STATUS OF THE EUROPEAN XFEL

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Abstract

The internationally organized European XFEL free-electron laser is under construction at the Deutsches Elektronen-Synchrotron (DESY). The project is the first large scale application of the TESLA technology developed over the last 15 years. Superconducting accelerating cavities will be used to accelerate the electron beam to an energy of up to 17.5 GeV. Recently an energy reduction by 20% to 14 GeV was discussed as a reasonable compromise between cost aspects and scientific potential of the facility. With realistic assumptions on lower beam emittance, the design photon beam parameters will be achieved. The talk briefly summarizes the overall XFEL design before presenting details about the status of the superconducting linac. The activities within the international collaboration are described. Final prototyping, industrialization and commissioning new infrastructure are the actual challenges. Contracts for long lead items are placed.

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.

CIVIL CONSTRUCTION STARTED

Construction work along the 3.4 km European XFEL facility started early 2009. Figure 1 shows the more than 30 m deep shaft of the injector located on the DESY site, together with a schematic picture of the injector building to be built inside. Tunnel boring was started in July 2010 and the first almost 500 m are finished. Figure 2 shows the for the XFEL Project Team fascinating moment when the cutter head of the tunnel boring machine was brought into the shaft. Figure 3 is a view into the new tunnel, a 5.4 m diameter section which will later house one of the undulators. The main linac tunnel, also 5.4 m in diameter, is next and to be finished in summer 2011. The fan of further undulator and photon beam tunnels will be bored using a second tunnelling machine.

Figure 1: Injector shaft of the European XFEL.

Figure 2: Arrival of the cutter head of the tunnel boring machine.

Figure 3: Tunnel section of the European XFEL.

NEW ACCELERATOR PARAMETERS

The 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 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. On the other hand the so far projected photon beam parameters can be reached at lower electron beam energy. Thus a new parameter set was studied in detail for an energy of 14 GeV. Extensive simulations support the new parameter set given in Tab. 1.

Table 1: Comparison of Baseline and New Parameter Set for the European XFEL

	Baseline	New Parameter Set
Electron beam energy	17.5 GeV	14 GeV
Bunch charge	1 nC	**0.02 - 1 nC**
Peak current	5 kA	2 - 5 kA
Slice emittance	< 1.4 mm mrad	**0.4 - 1.0 mm mrad**
Slice energy spread	1.5 MeV	4 - 2 MeV
Shortest SASE wavelength	0.1 nm	**0.05 nm**
Pulse repetition rate	10 Hz	10 Hz
Bunches per pulse	3000	2700

The 14 GeV accelerator as proposed to the European XFEL Council will consist of 80 accelerator modules, i.e. 640 superconducting accelerator structures, operated at a gradient of 24.3 MV/m. A total of 20 stations will supply the necessary RF power of typically 5.2 MW per four modules.

The European 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 [3, 4]. The necessary replacement of klystrons by IOTs seems to be possible [5]; 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, starting from the 17.5 GeV baseline design. Shortening the linac to 80 accelerator modules has the drawback that the investment towards cw operation becomes reasonably larger; the now missing 20 modules would have to be included in an upgrade scenario. 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.

EUROPEAN XFEL COLD LINAC

The construction of the cold linac is a common effort of many institutes sharing the responsibility for this superconducting linac. The overall coordination is with DESY chairing the XFEL Accelerator Consortium. Table 2 summarizes the major contributions.

Table 2: Contributions to the XFEL Cold Linac

Institute	Component / Task
CEA Saclay / IRFU, France	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

Cavities

In preparation for the series production of the European XFEL's accelerating cavities two schemes [6] 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 [7, 8], 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. After negotiations with the possible vendors the contract was allocated by DESY, the supervision of the cavity production will be in shared responsibility of DESY and INFN. Details of the cavity specifications will be made available to the SRF community around end 2010.

Research Instruments and E. Zanon were contracted to produce each 4+4 pre-series cavities followed by 280 XFEL type series cavities and 12 so-called HiGrade cavities, first used for quality assurance, later available for further investigations & treatments (high gradient R&D towards ILC). Nb / NbTi will be supplied by DESY. The production will precisely follow the specifications which also include the exact definition of infrastructure to be used. The final treatment after bulk electro-polishing (EP) will be different for the two selected vendors: EP for Research Industry / so-called flash BCP for Zanon.

In order to optimze the overall cost, no performance guaranty is given by the vendors, i.e. the risk of unexpected low gradient or field emission is with the contractor DESY (responsibility for re-treatment). The gradient goal is an average usable XFEL gradient of 24.3 MV/m at an unloaded quality factor of 1E10.

Additional 80 cavities are ordered as an option to be placed after the evaluation of the successful start of the series production. First series cavities are scheduled for beginning of 2012; all cavities to be delivered within two years. He-vessels for Research Industry's cavities will be supplied by DESY. Both contracts have a volume of almost 25 M€ each.

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 were fabricated with only minor changes. Key issue for the industrial use is automation and documentation [9].

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 commissioned [10]. 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 finished 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 approximately eight couplers per week, 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 [11]. The contract for the production of 640 RF main input couplers was placed recently.

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. All three 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.

All three cryostats were tested on DESY's Cryomodule Test Bench (CMTB). While the first one named PXFEL1 showed excellent results – average maximum gradient of 32.5 MV/m, some individual cavities in the second and third cryostat obviously suffered during module assembly. Since both modules were used to offer assembly training to new teams a detailed analysis of the used procedures is carried out.

Mechanical and cryogenic measurements support the call for tender for the 83 cryostats being required for the cold linac. In total four possible vendors were qualified over the last years. Contracts will be placed end of 2010.

Accelerator Module Assembly

The cavity string and module assembly at CEA Saclay / IRFU needs a complete new infrastructure. Construction has started already in 2009, and major parts of the new infrastructure were commissioned in 2010.

Figure 4: The new ISO4 cleanroom at CEA Saclay/IRFU.

Figure 5: First check of cleanroom tools.

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

Cavity and Module Acceptance Test

The production and preparation of the XFEL cavities was foreseen to conclude with the assembly in 4-cavity units to be transported to DESY and to be ready for the vertical test. Recently this concept was modified; the assembly to 4-cavity units will be done at DESY just prior to the vertical tests. 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 6 shows the overall layout of the AMTF. Two vertical test cryostats, three accelerator module test stands, and one waveguide assembly and test facility are part of the installation. Commissioning has to be finished in 2011.

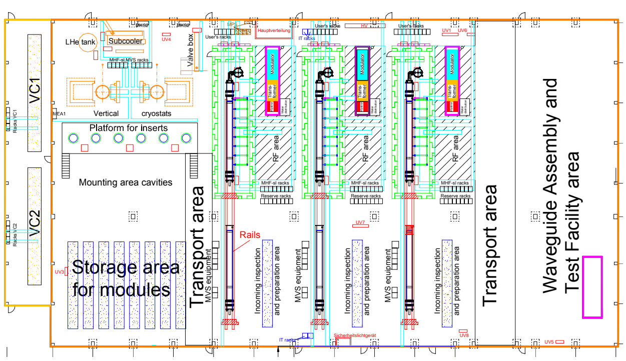

Figure 6: DESY's Accelerator Module Test Facility (AMTF).

The individual cavities will be RF checked at DESY in a 4-cavity unit which after the test is taken apart. Single cavities are going to be shipped to CEA Saclay / IRFU so that cavities not reaching the accelerating gradient specification can be sorted out beforehand and send either back to the deliverer to repeat the final preparation steps, or alternatively DESY can take over the re-treatment in its existing infrastructure.

OTHER LARGE SERIES PRODUCTION

Many more components are to be produced in large quantities. Each accelerator module houses a superconducting quadrupole package including a cold beam position monitor (BPM). While CIEMAT/Spain is taking care of the magnet itself, the BPMs will be contributed by CE Saclay and DESY. The final test of the completed package will be done in the new erected test facility at DESY. Figure 7 shows the test of one of the first magnets delivered by CIEMAT.

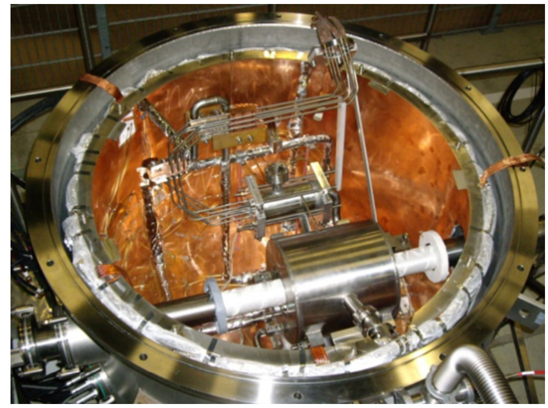

Figure 7: Cold quadrupole magnet produced by CIEMAT, in DESY's test cryostat.

The modulators of the RF power stations were carefully investigated at DESY, Zeuthen. Figure 8 shows one of the modulators with pulse transformer and klystron.

Figure 8: RF station under test at DESY, Zeuthen.

Approximately 100 undulators are required for the European XFEL. With a total length of almost 600 m, an effort comparable to the on of the accelerator modules is required. Sophisticated intersections between neighbouring undulators include precisely positioned beam transport magnets, advanced beam diagnostics, and inside the undulators precisely machined vacuum chambers. Thus the knowledge of many experts is required to fulfil demands. Figure 9 sketches the intersection.

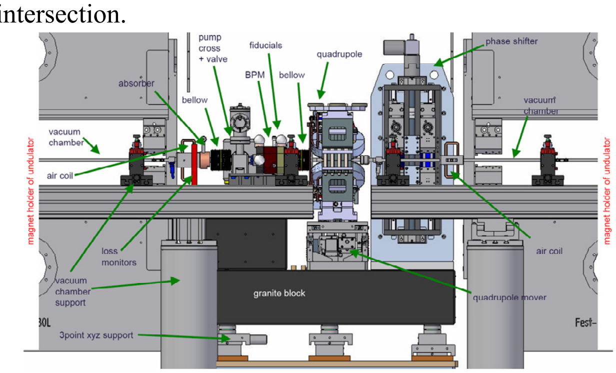

Figure 9: Intersection between two adjacent undulators.

SUMMARY

Construction of the European XFEL becomes more and more visible. The first 500 m tunnel section was recently finished. Long lead items required for the superconducting linac comprising of 80 accelerator modules are ordered. A new parameter set was extensively studied. Projected photon beam parameters can be achieved at lower electron beam energies. The XFEL Accelerator Consortium led by DESY follows the goal of developing one common schedule with all necessary links between the individual work packages.

ACKNOWLEDGEMENT

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