Technical developments at HASYLAB

5. The Sase-VUV Free Electron Laser Project at DESY
The VUV SASE FEL Project

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Overview

The Free Electron Laser (FEL) principle [1] allows to convert electron beam energy into electromagnetic radiation at a very high efficiency. Applying the „Self-Amplified Spontaneous Emission (SASE)“ principle [2,3] and using a linear accelerator with excellent electron beam quality, it should be possible to build a FEL in the VUV regime, promising a photon beam peak brilliance 8-10 orders of magnitude above state-of-the-art synchrotron radiation sources, see Figure 1. In 1995 DESY proposed to make use of the unique electron beam quality of the superconducting TESLA Test Facility (TTF) linac and to construct a VUV Free Electron Laser (FEL) based on the SASE principle [4]. Many scientists from research institutions in Germany and abroad are meanwhile involved in this project and have contributed to the machine concept and to the scientific case [5].

Fig. 1. Spectral peak brilliance of short-wavelength FELs compared with third generation synchrotron radiation sources and plasma lasers. Phases 1 and 2 of the FEL project at the TESLA Test Facility are indicated by TTF FEL 1 and 2, respectively.
The undulator for the VUV-FEL

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Status

The undulator for the VUV-FEL at the TESLA Test Facility, its magnetic design, prototype tests as well as its hardware setup under construction has already been described extensively in contributions to previous HASYLAB reports [1]-[3] as well as in a number of publications [4]-[9]. In 1998 the time schedule was further followed. A comparison with the Annual report 1997, ref. [1] shows the progress: All hardware components have meanwhile been completed or are in a very advanced state of production: Three complete undulator mechanics have been built. This also includes the micro-mover systems built by DESY Zeuthen, which are needed for the precise alignment of undulator modules. In parallel, the three magnetic structures have been produced by Vaccumschmelze Hanau. They were given the names SASE100 through SASE300. The third and last was delivered in September. Since September the mechanical assembling of the SASE100 structure was done and as of December 1998, the magnetic tuning and characterization is in full progress. Fig.1 gives a view in the magnetic measurement room in Hall 55. In the foreground the SASE100 structure is aligned at the 12m bench.

Fig.1: View into the magnet measurement room. On the 12m magnet bench in the foreground the first undulator module (SASE100) is readily assembled is being measured. In the rear the second module has been aligned and pre-adjusted and is waiting for final assembly.

In the rear the SASE200 is aligned and prepared for final assembly. The other components needed for the undulator section are well in time schedule too: The vacuum chamber, which is built by the Advanced Photon Source (APS) in Argonne, is near completion. The same holds for the four wire scanner stations. In this contribution we shall describe the following key activities of this year in more detail:
- The simulated annealing procedure which is successfully used for pairing and sorting the magnets,
- The method of “Undulator field fine tuning by pole height adjustments”,
- Finally, some examples of field measurements are presented.

**Magnet sorting by simulated annealing**

Each undulator module consists of 652 magnets which produce the sinusoidal varying $B_y$ field. The focusing magnets are not considered here, since they will be attached later in such a way that the do not contribute to field errors. Each of these magnets is magnetized in its nominal direction of magnetization. Due to unavoidable errors in the manufacturing process this value varies from magnet to magnet with a typical standard deviation of 0.27 percent. Moreover, the direction of magnetization also varies slightly, so that a magnetization perpendicular to the nominal results which may deflect the electron beam in an unwanted manner. Pairing of magnets in such a way that the error components mutually cancel out may help to reduce the error level. However each magnet has three error contaminated magnetization components attached to it which cannot be varied independently. For the number of 652 magnets available for each undulator segment this problem becomes very complex, and cannot be addressed with direct methods.

![Graph showing before and after sorting of field integrals](image)

**Fig.2: Demonstration of simulated annealing:** Left side second field integral of the $W$, $x$ and $y$ components before and after the simulated annealing procedure. The RMS values improve by factors of 1200, 130 and 150 for $W$, $X$ and $Y$, respectively.

Simulated annealing is a statistical method, which can deal with systems having very many degrees of freedom corresponding in this case to 700 magnets. Its goal is to find a configuration of all 700 magnets in which these errors are minimized. The magnets are thus sorted in such a way that the error in the three field components results in the smallest possible second field integral. The second field integrals of the three field components before and after simulated annealing are shown in Fig. 2. The $X$- and $Y$-components are due to direct fields caused by directional errors. The $W$-component corresponds to the magnetic flux which is causing the wiggling motion. A detailed description of the procedure is in preparation and will be given in ref [12].

**Field fine tuning by pole height adjustment**

The first half of 1998 was extensively used to develop the method of “Undulator field optimization by pole height adjustment” a method which is very essential to fine tune the undulator field to comply with the tough specifications [10]. Correcting field errors of the $B_y$ field component is not simple. One can
apply shims on the poles, which would limit the gap and which acts only in one direction to increase the local field. Also a reliable fixation of the shims in this case is problematic. One can place shims in between the poles, but this possibility is restricted to focusing free sections. In principle this problem also exists in the horizontal direction, but there it is much less severe, because the errors are smaller and they can be tolerated to some extent even if they are compensated not right in place but at the first occasion next to a focusing section, where there is space to place them. For the B_z field a more elegant way of field correction exists by slightly changing the gap of a pole. Consequently the undulators of the VUV-FEL have been designed to have height adjustable poles. They can be shifted in and out by a few tenths of a millimeter using set-screws. This capability is the basis of the technique of field fine-tuning by pole height adjustment. The basic idea is simple but rather complex to implement for an undulator system with 327 poles. It can be subdivided in the following steps:

- At the beginning the field distribution along the electron beam axis is measured. The deviation of this field distribution from a hypothetically "ideal" one resulting in a perfectly straight trajectory is calculated.
- The response of a local gap change of one pole onto the field of the neighboring poles is determined experimentally. From these data the coefficients which couple the movement of a pole i with field change on a pole j can be extracted. Experience shows that there is only short range interaction and only near neighbors interact, i.e. \( i - j \leq 5 \) is sufficient.
- The local gap changes of all poles, which are needed to produce the required correction, are calculated.
- Finally a list giving the pole numbers and the required local gap changes is generated. For quick and coarse adjustment with an accuracy of \( \approx 20 \mu m \) the turn angle of the set-screws can be used. More time consuming but much more accurate (1 \( \mu m \)) is the use of micrometer gauges directly attached to the pole during adjustment.

The whole procedure is described in detail in ref [10]. Tests have been made on the 0.9m long prototype structure with 65 poles. Trajectories calculated from magnetic measurements are shown in Fig.3. The trajectory before optimization, Fig.3 a) and after three iteration steps b) - d) are displayed. The improvements between the steps are evident, a straight trajectory results. A large number of adjustments was needed for the first iterations. The last iteration required only a very few corrections.

**First results of magnetic field measurements**

The undulator of the VUV-FEL has to meet very tough specifications for the second field integral in order to guarantee a close overlap between the laser field and the electron beam [11]. This imposes tough requirements onto the quality of the field in the directions perpendicular to the electron beam (Y and Z direction). The magnetic field measurements and the subsequent optimization of the magnetic structure therefore have to be subdivided and ordered in three steps:

1. The horizontal B_x field component will be measured and optimized on the “naked undulator” without the focusing magnets attached. In an ideal structure this field component is zero. In a real structure it is expected to be small or even very small, due to good quality of the magnet material used and the simulated annealing procedure applied for assembling. Small errors due to manufacturing tolerances however cannot be excluded. In order to achieve the specified values a very few shims acting exclusively on the horizontal field will be applied (see below).
2. The vertical B_y field component is optimized again on the “naked undulator” by fine tuning the poles as described above.
3. In the final step the focusing magnets forming the quadrupole lattice are mounted, adjusted and aligned using the Rectangular Coil Method as described in [9]}

The horizontal B_x field components are small as compared to B_y. Typical values observed are a few tenth of a percent of the B_y component. Furthermore they have to be measured in the presence of the strong B_y field. Such measurements are difficult to perform using Hall probes since the results may be erroneous due to the planar Hall effect. Measurements using appropriate search coils are a better choice, but here drift of the electronics is a severe problem. A solution to this problem is to use small coils with as large a winding
area as possible together with drift electronics and spectrum averaging to obtain the most accurate results. Small coils with about 3500 windings in a 2x5 mm$^2$ winding cross section and total outer winding dimensions of 5x5x10 mm$^3$ have been made for this purpose. With this technique it has been demonstrated that the ultimate limit for the determination of the second field integral on a 5m long magnetic structure is about ±10 Tmm$^2$ RMS. This corresponds to the requirement that the horizontal field of such a structure has to be measured with an average accuracy in the order of 1μT.

So far the horizontal fields of the SASE100 and SASE200 structures have been measured and optimized. The SASE100 structure required 14 horizontal shims to bring the second field integral to the required specification of ±10 Tmm$^2$ which at 300MeV corresponds to about 10 μm. The SASE200 structure needed only 3 shims to be brought to this value. The difference is not completely understood, but there is some evidence that the larger field error of the SASE100 structure was caused by a weak residual magnetization in the soft iron support structure which was not the case for SASE200. Fig. 3 shows the measured horizontal field, the first and second field integral of the SASE200 structure. The location of the three shims is clearly visible in the field distribution and in addition is indicated by arrows. The second field integral has been centered so that the beam enters and leaves the structure under a small angle, but the average trajectory stays parallel to the axis. If the beam enters with a horizontal slope two additional weak shims at the entrance and exit would be needed. Fig 4 demonstrates that for the horizontal field component the required field specifications can be achieved.

![Fig.3: Demonstration of the field optimization onto the measured trajectory of the prototype structure: a) Initial trajectory b) - c) after three consecutive iteration steps](image-url)
Fig. 4: Measured horizontal field $B$ of the SASE200 undulator module and the first $I_1$ and second field integral $I_2$. Only three horizontal shims have been applied. Their effect onto the field is clearly visible. The second field integral has been centered so that the average is zero. The beam enters and exits under an angle. If a horizontal slope of the trajectory is required two weak additional shims have to be placed near the entrance and the exit of the undulator to compensate for this kick.
References

The Undulator Vacuum System

U. Hahn

The 15 m long undulator of the FEL made of three sections is passed by the particle beam in a beam pipe with an inner diameter of 9.5 mm. The whole vacuum system of this section consists of four 185 mm long diagnostic blocks which are connected by the three 4.5 m long undulator vacuum chambers. The dust free vacuum system has to reach a pressure $p_{\text{max}} < 1 \times 10^{-6}$ mbar to keep the bremsstrahlung in the experimental beam area on a reasonable level. The vacuum system contains also components for particle beam detection and beam steering. This shall provide a sufficient overlap between particle and photon beam in the undulator range for the FEL process to take place. The basic design and concept of all these components were developed in 1997[1]. In 1998 the design was improved and finished according to the needs of the linac[2]. Several prototypes of single components were designed, produced, and tested.

## Diagnostic Blocks

![Diagram of Diagnostic Blocks](image1.png)

Figure 1: The diagnostic block: Together with a crosssection of the block (on the left) the preassembled device (on the right) is shown.

The main purpose of the diagnostic block is the absolute particle beam position measurement in front and at the end of each of the three undulator modules. The absolute position measurement is achieved by:

1. horizontal and vertical wirescanners with a mechanical calibrated reference plane [3]
2. horizontal and vertical cavity monitors. These uncalibrated monitors will be absolute after calibration by the wirescanners.

Figure 1 shows a crosssection and the preassembled diagnostic block. The beam enters the block in the centre and passes the four monitors. The horizontal and vertical cavity monitors with their RF decoupling feedthroughs are followed by narrow (1 mm) slits which allow the wire of the vertical and horizontal wirescanners to pass the beam pipe and interact with the particle beam. The bremsstrahlung produced by the interaction of beam and wire is detected by scintillation counters downstream of the diagnostic block. The top flange carries the vertical wirescanner.
In the back of the block an ion getter pump is installed. THW diagnostic blocks are the only positions in the undulator section to pump the beamline. The longitudinal slits in the beam pipe are for better pumping the beamline. Two trigger pumps are installed at each diagnostic block to trigger closing of the upstream fast acting valve to avoid accidental venting.

The perpendicular slits for the wire passage are minimized to reduce the impedance losses which affect the beam quality. For the same reason narrow coupling slits for the redesigned cavity monitors are introduced. The whole block is made from stainless steel (1.4429). The cavity inserts are made from copper and connected to the block by vacuum furnace brazing. For impedance reasons the narrow beampipe has to be manufactured from Al or Cu. So the other inserts forming the scanner slits are made from copper. The whole block is vacuum conditioned by „vacuum firing“. The complicated internal structures are machined with high precision by electrical discharge machining (EDM).

At the end of 1998 all 8 wirescanners are delivered. Five diagnostic blocks are machined and assembled in the DESY workshop. At the beginning of next year the diagnostic stations will be prepared for installation in the linac:

- particle free cleaning and assembling according to TESLA specification
- calibration of the wire scanner reference plane and wire position under class 100 clean room conditions
- vacuum tests
The FEL Vacuum Chamber

Three FEL vacuum chambers are under construction and will be ready for cleaning and final assembly in January 1999. These chambers are designed and manufactured in collaboration with the APS at Argonne Nat’l Lab.[4]. The chambers are made from extruded Al with stainless steel flanges. The crosssection of the chamber is 128x11.5 mm with a length of 4492.2 mm. The chamber hole diameter is 9.5 mm. The extruded hole has a microroughness of 0.47 μm along the extrusion and 0.98 μm perpendicular to the extrusion direction. To reach a sufficient low pressure in the chamber (<1×10^-6 mbar) an specific outgassing rate of < 1·10^{-11} mbar-l/sec-cm_ has to be reached.
The chamber design followed the need to detect the beam position in combination with a steering option of the particle beam in the undulator gap.

For the position detection two monitor types were developed and will be installed in the vacuum chamber:

- Two chambers are equipped with 10 pick up monitors, i.e. this 40 electrodes will be installed in the chamber. The pick up pins are able to detect the relative beam position within several μm. After first successful tests of a prototype monitor chamber at CERN, a prototype structure (shown on Fig. 4) with related steering coils were manufactured, RF tested, and also vacuum tested. The prototype is also used to develop a mounting device for the final assembly of the 80 pick up electrodes.

- To overcome the risk of sparking with higher beam energies and shorter bunch lengths the third chamber is manufactured with 10 waveguide monitors [5]. These monitors decouple through a small RF window beam position influenced RF from the beam pipe. RF signal processing allows to define the relative beam position within a few μm. Successful tests of the first prototype at CERN and the second improved design at DESY have proven the capability of this monitor type. Figure 5 shows the improved waveguide monitor design after machining by an electrical discharge machining (EDM) process. At the end of the U-type waveguide an asymmetric window couples to the beam pipe. Figure 6 shows the final chamber on the electrical discharge machine in the workshop.
In 1998 the final connection of the vacuum chamber to the undulator frame was designed. The chamber is fixed on one side to the diagnostic block which defines the longitudinal position of the chamber. The
chamber is then connected by 9 sliding chamber supports to the undulator support system. Each support allows to align the chamber within a tenth of a mm in vertical direction. The number of supports are defined by finite element model calculations. Figure 7 shows the calculation for one supporting period. The vertical deviation due to bending is of the order of 6 \( \mu \text{m} \).

![Diagram showing the displacement of the chamber between two chamber supports.](image)

**Figure 7:** The displacement of the chamber between two chamber supports.

The last figure in this section shows the first undulator assembled with diagnostic block, vacuum chamber with monitors, steering coils and supporting structure.

![Diagram showing the final assembly of the first diagnostic block and the first undulator chamber with chamber supports connected to the lower part of the undulator structure.](image)

**Figure 8:** The final assembly of the first diagnostic block and the first undulator chamber with chamber supports connected to the lower part of the undulator structure.
The final cleaning and assembling of the monitors is planned for February 1999. The final assembling of the whole FEL vacuum system will take place in the first half of 1999.

References

Photon Beam Diagnostics for the TTF Phase I VUV SASE-FEL

R. Treusch, T. Lokajczyk, J. Feldhaus

In 1995 DESY proposed to make use of the unique electron beam properties of the TESLA Test Facility (TTF) and to construct a VUV FEL based on self-amplification of spontaneous emission (SASE) [1]. Since the initial work of Kondratenko et al. [2, 3], Bonifacio et al. [4] and Pellegrini [5], the SASE theory has been elaborated for short wavelength coherent radiation ([6, 7] and references therein). These calculations serve as a sound basis for the experimental verification of the SASE principle. Among other things, the calculations predict a specific gain for given electron beam and undulator parameters, the photon beam profile and especially the “spiked” structure in temporal and energy distribution due to the startup from noise in the amplification process (Fig. 1).

Figure 1: Typical frequency spectrum of a single pulse, calculated for the VUV SASE-FEL in saturation.

For the Proof-of-Principle experiment of the VUV SASE-FEL in summer/autumn 1999 a multi-facetted setup for photon beam diagnostics has been designed (Fig. 2) and is currently being realized at HASYLAB in collaboration with various European institutions (Universität Jena, LURE Paris, Lund Laser Centre, MAX-LAB, FZ Jülich, INFN Milano, Dublin City University, Sincrotrone Trieste, Universität Hamburg, Daresbury Laboratory, IFPAS Warszawa). It will provide the opportunity to characterize the spectral, temporal and statistical properties of the FEL beam, and to measure its power and angular distribution. In addition, there will be a setup to determine radiation damage thresholds of optical components. Due to the unique properties of the VUV FEL beam, such as the extremely high power and brightness and the short pulse length (Table 1), new concepts have been developed to measure the SASE specific properties.

<table>
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<th>Parameter</th>
<th>Minimum Energy</th>
<th>Maximum Energy</th>
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<td>Bunch Length [μm] (rms)</td>
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<td>No. of Bunches per Macropulse</td>
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<td>Macropulse Repetition Rate [Hz]</td>
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<td>Photon Energy [eV]</td>
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<td>$P_{average}$ [W]</td>
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<td>Energy/Pulse [μJ]</td>
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<td>400</td>
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Table 1: Parameters of the TTF Phase I VUV SASE-FEL
Figure 2: Layout of the experimental area for photon beam diagnostics. 1: bending magnet to deflect the electron beam, 2: alignment laser, 3: aperture unit, 4: detector unit, 5: deflecting mirror, 6: Titanium Sublimation Pump + ion pump unit, 7: 1 m normal incidence monochromator, 8: CCD-camera, 9: second chamber with aperture/detector unit and focusing mirror (optional), 10: beamline for autocorrelation experiments and radiation damage investigations (schematic drawing)

Due to the extremely strong absorption of VUV radiation by any material, all devices for beam diagnostics are operated under UHV conditions. A HeNe-laser, coupled in through a Suprasil (fused silica) viewport, will be applied to preadjust all optical components to a reference coordinate system, and collinear to the FEL beam later on. A set of apertures attached to a water cooled frame will be used to scan the beam profile and to define the cross section of the beam impinging on the detectors and the optical components downstream. To cope with beam intensities varying over roughly five orders of magnitude, a multitude of different detectors will be mounted on a cooled frame just behind the apertures. It will comprise simple, electrically insulated metal plates to measure the beam intensity through the photocurrent, a position sensitive detector (PSD), PtSi-photodiodes and different layouts of thermopiles based on YBCO High-Tc-superconductors (HTSCs). The PSD is a square PIN-diode with 4 electrodes, one on each edge of the frontside p-layer, and a fifth electrode on the rear side, i.e. the n-layer. Due to the homogeneous resistivity across the p-layer the current signal from each of the 4 electrodes depends on the distance of the beamspot from the respective electrode allowing to determine the intensity weighted center of the beam. This detector finds its application for both, the continuous-wave HeNe-laser as well as the pulsed FEL and will facilitate the alignment of the optical components and the other detectors.

PtSi-photodiodes were preferred to Si- or GaAsP-diodes due to their radiation hardness. For \( \lambda \leq 150 \text{ nm} \), Si- and GaAsP-photodiodes exhibit an extreme deterioration already at low exposure doses of several \( \text{mJ/cm}^2 \), i.e. after a few “shots” of the FEL, while PtSi does not even show significant damage at a hundred times higher irradiation. The PtSi-photodiodes will be used for low to intermediate power densities of the FEL, starting with the spontaneous radiation of the undulator. For short pulses (smaller than their response time of \( \approx 500 \text{ ps} \)) the onset of saturation for PtSi-photodiodes lies around 1-2 \( \mu \text{J} \), i.e. two orders of magnitude below the saturation power of the VUV FEL. Using pinholes to reduce the cross section of the FEL beam, the range of operation of the photodiodes might be slightly extended.

The thermoelectric HTSC-detectors based on the “Seebeck-Effect” will fill the gap from intermediate power to saturation of the FEL (184–400 \( \mu \text{J} \) in a 500 fs pulse, cf. table 1). They work at room temperature and are insensitive to temperature changes (0.5%/K). They combine a fast response time of 1 ns with linearity over
12 decades up to megawatts of power delivering an output signal of 1 V/mJ for short pulses. It is intended to use single elements as well as a matrix arrangement with $4 \times 4$ elements $2 \times 2 \text{mm}^2$ each (Fig. 3) for a rough but fast measurement of the intensity distribution in the beam.

The matrix readout is done through delay lines with delays of 0, 25, 50, and 75 ns, respectively, so that each full column (4 elements) of the matrix can be combined and fed into one out of 4 channels of a 1 GHz digital oscilloscope (Fig. 3). Fast amplifiers are employed to compensate for the signal drop due to the damping of the delay lines made from coaxial cables. With the large memory of the oscilloscope several consecutive FEL pulses can be sampled even running at the maximum repetition rate of the TTF linac, i.e. 9 MHz (111 ns bunch/pulse separation).

The detectors will be complemented by fluorescence screens viewed by external CCD-cameras through Suprasil viewports. We have chosen Ce:YAG and PbWO$_4$ crystals for that purpose, since they have a fast fluorescence channel (several 10 ns relaxation), emit in the visible range (matching viewport transmission and camera sensitivity), and are very homogeneous, radiation hard and UHV compatible. PbWO$_4$ crystals are key materials for future use in enormous quantities in scintillation detectors for high energy particle calorimeters, e.g. at ZEUS (HERA) and at LHC (CERN), and have also been investigated for applications based on photon excited fluorescence. The fluorescence screens will be used for a coarse adjustment of the detectors and optical components with respect to the FEL beam and, in particular, to investigate the beam profile and its statistical fluctuations.

For further characterization of beam properties, such as spectral and temporal structure, a plane mirror will allow to deflect the beam from the first detector chamber described above into one out of three branches. The topmost branch of the beamline is connected to a normal incidence monochromator which will be equipped with a spherical grating of either 1200, 2400, or 3600 lines/mm. Since the high resolution 3600 l/mm grating is pretilted to make the full spectral range of the Phase I VUV FEL (42-122 nm) accessible, it is no longer possible to preadjust the grating using the 0th order reflection. Therefore, a hollow cathode lamp will be used for monochromator alignment and calibration (Fig. 4): a noble gas discharge at well defined operating conditions yields a calibrated photon source covering the relevant range for Phase I FEL operation with a multitude of narrow lines of known flux.

The 3600 l/mm grating, in conjunction with a precise piezo-actuated entrance slit that can be closed down to less than 10 $\mu$m, results in a maximum resolving power of $E/\Delta E = 2 \times 10^4$ at $\lambda = 120$ nm, which should be sufficient to fully resolve the fine structure shown in Fig. 1. For parallel detection of the full linewidth of the FEL beam (0.4–0.7 % rms) a CCD-camera will be put in the focal plane of the detector. In the beginning it is
intended to use a thinned, back-illuminated UV-sensitive CCD with a pixel size of 24 μm, directly attached to the vacuum chamber. Tests at an identical monochromator, using a laser produced plasma source with varying targets, revealed the potential of the camera (Fig. 5). This camera with its low electronic noise is ideally suited for the commissioning phase of the FEL at low beam intensity.

Figure 5: Typical spectrum of a laser produced plasma source measured with a 1 m normal incidence monochromator using a 1200 lines/mm grating and the back-illuminated CCD-camera for detection. The experiments were performed in collaboration with the Centre for Laser Plasma Research, Dublin City University.

High resolution measurements at high intensities will be performed using a different camera equipped with a fast fluorescent screen in the focal plane of the monochromator, and an intensifier (MCP). While the pixel size of the CCD is 6.7 μm, the “effective” pixel size of the whole system (including the MCP and some
lenses) amounts to \( \approx 12 \, \mu \text{m} \). This results in a spectral resolution twice as large as with the other camera and close to the aberration limit of the monochromator. The MCP is used as a fast shutter enabling exposure times down to 5 ns. This makes it possible to select a single pulse from a sequence of pulses and to study a possible change of electron beam parameters for the first couple of bunches in a bunch train (macrobunch).

The beamline in forward direction (with retracted mirror) provides space for an additional set of apertures and detectors to determine the FEL beam direction and to align the HeNe-Laser. At a later time it is planned to add a spherical normal incidence SiC-mirror as part of a feedback system in order to realize a regenerative amplifier FEL (RAFEL)[9]. This feasibility study in collaboration with JINR, Dubna, and IFPAS, Warszawa aims at producing narrow-band, fully coherent FEL radiation and exploring SASE in the deep saturation regime.

The third beamline will accommodate different experiments which will be installed after the initial characterization of the FEL beam using the diagnostics in the upper two beamlines. Groups from FZ Jülich and Universität Jena are presently designing two separate autocorrelation experiments to study the properties of the FEL beam in the time domain [8]. Later on it is intended to investigate the radiation damage of materials for optical components in a specially designed UHV chamber containing a focusing mirror and time-of-flight spectrometers for electrons and ions. This experiment is in preparation at the IFPAS, Warszawa.

References


Phase 1 of the TTF FEL project will be completely accommodated in the existing hall housing the TESLA Test Facility. For Phase 2, three main buildings have to be constructed, see Figure 1.

1. The Cryogenic Hall will give room for an extended cryo plant for liquid Helium supply, for cooling water pumps and for a test stand for TESLA accelerator modules. This hall is structurally complete.
2. A new tunnel has to be built to accommodate the linac extension, the 30 m long undulator, and a monochromator section. This tunnel has been designed to resemble as much as possible the future linear collider tunnel in order to gain installation and operation experience. It is assembled from pre-fabricated tunnel segments and will be covered with sand for radiation protection. Figure 2 shows a photo of the status of civil engineering as of end of Nov. 1998.
3. The experimental hall for potential users will be located on the other side of the PETRA storage ring tunnel (a small beam pipe will cross the PETRA tunnel without severe mutual interference).

Figure 1: Overview of buildings for Phases 1 and 2 of the TTF FEL.
Experimental Hall

To accommodate the experimental hall, the DESY site will be expanded in northern direction beyond the PETRA storage ring. During 1998 the design has been finished. Construction of this building will be completed before end of 1999, because it will be the center of DESY’s EXPO2000 exhibition. Afterwards, installations for users of the FEL will begin. First operation for users is foreseen for the year 2003.
The world exhibition EXPO 2000 takes place in Hannover from June, 1st, to October, 31st, 2000. The Free-Electron Laser for VUV and soft X-ray radiation, which is under construction at DESY, was elected as one of the world wide projects of EXPO 2000 and will be presented in Hamburg at the DESY site.

Between 50000 and 75000 visitors are expected. A big effort is made to arouse people’s interest for science in general, for the VUV Free-Electron Laser under construction at DESY, for the project of a Linear Collider with incorporated X-ray FELs, and for DESY as a modern research centre.

The experimental hall shown in Fig.1 is located on a former ”Volkspark Stadion” car park, which became part of the DESY site. It offers 1500 m$^2$ floor space on three levels for the exhibition. In addition FEL hardware components will be presented in the tunnel. Visitors will be able to look at the X-ray laser right on the spot and to witness its construction. We very much hope that they will experience all the scientific fascination of the new device and learn more about research at DESY. Efforts are made to make the whole tour exciting, easy to understand and entertaining. Those who want to go deeper into the subject will be taken care of as well.

Everybody is heartily welcome to visit the exposition. For further information please look at

WWW: http://www.desy.de/expo2000/

Figure 1: DESY VUV : Experimental hall EXPO 2000