CLOSING IN ON THE DESIGN OF THE BESSY-FEL*

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Abstract

The SASE-FEL at LEUTL (APS) [1], the demonstration of SASE laser saturation at wavelengths below 100 nm at TTF (DESY) [2] and the operation of the HGHG-FEL at BNL [3] has stimulated proposals on future 4th generation light source user facilities in the VUV to soft X-ray spectral range and hard X-rays worldwide, refs. [4-10].

The BESSY Soft X-Ray FEL is planned to be built next to the 3rd generation BESSY II light source, covering the spectral range 62 nm to 1.24 nm. A superconducting 2.25 GeV linac will supply three independent FEL-lines with a highly flexible electron-bunch pattern; the use of APPLE II type undulators will deliver variable photon-beam polarization. These SASE-FELs will permit unprecedented spectral-, spatial- and temporal resolution for user experiments.

A Status of the design work is presented in the paper.

INTRODUCTION

The scientific case for the BESSY-FEL was published in 2001 [11]. The technical features of the Soft X-Ray FEL will guarantee a tremendous improvement compared to present day synchrotron radiation and conventional laser facilities.

The laser-like coherent radiation with extremely short pulses will extend existing research techniques to ultra-short time resolution for investigations of the electronic structure of matter. The intrinsic pulse duration determined by the electron pulse will be shortened to less than 20 fs. This opens the field for unprecedented studies on the structural and electron dynamics of systems.

The flexible time structure provides various possibilities to synchronize the FEL with external laser sources to perform unique pump-probe experiments. The pulse peak power of a few GW will enable the study of non-linear properties of matter, while non-linear processes involving core electrons localized at individual atomic centers, are adding a totally new quality to experiments.

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THE SOFT X-RAY FEL

General Layout

The general layout of the FEL facility is shown in fig. 1. Bunches of electrons are generated in a normal conducting 1.3 GHz RF-photoinjector at a normalized emittance of 1.3 πmm·mrad at a charge of up to 1 nC with a typical pulse length of $\sigma_{l,rms}$ = 2000 μm. Repetition frequency of the injector is 1000 Hz. The bunches are compressed in two stages (BC1 and BC2). In BC1 the bunch is shortened by a factor of 10 at an energy of 200 MeV while in BC2 the 715 MeV beam is compressed by a factor of 4 resulting in a final bunch length of 50 μm rms. The peak current thus is about 5 kA. A superconducting CW linac based on the TESLA design accelerates the beam to suitable energies which are 1.875 GeV for the "Low-Energy-" and "Medium-Energy FEL" while the "High Energy FEL" operates at variable energies of 1.5 to 2.25 GeV.

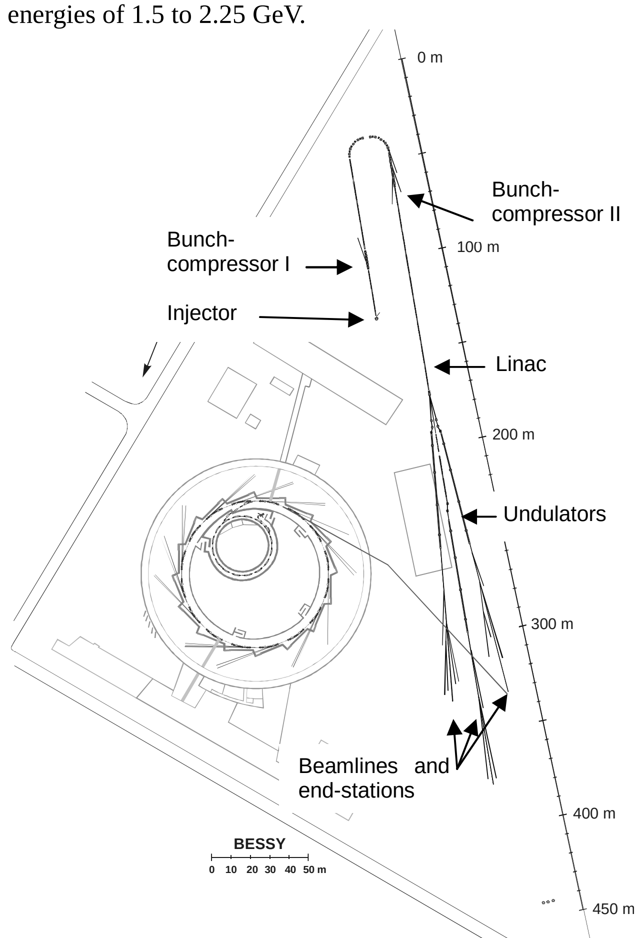

Fig. 1: Overview on the FEL adjacent to the present 3rd generation SR-source BESSY II operational since 1998.

To cover the photon energy ranges of 20 to 300, 250 to 550 and 500 to 1000 eV, undulators of length up to 60 m will be installed. Eight beamlines of up to 80 m distance between undulator exit and target station were designed. Four beamlines are optimized for short pulse techniques as XPS, UPS and PEEM, while others are for high resolution experiments as HR-PES, XRMS and RIXS.

To save space for future activities a 85 m zone towards the site boundary is presently not used, made possible by folding the linac with a 180° bend in-between BC1 and BC2.

Start to End Simulations

The code ASTRA [12] is used to evaluate the beam emittance in the injector region up to BC1. Simulation of coherent synchrotron radiation in the bunch compressors, in the 180° bend and for single particle wakes in the linac structures were carried out with ELEGANT [13] to derive realistic beam parameters at the entrance to the undulators. To study the SASE-process time-dependent, the code GENESIS [14] was utilized. Figure 2 gives typical results for the most demanding case: the 1 keV beam at the HE-FEL; plotted are output power along the undulator, pulse duration, radial beam-size and photon-beam spectrum.

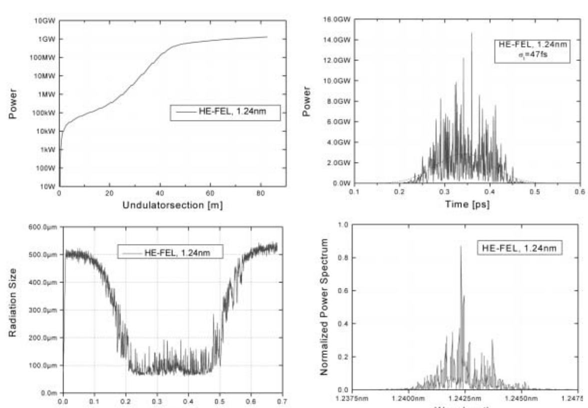

Figure 2: Results from Start to End simulations. Top graphs, left hand: output power along the undulator, right hand: photon pulse duration. Lower graphs, left hand: radial size of the photon beam at saturation, right hand: photon beam spectrum. All calculations apply for a 1 keV (1.24 nm) photon-beam.

Starting with a normalized beam emittance of 1.3 π mm·mrad at the gun exit, insignificant dilution of phase space occurs up to the end of the linac. As the FELs photon-energies span wide ranges, the active lengths of the undulators have to be adjusted according to the saturation-length. Thus the undulators are segmented to a typical length of 3.5 m by independent gap drive. More than 50% of the segments have to be opened in the case of the long wavelength limit at the 'Low Energy FEL', e.g. at 20 eV.

Table 1 gives a summary of major undulator- and photon-beam parameters for the three FEL lines.

Table 1: Summary of undulator- and FEL performance parameters for the three FEL lines. Values are listed according to their operation range e.g. for rms beam size σ and divergence σ'.

Parameter	**LE-FEL**	**ME-FEL**	**HE-FEL**
Photon energy (eV)	20 - 300	270 - 550	500 - 1000
U-period (mm)	66	36.5	27.5
K-value	4.3 - 0.82	1.5 - 0.80	0.82
No. of periods	312 - 728	864 - 1344	1560 - 1820
Output power (GW)	10 - 2	5 - 1	2.5
Peak brilliance ($s \cdot mm^2 \cdot mrad^2 \cdot 0.1\%$ bw)	$3.8 \cdot 10^{29}$ - $0.4 \cdot 10^{29}$	$1.5 \cdot 10^{31}$ - $0.3 \cdot 10^{31}$	$2.5 \cdot 10^{31}$
Pulse duration (fs)	40 - 50	~ 40	~ 40
σ_{rms} (μm)	110 - 230	~ 80	~ 80
σ'_{rms} (μrad)	12 - 105	~ 13	~ 12

Detailed studies on tolerances have been performed using GENESIS in time-independent mode. The influence of rms-beam wander caused by different sources on the saturation power is displayed in figure 3. As expected, beam wander should not exceed 20% of the electron beam radial size in order not to decrease saturation power.

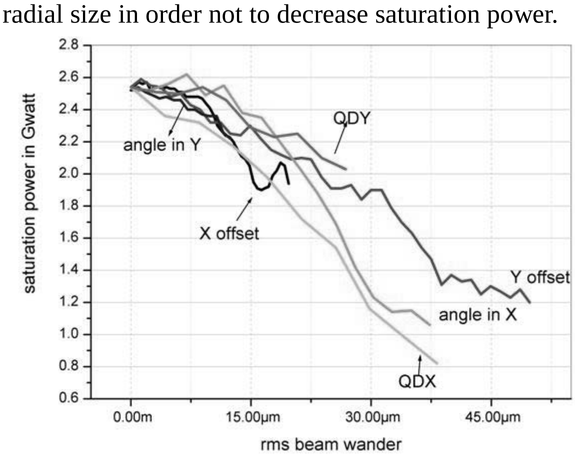

Figure 3: Influence of beam wander on saturation power caused by horizontal and vertical quadrupole misalignment (QDX, QDY), electron beam position offset (X offset, Y offset) and angle error (angle in X, angle in Y) at the undulator entrance. Calculations apply for the HE-FEL.

The n.c. Photoinjector

Generation of electron beams at a charge of up to 1 nC at a normalized emittance of approximately 2π mm·mrad has been demonstrated within the PITZ collaboration [15].

Based on this n.c. photoinjector a high power gun-cavity is developed to operate at a repetition frequency of 1 kHz in short bunch mode. 100 kW of input power are needed to generate a gradient of 40 MV/m at the cathode surface, essential to achieve small beam emittance. The cavity, see fig. 4, will be tested at the PITZ facility.

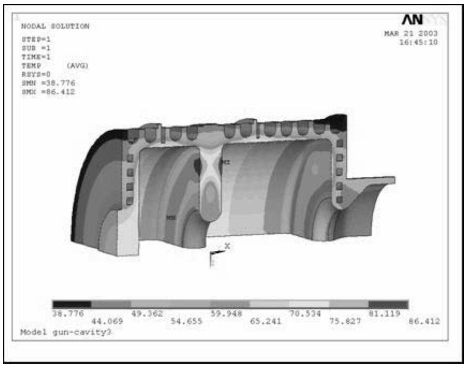

Figure 4: Temperature distribution in ¼ of the gun-cavity when operating at an input power of 100 kW.

The s.c. Photoinjector

In order to fully exploit the capabilities of the CW linac generating a free selectable bunch pattern, a super conducting photoinjector is required as a phase II upgrade for the BESSY Soft X-Ray FEL

A collaboration of FZR Rossendorf, MBI and BESSY presently started to work on an improved s.c. gun, based on recent work [16].

The s.c. Linac Modules

For the linac superconducting modules of the TESLA type [17] will be used. The modules of 12 m length are equipped with eight 9-cell cavities, delivering an energy of 125 MeV to the beam at a gradient of 15 MV/m.

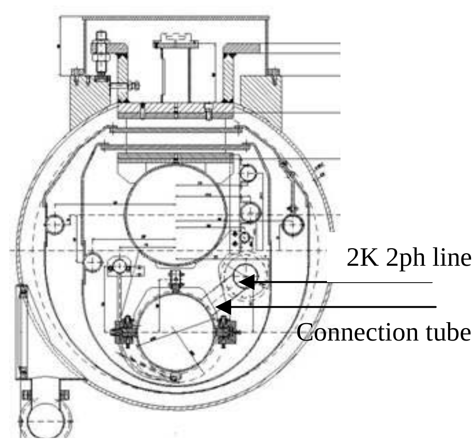

Fig. 5: Cross section of the TESLA cryo-module. The 2-phase-LHe line and the connection to the LHe-bath cryostat will be modified for CW operation.

There will be 18 modules grouped into three sections to accelerate the beam to 1.875 and 2.25 GeV respectively.

Detailed studies on the CW operation mode show that minor modification have to be introduced to the original design as a consequence of the 40 times larger cooling requirement at 2K, see fig. 5. The dimensions of the connection tubes from the cavity-LHe tank to the 2-phase-2K-He-return line and the return line itself have to be increased.

In preparation of qualifying s.c. linac components for CW operation mode, a horizontal bi-cavity test stand is set up. The stand [18] enables detailed studies on operation and RF control of the cavities at high loaded Q, controlling of micro phonics and test of fast piezo-tuners. Also couplers and tuners will be tested under realistic conditions.

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