THE EUROPEAN XFEL BASED ON SUPERCONDUCTING TECHNOLOGY

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Abstract

The internationally organized European XFEL free-electron laser is under construction at the Deutsches Elektronen-Synchrotron (DESY). Compared to present-day synchrotron radiation sources, its peak brilliance will be more than 100 million times higher, the radiation has a high degree of transverse coherence, and the pulse duration is reduced from the 100 picosecond range down to the 10 fs time domain. The possible wavelength will be down to 0.1 nm. The electron beam energy of up to 17.5 GeV will be achieved by using superconducting accelerator technology. The project is the first large scale application of the TESLA technology developed over the last 15 years. The paper briefly summarizes the XFEL design before presenting details about the status of the superconducting linac. The international collaboration with its contributions will be described. Final prototyping, industrialization and new infrastructure are the actual challenges.

INTRODUCTION

The European XFEL [1] is going to be built to explore the femtosecond dynamics of nature. It will allow studying the machinery of a living cell at work at atomic resolution. The shape change of molecules during chemical or biochemical reactions can be observed on the femtosecond time scale. A number of fascinating experiments will become possible, and at long last one might see, and not just model, how molecular machines really work [2]. An excellent start was made at the at DESY already operating free-electron laser FLASH. Details about the operation and the upcoming upgrade were presented at this conference [3].

XFEL RADIATION PROPERTIES

Being based on a superconducting accelerator the European XFEL will be operated in the so-called burst mode. As depicted in Fig. 1, 600 µs long RF pulses will be used to accelerate pulse trains of up to 3,000 electron bunches typically separated by 200 ns; the bunch train repetition rate will be 10 Hz.

Distributed to different undulator beamlines the electron beam produces either X-ray FEL radiation (0.2 – 12.4 keV) or spontaneous radiation (20 – 100 keV). The duration of the individual photon pulses will be less than 100 femtoseconds. Extreme high pulse intensities of up to 10^{14} photons per pulse can be expected for the FEL radiation. According to the XFEL technical design the shortest wavelength will be 0.1 nm, achieved at an electron beam energy of 17.5 GeV.

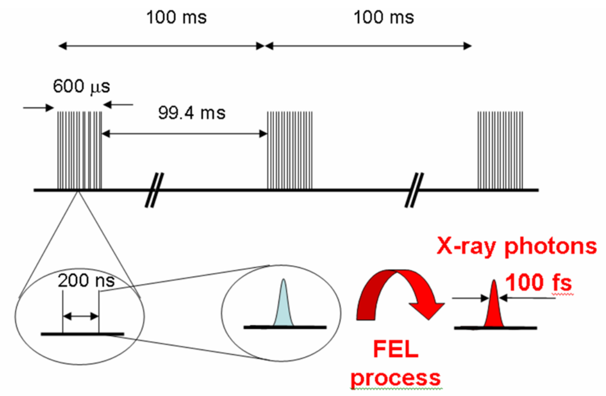

Figure 1: Time structure of the European XFEL.

PERSPECTIVES IN VIEW OF LCLS COMMISSIONING

The recent start-up of the LCLS has been remarkably fast and successful. It has shown (besides the excellence of the SLAC team) that the SASE process in the Ångstroem regime works robustly and as predicted. According to common knowledge, the lasing depends on the 6-dimensional phase space density. When optimizing the FEL performance, pulse length and brilliance of the photon pulse are the issue. The parameter space leaves some options; after the LCLS commissioning, the future discussion of X-ray FELs needs inclusion of shorter bunches at lower charge.

The conclusion for the European XFEL is that safety margins in the XFEL design can be less conservative. Based on a lower projected emittance (recently measured at DESY, Zeuthen - PITZ), the XFEL can reach shorter wavelength without any change in the facility layout. Details are to be worked.

The XFEL is the only X-ray free-electron laser which can be operated cw. Thus it is worth keeping the option open and to closely follow and support R&D on high duty cycle injectors [4, 5]. The necessary replacement of klystrons by IOTs seems to be possible [6]; infrastructure is not a challenging issue. A rough estimate with respect to the needed resources including additional effort for undulators shows that of the order of 20% of the initial investment might be required. In summary: When the injector technology becomes available and the user case is well developed, the already very attractive XFEL can be made even more attractive, i.e. cw operation might become available in an attractive upgrade scenario.

CONSTRUCTION STARTED

Construction work along the 3.4 km European XFEL facility started early 2009. Figure 2 shows the more than 30 m deep shaft of the injector, located at the DESY site. Figure 3 gives an overview about the complete XFEL site seen from the future experimental hall with DESY being in the back of the picture. The tunnel construction will start early spring 2010, the main linac tunnel is to be finished in 2011 and ready for accelerator module installation in summer 2012.

Figure 2: Construction site of the XFEL injector.

Figure 3: Construction site of the European XFEL.

XFEL COLD LINAC

The European XFEL is based on a superconducting linac comprising of 100 accelerator modules housing eight TESLA type cavities each. In order to operate all cavities at its design gradient of 23.6 MV/m, 25 RF stations will be installed supplying 5.2 MW each. The construction is a common effort of many institutes sharing the responsibility for the superconducting linac. The overall coordination is with DESY chairing the XFEL Accelerator Consortium. Table 1 summarizes the major contributions.

Table 1: Contributions to the XFEL Cold Linac

Institute	**Component / Task**
CEA Saclay / IRFU, France	Cryostats; cavity string and module assembly; cold beam position monitors
CNRS / LAL Orsay, France	RF main input coupler incl. RF conditioning
DESY, Germany	Cavities & cryostats; contributions to string & module assembly; coupler interlock; frequency tuner; cold vacuum system; integration of superconducting magnets; cold beam position monitors
INFN Milano, Italy	Cavities & cryostats
Soltan Inst., Poland	Higher Order Mode coupler & absorber
CIEMAT, Spain	Superconducting magnets
IHEP, China	(Cryostats) (final agreement req.)

Cryostats

In preparation of the series production DESY has ordered one cryostat each from two new vendors. In addition IHEP Beijing, China, offered to supply a third one based on the DESY specifications; the costs were taken over by IHEP. Two of the cryostats, consisting of the so-called cold mass, i.e. the supporting structure with all cryogenic process lines and temperature shields, and the outer vacuum vessel, were meanwhile assembled at DESY. Strings of eight cavities each as well as the magnet / BPM package were composed and integrated into the cryostats. As a result the first prototype named PXFEL1 could be tested on DESY's Cryomodule Test Bench (CMTB), the second one, PXFEL2, is ready for testing.

Figure 4 shows the PXFEL1 test results after RF conditioning at the CMTB. All eight cavities were measured individually. The solid red bars depict the measured accelerating gradient in 10 Hz and 800 µs flat top operation.

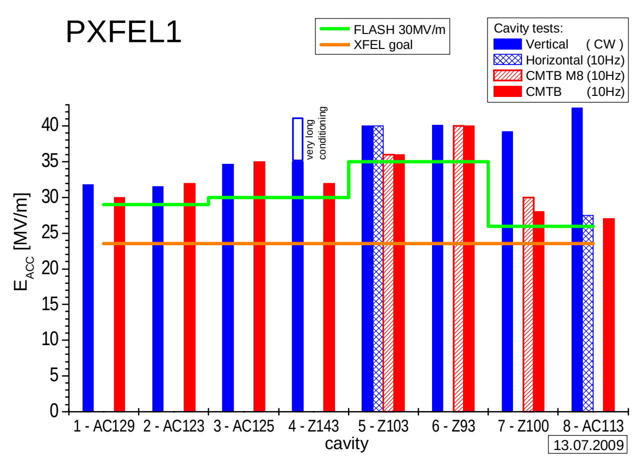

Figure 4: Test results of accelerator module PXFEL1.

Some cavities were previously used in accelerator module M8; thus the in M8 measured gradient is shown in comparison (dashed bars). All cavities were measured in the initial vertical test (cw mode), and one single cavity was measured in horizontal test. The direct comparison of the final PXFEL1 result with the last measurement before string assembly can be used to judge the quality of the overall work. The average maximum gradient of PXFEL1 is 32.5 MV/m. String and module assembly could be the explanation for the observed gradient reduction of about 5%; this number is dominated by the high gradient of cavity Z143 measured in vertical test and achieved only after very long cw RF conditioning. The module PXFEL1 is going to be installed in the FLASH accelerator. The XFEL waveguide distribution will be used which allows for a pair-wise power adaptation. Thus the maximum operating gradient in FLASH will be 30 MV/m (green line). Further details about the PXFEL1 test are given in Ref. [7].

Cavities

In preparation for the series production of the European XFEL's accelerating cavities two schemes [8] for the final surface treatment – electro-polishing (Final EP) and final buffered chemical polishing (BCP Flash) – were studied with cavities from two different vendors. At the same time the strategy to weld the cavities in its He-vessel prior to the final surface treatment was investigated. As the result yield curves for the different schemes (with or still without He-vessel), yield curves for the different vendors being qualified for the XFEL cavity production [9, 10], a preparation strategy, and a strategy for the FEL cavity call for tender became available.

The XFEL cavity call for tender was published in July, 2009. Production and preparation will be done in industry. The contract is to be allocated by DESY, the supervision of the cavity production will be in the responsibility of DESY and INFN. Details of the cavity specifications may be published not earlier than six months after the contracts are placed.

The optimized preparation procedure requires He-vessel welding after the Final EP. Thus the field profile needs to be measured, i.e. a bead bull is to be done under clean conditions [11].

One important step during cavity fabrication is the RF frequency tuning of half cells as well as dumb-bells (pairs of half cells). In order to considerably shorten the tuning time and thus the costs, a dedicated apparatus was developed. The prototype was successfully used for the recent cavity production. Two more machines are under fabrication with only minor changes. Key issue for the industrial use is automation and documentation [12].

The finished cavities need to undergo a frequency and field flatness tuning. Also here two dedicated machines for the series cavity production were built and are under commissioning [13]. While the mechanical parts were contributed by DESY, the development of software and electronic devices was done at FNAL. CE certification of the entire machine according to European rules and laws is a must. The final machines can be operated by Non-RF-experts.

RF Main Input Coupler

The responsibility for the XFEL RF power production was taken over by LAL Orsay. In order to prepare for the RF conditioning a new dedicated 5 MW RF station will be set up at Orsay. In order to fulfil the required conditioning rate of eight couplers per week, presently the common conditioning of four cavities is under investigation. The interfacing with the string and module assembly is an organizational issue being discussed with CEA Saclay being the assembly site. The coupler interlock system needed after installation in the XFEL tunnel was developed and will be contributed by DESY [14, 15].

Accelerator Module Assembly

The cavity string and module assembly at CEA Saclay / IRFU needs a complete new infrastructure. Thus the design and cost estimate for the civil engineering and general equipments was done and recently finished. Construction has started, and major parts of the new infrastructure are already in the commissioning phase.

Figure 5: The new ISO4 cleanroom at CEA Saclay/IRFU.

Figure 6: First check of cleanroom tools.

Figure 5 shows the new ISO 4 cleanroom with its two string assembly lines readily identifiable from the two rails located under the floor, and Fig.6 captures the first checks of cleanroom tools.

Cavity and Module Acceptance Test

The production and preparation of the XFEL cavities concludes with the assembly in 4-cavity units to be transported to DESY and to be ready for the vertical test. At DESY the so-called Accelerator Module Test Facility (AMTF) is under construction in which both, the 4-cavity units at a rate of at least 2 units per week, and the at Saclay completed accelerator modules at a rate of 1 unit per week will be tested.

Figure 7 shows the connection of the 4-cavity unit as received in a special transport box to the lower part of the vertical test cryostat's insert.

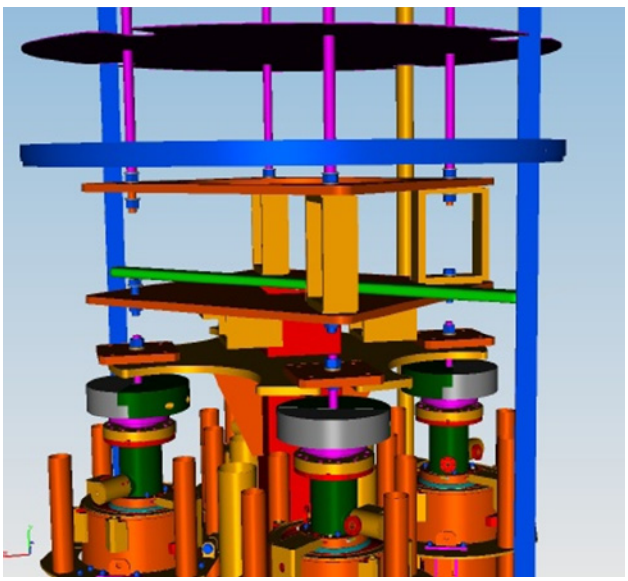

Figure 7: 4-cavity unit assembled for the vertical test at DESY's Accelerator Module Test Facility (AMTF).

The cavities will be RF checked at DESY before the complete 4-cavity unit is going to be shipped to CEA Saclay / IRFU. In case single cavities do not reach the accelerating gradient specification, they will be sorted out at CEA Saclay and send back to the deliverer who can then decide to repeat the final preparation steps.

Figure 8 shows the first module loaded for a round trip DESY – Saclay – DESY; a number of checks including extensive vibration measurements was done [16]. For the transport, a special frame as well as a transport lock was designed on the basis of two industrial studies.

Figure 8: The first accelerator module on its travel from CEA Saclay / IRFU, Paris to DESY, Hamburg.

SUMMARY

The European XFEL is based on a superconducting linac comprising of 800 accelerator cavities. The XFEL Accelerator Consortium led by DESY followed the goal of developing one common schedule with all necessary links between the individual work packages. The engineering itself is clearly based on the successful work within the TESLA Technology Collaboration. The common work on the Cold Linac is the essential on the way to the success of the European XFEL project.

ACKNOWLEDGEMENT

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