	building construction		Accelerator and ARAMIS FEL installation	commissioning	friendly users

Table 2: Emittances measured in the SwissFEL injector test facility at 250 MeV (without bunch compression) compared with simulations and required emittances.

Measurement	σ_{laser} [mm]	$\varepsilon_{n,x}$ [μm]	$\varepsilon_{n,y}$ [μm]	$\varepsilon_{n,simulated}$ [μm]	$\varepsilon_{n,required}$ @undulator [μm]
High-charge mode (~200 pC):					
projected:	0.21	0.38	0.37	0.350	0.65
core slice:	0.21	0.25	–	0.330	0.43
Low-charge mode (~10 pC):					
projected:	0.10	0.16	0.18	0.096	0.25
core slice:	0.10	≤ 0.15*	–	0.080	0.18

LINAC

The main linac of SwissFEL uses 26 accelerator modules [12]. Each module is assembled from four accelerating structures mounted on two granite girders. The four structures are fed by one klystron modulator unit with a BOC type pulse compressor. The RF frequency is 5.72 GHz and the nominal accelerating field is 28 MV/m. With an active structure length of 2 m, this provides a nominal energy gain of 224 MeV per module. This voltage is obtained with the klystrons running at 80% of their nominal power specification, thus leaving a margin for linac energy management and feedbacks. Toshiba has, for PSI, further developed its E37202 klystron to the E37212 klystron for PSI. This klystron maintains a peak power of 50 MW, but allows for a repetition rate of 100 Hz and an RF pulse length of 3 µs. The cooling of the collector is separated from the RF part, so that the collector can be run at a significantly higher temperature than the RF part of the klystron. This is required for the SwissFEL energy recovery system described in the building and infrastructure section below. The full power capability of the klystron has successfully been demonstrated, the two-temperature operation will be tested later this year. The klystrons are powered by an IGBT switched modulator. Although modulators of this type are already in operation in the SwissFEL injector test facility, the development of a new generation of these modulators has been initiated. One of the reasons is the need for a mechanical separation of the klystron tank from the charging supplies and auxiliary parts. This is required because of the limited space available in the SwissFEL technical buildings and for ease of system maintenance. Another improvement will be the capability to control the modulator settings synchronously with the 100 Hz repetition rate. Each klystron is connected to a C-band variant of the barrel open cavity type RF compressor [13]. The BOC design allows for a Q value of about 190,000 with a compact design. The first prototype of the C-band BOC is presently under construction. A high power test of a BOC is planned towards the end of this year.

For the C-band accelerating structures a sophisticated machining, assembly, and brazing process has been developed at PSI. This process allows one to build the structures at the nominal frequency without requiring further tuning steps. Three short prototypes with eleven cells each have already been tested with high power. In the last test an accelerating field of 58 MV/m, limited by klystron power, has been achieved [14,15]. A new vacuum brazing furnace with sufficiently large dimensions for the full-size 2 m structures has recently been delivered to PSI. The first full-size structure will be ready for tests in early 2013.

The parameter choices of the linac module allow for a reasonably high accelerating field while keeping the number of RF stations small. In consequence the linac power consumption, cooling requirements, and investment cost can be kept comparatively low.

The bunch compression scheme which uses two bunch compressors at 350 MeV and at 2 GeV is described in [16]. A detailed design of the collimation system used for the protection of the undulators has been worked out [17].

UNDULATOR LINES

The technical progress on the SwissFEL undulators and inter-segment-girders is described at this conference [18,19,20]. The first prototype of the 4 m long U15 undulators for the ARAMIS hard X-ray FEL will be completed in early 2013 and will be tested with beam thereafter in the injector test facility. Motivated by the recent progress and successful demonstration of self-seeding at hard X-ray wavelengths [21,22], provisions for the implementation of a self seeding scheme in ARAMIS have been taken [23]. Whether such a system will be available from the beginning remains to be decided. For the soft X-ray FEL, ATHOS, which will be installed in the 2nd SwissFEL construction phase, self seeding will be implemented from the beginning, replacing the EEHG scheme, which was previously considered for ATHOS [24].

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Figure 2: Building layout and location.

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The detailed design for the dogleg-shaped transport line from the linac midpoint extraction to the ATHOS FEL has been worked out [25] and a new method for orbit correction in the undulator lines has been devised [26].

SITE CHOICE, BUILDING AND INFRASTRUCTURE

The SwissFEL construction site is located in a forest at about 300 m distance to the PSI site. A picture of the building is shown in figure 2. The accelerator and undulator housing as well as the experimental areas are realized with a concrete structure in a cut and fill trench. The technical buildings on top of the linac, used for technical infrastructure, RF modulators, and other electronic equipment, are realized in concrete as well and are covered on one side and on top with soil. This is required for environmental reasons, but helps also for a good thermal stability of the buildings. Because of the environmental situation, special care has to be taken for wild game transit corridors and minimum sound and light emissions.

The call for tender for the building has been launched, preparatory work for access roads, ground water well and infrastructure connections to PSI have started, and ground breaking for the main building is expected for April 2013. The air conditioning systems put special emphasis on temperature stability. The air temperature in the accelerator and undulator housing will be kept within $\pm 0.1^0$C and in the technical buildings within $\pm 2^0$C.

The bulk of the heat loads will be cooled by ground water from a dedicated well. The temperature stability of the ground water allows for a very efficient cooling concept, where the primary water is used in three consecutive exchanger stages with the last stage feeding heat into the PSI heating network. For permission reasons the used cooling water is not brought back into the ground but is pumped into the nearby Aare river.

The maximum total electric power consumption is estimated at 5.6 MW with two undulator lines and 6 fully equipped experimental stations.

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