PITZ 2 – Development of an Optimized Photoinjector for Free Electron Lasers and Linear Colliders

0. Executive Summary

0.1. Introduction

The Photoinjector Test facility at DESY Zeuthen (PITZ) was built in order to test and optimize sources of high brightness electron beams for future free electron lasers and linear colliders. For both applications intense electron beams with very small transverse emittance and low energy spread are required in order to meet either the high-gain conditions of FEL operation or luminosity specifications of a TeV collider. The challenge of PITZ is the production of such beams with extremely high quality by applying the most advanced techniques in combination with key parameters of projects based on TESLA technology like TTF2, TESLA and BESSY III. In autumn 1999 the decision for building this facility was taken and in January 2002 the first photoelectrons were produced. Since then, several operation periods have followed and the first beam measurements have been presented at the conferences EPAC2002 [1] and FEL2002 [2]. The current near term goal of PITZ is to do a full characterization of the existing electron source and then to install it at the VUV-FEL at TTF2 in Hamburg in summer 2003.

The second stage of PITZ, called PITZ2, is a large extension of the facility and its research program. The concept of PITZ2 is to basically resemble TTF2 up to that critical beam energy where emittance becomes a constant of motion for the rest of acceleration. In this way, TTF2 will be relieved from the time consuming studies on improvement of electron beam quality, while all results achieved at PITZ can readily be transferred to TTF2 and other facilities, thus improving their performances. In addition, PITZ will be able to study injector schemes beyond TTF2 demands, e.g. for TESLA and BESSY III.

PITZ2 will comprise the following main aspects:

- The key technical element of PITZ2 is a booster cavity, which allows accelerating the beam to ~ 40 MeV, an energy necessary to prove the basic principles of conserving small transverse emittance.
- For the detailed study of the electron beam parameters at higher energies new diagnostic elements have to be developed and installed.
- A stable and reliable laser system with the required flat-top temporal and transverse laser beam profiles has to be developed and installed.
- Further optimization of all others subsystems is needed in order to reach optimum electron beam parameters. This requires extensive beam dynamics studies.
- In addition, testing of a new gun cavity for high duty cycle operation and further improvement on photocathodes are foreseen.
- The delivery of improved guns for the VUV FEL at TTF is planned.

Key issues of PITZ2 are given in the following table.
The second stage of PITZ will be realized in collaboration of BESSY, DESY, MBI and TUD. Contributions from INFN Milan (cathodes), INR Troitsk (CDS booster) and INRNE Sofia (diagnostics) are also included.

The total costs and the requested support are listed in the table below.

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<td>16641</td>
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Included in the total costs are 109 person-years. A large fraction of that is needed for the continuous operation and optimization of the facility as well as for the laser development. 41% of the total manpower is already available in the PITZ collaboration.

0.2. Booster cavity for the emittance conservation

A booster cavity plays a significant role in the emittance compensation technique. According to simulations, a minimum normalized transverse beam emittance can be conserved by locating a booster cavity at the position of the beam envelope waist, together with a proper choice of rf-gun and solenoid parameters. Future FEL proposals rely on this technique [3, 4, 5]. A proof of this concept and experimental optimization are the main objectives of PITZ2. The experimental study will be done in two stages. First, a TESLA prototype cavity (normal conducting, copper) will be used together with an upgraded diagnostics beamline to measure beam parameters along a distance of about 10 m. Later, this preliminary booster will be replaced by a normal conducting cavity specially designed for PITZ, which will reach higher beam energies.

0.3. Diagnostics

In order to provide the most complete characterization of the electron source a new diagnostics beamline will be needed. This includes devices that allow efficient and precise measurements of longitudinal and transverse phase space parameters for the full range of beam energies.

0.4. Optimization of the photoinjector including all subsystems

In order to obtain optimum electron beam parameters a photo cathode laser system of high stability and reliability is required. It was found from beam dynamics simulations that an optimal working point corresponds to the following laser parameters: laser pulse with a flat-top temporal shape (about 20 ps FWHM), short rise/fall times (≤ 2ps), and homogeneous transverse intensity profile of variable diameter. In addition to these requirements on each laser pulse, long pulse trains need to be realized for TTF2 and the TESLA XFEL.

Further development on simulation codes is another central field of R&D. This includes studies on beam induced fields and their influence on the beam dynamics as well as implementation of digital filters in particle-in-cell codes and detailed numerical study of dark currents in the photoinjector.

For the gun cavity development it is foreseen to design and test a high duty cycle rf gun, which is important for the operation of high repetition rate FELs and energy recovery linacs. In addition, further studies on photocathodes are planned.
1. Introduction and Motivation

The linear collider project TESLA and its X-ray Free Electron Laser facility (TESLA XFEL) which both are to be realized in international collaboration at DESY Hamburg, as well as the scientific case of a future Soft-X-ray-FEL facility at BESSY have been evaluated positively by the German Science Council. Research in electron sources for these projects is of great importance. Therefore, further development of the Photo Injector Test facility at DESY Zeuthen (PITZ) together with the collaboration partners and with support from the BMBF is strongly motivated.

In autumn 1999, the decision for building the photoinjector facility at Zeuthen was taken, and on January 13th, 2002, the first photoelectrons were produced. Since then, several operation periods have followed and results of the first measurements have been presented at the EPAC2002 [1] and FEL2002 [2] conferences. Currently, the following laser and electron beam parameters have been achieved:

- laser micro pulse length: \((7 \pm 1)\) ps FWHM,
- rms laser spot size at the cathode: \(0.3\)–\(1\) mm,
- quantum efficiency of the photocathode: \(\sim 0.5\) \%,
- maximal achieved bunch charge: \(\sim 7\) nC,
- typical transverse rms size of the electron beam: \(\sim 0.2\)–\(3\) mm,
- maximal electron beam momentum: \(4.7\) MeV/c, measured at an accelerating gradient of \(~ 41.5\) MV/m,
- momentum spread of the electron bunch: about \(15\) keV/c for a beam charge of \(\sim 1\) nC,
- normalized transverse emittance: \(1.5\)–\(20\) \(\pi\) mm-mrad for a beam charge of \(0.5\)–\(2\) nC.

A view along the PITZ tunnel and schematics of the present setup are shown in Fig. 1.

The current near term goal of PITZ is to fully characterize the existing electron source before delivering and installing it at the VUV-FEL at TTF2 at DESY Hamburg in summer 2003.

The second stage of PITZ, called PITZ2, is a large extension of the facility and its research program. It includes the installation of a booster cavity in order to reach higher beam energies and to study the principle of conserving small emittances. Using a booster enables a more complete characterization of the photoinjector which is planned to be used at the VUV-FEL at TTF2, the TESLA X-ray-FEL, as well as the BESSY Soft-X-ray-FEL. The increase of beam energy requires a new design for the beam diagnostics section. The study of conserving small transverse emittances is one of the central fields of PITZ2.

Production of high brightness beams, being an important specification of advanced electron sources, complicates the photoinjector operation. The enhanced particle density leads to increased space charge forces, which are only cancelled in part by the beam acceleration in the rf gun. A significant part of the projected emittance growth is caused by longitudinal correlations between phase space distributions of bunch slices. By applying a solenoid field in a certain parameter range, one can possibly inverse for a while the space charge force action. This results in two local minima of the transverse projected emittance (blue solid curve in Fig. 2). After the second emittance minimum (where the transverse phase space distributions have a similar orientation in each longitudinal slice), space charge action leads to a dramatic growth of the projected emittance. To prevent this growth, an additional accelerating cavity has to be placed at a suitable position in order to reduce space charge effects by further beam acceleration (space charge scales roughly with \(1/\gamma^2\) where \(\gamma\) is the beam relativistic factor). The invariant envelope matching
condition requires the beam to be injected at a laminar waist $\sigma$ (which coincides with a local emittance maximum) at the entrance of a booster cavity with a matched normalized accelerating gradient $\gamma'$ given by

$$\gamma' = \frac{2}{\sigma} \sqrt{\frac{\hat{I}}{3 I_A}},$$

where $I_A$ is the Alfvén current ($I_A \approx 17$ kA for electrons), $\hat{I}$ is the electron beam peak current.

Beam acceleration in the booster cavity under matched conditions leads to further extension of the emittance compensation process, and the projected emittance stays near the minimum level (red and green solid curves in Fig. 2).

In this figure, the red curves correspond to a normal conducting 9-cell TESLA prototype cavity (preliminary version of the PITZ booster). The green curves represent the beam parameter development in a 10-cell CDS cavity specially designed for PITZ. For comparison purposes the gradient was chosen so that it corresponds to that of the preliminary booster. In the realization,
the final booster will have more than 10 cells. Therefore, the energy gain increases and better emittance compensation takes place.

The design concepts of the future injectors for FEL operation [3, 4, 5] are based on numerous simulations, which show the possibility of achieving smaller emittance using a booster cavity as explained above. By now, these predictions have not been verified experimentally. Therefore, the proof of these design concepts and the experimental optimization of the photoinjector are the main goals and challenges of PITZ2.

Figure 2: Development of beam size and normalized emittance along the beamline for three different cases: without booster ('drift'), with a 9-cell normal conducting TESLA prototype cavity ('TESLA 9'), and with a 10-cell PITZ booster ('CDS 10'). For comparison, the number of cells for the CDS booster was chosen such that a similar energy gain as for the 9-cell TESLA booster is achieved [6]. The strong increase of beam size and emittance in the drift case is clearly visible. As explained in the text, the emittance minimum can be conserved by placing the booster at an optimized position. This position ('booster'), as well as the position of an emittance measurement system ('diag'), is indicated. An accelerating gradient of 40 MV/m was assumed for the gun. In this case, the optimum gradient for the booster is about 12.5 MV/m.

The second important task of PITZ2 is the continuation of research and development activities for the optimization of electron sources. This is of great importance for achieving the specified parameters for Free Electron Lasers. In order to produce electron beams with optimal beam quality for FEL operation, the driving laser system must provide high stability and reliability. It was found from beam dynamics simulations, that an optimal working point corresponds to the following laser parameters: laser pulse with flat-top temporal shape (about 20 ps FWHM), short rise/fall times (∼2 ps), and homogeneous transverse intensity profile of variable diameter. Plans for further development and improvement of the laser system are described in section 3.

Another field of research for improving and extending the capabilities of rf gun electron sources is the design and test of new gun cavities. On the one hand, this concerns the cavity design for high duty cycle operation, as it is planned to be used at the BESSY-Soft-X-ray-FEL or Energy Recovery Linacs (ERLs). On the other hand, the development of new gun cavities (if necessary in improved geometrical design) aims to further improve the beam quality and to satisfy the needs
of the VUV-FEL at TTF2 in spare cavities. All these works require detailed experimental studies and numerical simulations.

Studies on further improvement of photocathodes represent another important component for the whole project. They are foreseen to take place in collaboration between BESSY and the working group of INFN Milan which up to now has produced photocathodes of high quality for TTF and PITZ1. Conceptual research on flat and polarized electron beams at PITZ is planned to start in 2005. Furthermore, remote control operation in the frame of the Global Accelerator Network (GAN) has to be tested at PITZ. Future plans for PITZ include the installation of a bunch compressor (BC1 from TTF1) at Zeuthen. It shall be used for investigations on beam compression, electron bunch length measurements, and detailed studies of coherent synchrotron radiation (CSR). Perspective plans of PITZ include also research in alternative compression methods, i.e. ballistic bunching, which allow to achieve FEL specified bunch density distributions avoiding unwanted CSR effects.

2. Setup with Booster Cavity (PITZ2)

Similarly to PITZ1, the upgrade of the photoinjector test facility at Zeuthen (PITZ2) includes the development of an accelerating section (with booster) and an extended beam diagnostics section for detailed studies and full characterization of the electron source.

2.1 Accelerating Section

The accelerating section for the second stage of PITZ consists of a gun cavity with an upgraded gradient of about 40 MV/m, and a booster cavity. Being a key technical element, the booster cavity for PITZ2 should have a special design allowing a maximum energy gain without degrading the electron beam quality. The positron pre-accelerator cavity with the so called cut disk structure (CDS) which is planned to be used for the TESLA linear accelerator provides a good starting point for finding an optimal solution for a normal conducting PITZ booster. To get a suitable design, the CDS cavity will be further developed in close cooperation with INR Troitsk.

The maximum attainable energy of the electron beam depends on the available rf power and the requested accelerating gradient, see equation (1). Further depending on the detailed design of the booster cavity geometry, this results in a certain number of accelerating cells. To achieve the envisaged total beam energy of 40 MeV with this booster at the proposed PITZ setup, about 27 cells with an acceleration gradient of approximately 12 MV/m are required.

2.2 Diagnostics Section

For the full characterization of the electron source detailed measurements of transverse and longitudinal phase space properties have to be done. The increased beam energy requires various new diagnostics elements. A list of the diagnostic tools foreseen for PITZ2 is given below:

- The beam offset at different positions along the beamline has to be known in order to steer the beam onto the ideal orbit as well as for lattice devices alignment studies. For these purposes Beam Position Monitors (BPMs) have to be installed.
- Faraday Cups (FC) allow absolute bunch charge measurements, at the same time they can serve as beam collector.
- The transverse electron beam distribution at various longitudinal positions along the beamline has to be determined by means of observation screens and CCD cameras. The increased beam energy causes the use of Optical Transition Radiation (OTR) screens.
However, Yttrium:Aluminum:Garnet (YAG) screens are suitable for measurements of low intensity and low energy beams (for example, behind a slit-mask or directly after the gun).

- The transverse projected emittance can be measured using an Emittance Measurement System (EMSY), composed of slit masks and/or hole masks (pepper pot), and screens 1.5–2 m downstream which are observed by CCD cameras. In an alternative method – a quadrupole scan - the gradient of a quadrupole is varied and the corresponding beam size variation is measured on screens. Later Twiss parameter analysis yields a beam emittance computation. In order to observe the beam emittance evolution along the beamline, three EMSYs have to be installed: at the place of the smallest emittance (approximately at \( z=6 \) m, see Fig. 2), as well as at the beginning and at the end of the beamline (i.e. at \( z=4 \) m and \( z=12 \) m).
- For a non-interceptive beam current measurement a commercial Integrating Current Transformer (ICT) will be used.
- For the bunch length measurements as well as for the corresponding longitudinal phase space analysis OTR screens with streak camera readout need to be available.
- For measuring the beam momentum distribution a spectrometer is required, consisting of a dipole magnet and a screen in the dispersive section. The image can be recorded by a conventional CCD camera as well as by a streak camera.
- The slice emittance can be measured by using off-crest acceleration in the booster and a quadrupole in the dispersive arm.
- Moreover, beam phase space analysis becomes possible using one out of two OTR screens placed one behind the other. Beam energy, intensity and divergence can be determined by analyzing the interference pattern of forward and backward scattered radiation [7].

All magnets and diagnostics elements mentioned above (screen stations, Faraday Cups, BPMs, ICTs, and EMSY) have to be developed in order to fit the requirements of increased beam energy and improved measurement accuracy. Some new diagnostics elements (e.g. EMSY) can be designed by changing the existing construction and adapting the inner components to higher beam energies. Then they can be reproduced in the needed quantity. An overview of the general diagnostics layout for PITZ2 is shown in Fig. 3. The setup consists of separated modules that may be positioned and eventually exchanged independently from each other.

### 3. Development of an optimized laser system

To meet the high requirements on electron beams for FEL operation, the photoinjector including all subsystems has to be optimized in a wide parameter range. Being one of the central elements of the optimization process, the driving laser needs to allow for a wide spread variation of laser beam parameters. Laser developments made in the context of PITZ1 show that the combination of TESLA demands on pulse structure (micro pulses and macro pulses), mean laser power, and micro pulse rise time are at the frontiers of today’s possibilities of laser materials. Therefore, strongly research oriented work is necessary to reach the TESLA specifications.

The MBI is currently working on the development of a laser that generates quasi rectangular pulses with rise times of \((3 \pm 1)\) ps and a pulse length of about 20 ps. This laser should be realized by the end of 2002. Beside its operation at DESY Zeuthen and the perfection of its controls and regulations, the Nd:YLF laser system shall be further developed and extended. In a first step, the flash lamps used as pump sources up to now should be completely exchanged by semiconductor pump diodes. In addition, a flexible adjustment of laser parameters on actual user demands has to be possible with this laser system, e.g. due to adaptive optics in the laser beam transport system. An important emphasis at PITZ2 is the use of laser pulses with rectangular
**Figure 3:** PITZ2 general layout. The acceleration section consists of the gun cavity and the booster cavity. The gun is followed by a pair of steering dipoles and a diagnostics cross consisting of a Beam Position Monitor (BPM), a YAG screen, and a removable Faraday Cup (FC) (serving for charge measurement and as low energy beam dump). A low energy diagnostics module follows, consisting of a dipole spectrometer, an ICT, a second pair of steerers, and a second diagnostics cross which contains in addition a collimator for dark current absorption. A Cherenkov radiator with streak camera readout for bunch length measurements is positioned afterwards, as well as in the first dispersive section, after a screen (OTR + YAG). Module 3 consists of the booster cavity, followed by a BPM and a screen with the possibility of choosing a streak camera readout. The high energy diagnostics section begins with an Emittance Measurement System (EMSY), followed by a screen (OTR as well as YAG) at a distance of 1.5-2 m. In the space between them, a BPM and the second spectrometer should be installed. The second EMSY follows in analogy to the first one. Between EMSY and its screen of observation a quadrupole triplet (for the beam focusing) as well as another BPM would be positioned. In order to do the beam tomography described in the text, one still needs a matching section in front of the tomography module consisting of 4 quadrupole magnets and 4 OTR screens. This module should contain at least 2 additional BPMs. At the end of the beam pipe the third EMSY will be installed, followed by the third spectrometer in order to allow a beam energy measurement at this position. It follows a screen, an ICT for the beam current measurement, and finally a beam dump. The dispersive arms that belong to the two last spectrometers consist of a quadrupole, a screen, a BPM, an ICT, and finally a beam dump, which can absorb the whole beam energy. Furthermore, there must be a possibility for using the streak camera in the dispersive areas.
intensity profile in time. One possibility for producing this kind of pulses is to use linear pulse shapers that form short, Gaussian shaped input pulses. Since the production of rectangular pulses in such linear systems happens via rejecting a large part of the spectral components of the laser beam, the total transmission is small. For compensating these losses high gain amplifiers have to be used afterwards. For PITZ2, several possible pulse shapers shall be tested in order to create a laser system with minimum rise time of the rectangularly shaped pulses, while intensity modulations in the flat-top region remain small.

Stable phase relations between the photocathode laser pulses and the accelerating rf field are a fundamental requirement for reproducible electron beam dynamics in the gun cavity. Only in this case, an optimized adjustment of quasi static components like solenoid magnets can be achieved. Therefore, the long term phase synchronization of the laser system is a necessary condition for reaching the optimized emittance of the accelerated electron beam. As a consequence, synchronization precisions of 1-2 ps over time scales from hours to days (far beyond the actual time scale of about 10 minutes) have to be achieved. Since the combination of two synchronous laser subsystems is an important part of the final laser system described below, this working package on the synchronization has to be finished before starting the realization of the final laser system.

For the years 2003 and 2004, the primary goal is to develop and install a reliable laser at PITZ which is simple to operate and can be adjusted to the needs of the experiments. Consequently, laser beam parameters like single pulse duration, shape, and energy, laser power, pulse train length, single pulse phase relative to the rf, and transverse beam profile at the photocathode have to be controllable in a wide range. For future production of rectangularly shaped pulses with rise times of about 1 ps the system has to work with a broad band laser material. Therefore, suitable materials like Nd:Glass, Nd:LSB, and Nd:BEL have to be investigated for a photocathode laser system with the TESLA pulse structure (pulse trains of ps pulses). A severe disadvantage of such a one-channel laser system comes from the non-linear transmission of the laser light from the IR to the UV. This frequency conversion is a 4th order process and therefore leads to a strong enhancement of small intensity modulations in the flat-top region. Since the modulations in the IR can be larger than 10 %, modulation depths of more than 40 % can occur after the conversion to the UV, leading to significant beam emittance growth, as simulations of e.g. TUD show.

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**Figure 4:** Schematics of the mixing two-channel laser system.
To prevent the amplification of the intensity modulations during the light conversion into the UV, the planned high stability photocathode laser for PITZ should be realized as a mixing two-channel laser system. Fig. 4 shows the principle: it consists in mixing the rectangular pulse produced by a broad band laser system with the third harmonic of a long Gaussian pulse produced by an Nd:YLF laser system. The advantage of such a mixing scheme is that intensity modulations of the pulse shaper are transmitted only 1:1 to the UV during the conversion. In addition, the complicated broad band laser channel needs to produce only 25 % of the total laser energy, while the remaining 75 % are supplied by the system generating the long Gaussian pulses. However, difficulties remain from the special demands on the precision of the synchronization system. For both laser systems a long term stability of a few ps is required. Therefore it is necessary to develop such a synchronization system for both channels in the separated working package mentioned before.

From today’s point of view, the mixing system is the best possibility to generate rectangular pulses at 262 nm (UV) with the required parameters for PITZ (rise times of 1 to 2 ps, good flatness in the flat-top region). However, since the mixing system is more complex than the one-channel system, the application of this system increases operation and maintenance efforts.

4. Contributions of the Collaboration Partners

4.1 Contribution of DESY

Activities of DESY within the framework of PITZ2 can be summarized as follows:

- Continue with the full characterization of the electron source. In summer 2003, the gun has to be delivered to the VUV-FEL at TTF2 in Hamburg. Before this date, the electron beam parameters (transverse emittance, momentum and momentum spread, bunch length) have to be measured in detail.
- Installation and commissioning of the second rf system (for the booster) as well as realization and test of an extended interlock concept for a commercial rf system in collaboration with DESY Hamburg.
- Installations of Gun 3 at Zeuthen, together with a new diagnostics cross on an existing girder which replaces the setup with Gun 2 after its delivery to Hamburg.
- Physical design (including simulations) of a normal conducting booster cavity as well as of a new diagnostics beamline for analysis of high energy beams; technical design, construction, commissioning, and operation of the facility. The booster cavity will be realized in several intermediate steps: at first, an existing normal conducting TESLA prototype cavity will be installed. Later, it will be replaced by a booster cavity specially designed for PITZ.
- Dark current studies
- Transfer of simulation and analysis tools elaborated at PITZ to the VUV-FEL at TTF2 in Hamburg and adaptation of these programs to the DESY Hamburg data environment.
- Design and characterization of Gun 4 as a spare gun for TTF2.
- Development of a new kind of rf cavities: new geometry (multi-cell structures), cavities with rf pick-up.
4.2 Contribution of MBI

The work of the MBI on the development and optimization of the laser system can be summarized as follows:

- **Operation and development of the existing Nd:YLF laser system:** improvement of control tools, replacement of flash lamps by semiconductor pump diodes, correction and control of the laser beam profile at the photocathode, e.g. using adaptive optics, flexible adjustment of the beam parameters depending on user demands.

- **Test of different possibilities of pulse shapers** for the production of temporal rectangularly shaped pulses with short rising time and minimum modulation in the flat-top region.

- **Development of a system for stable long term synchronization of laser systems with a precision of 1-2 ps**: Synchronization of the produced laser pulses with the rf is a key problem for the stable operation of the rf gun. The necessary long term stability of the synchronization system shall be reached by optimization of phase noise and phase drift sources, development of phase detectors, and temperature stabilization of critical elements (mode locker, mode mixer).

- **Development of a high stability diode pumped pulse train photocathode laser** with possibilities for the adjustment of e.g. single pulse duration and single pulse shape (rectangular or Gaussian), as well as of beam parameters like laser power, single pulse energy, pulse train length, single pulse phase relative to the rf, and transverse laser beam profile at the photocathode. From today’s point of view, the two-channel mixing laser scheme described in section 3 is the most appropriate system that fulfills these demands.

4.3 Contribution of TU Darmstadt

The following work on the development of simulation programs and their application for PITZ is planned by the TUD:

- **Simulations for the new booster cavity and diagnostics devices.**

- **Laser parameter optimization**: Simulations of beam dynamics in the photoinjector show strong influence of the laser parameters on electron beam performance (transverse projected and slice emittance, energy spread, and bunch length). The transverse and longitudinal phase space properties depend on temporal and spatial laser profiles. Moreover, many parameters (accelerating gradients, rf phase, and solenoid fields) have to be optimized for the different laser parameters. A by-product effect of producing longitudinally rectangular laser pulses, the laser intensity modulation in the flat-top region, has to be simulated; tolerance requirements have to be studied.

- **Optimization of the PIC-codes**: Particles-In-Cell (PIC) programs are capable of self-consistent simulations of many physical effects in beam dynamics over a wide parameter range. However, because of the well-known noise effect it is extremely difficult to simulate adequately electron beam emittance for long beamlines. Digital filters are promising tools for the reduction of numerically induced noises. Two types of the digital filters have to be studied: Finite Impulse Response (FIR) and Infinite Impulse Response (IIR) filter. Solving the problem of numerical noises allows simulating beam dynamics for long accelerator structures. Such simulations should help to understand complicated phenomena which take place in photoinjectors, and to explain the corresponding measurements.

- **Influence of the electron beam induced fields**: It was found from simulations that for space charge dominated beams in photoinjectors a main part of the beam emittance (slice and projected) growth appears in the cathode vicinity just after the laser illumination. The
influence of beam-induced fields on electron beam performance is an object of detailed studies. Furthermore, the impact of the coaxial coupler on the transverse and longitudinal beam phase space has to be investigated by using the PIC-codes MAFIA TS2 and TS3.

- **V-Code**: Based on the Ensemble Model, the V-Code provides a fast solver for beam dynamics problems and can be used for online simulations. The new PITZ beamline has to be implemented in the V-Code database; tools for the online data acquisition procedure have to be elaborated. A dedicated alignment utility should be applied for the PITZ misalignment study, and for a proper positioning of the laser on the photocathode, and the gun solenoids' alignment.

- **Dark current simulations**: In high power rf systems like PITZ, dark current can cause serious problems. Simulations of the dark current can help to guarantee a safe and stable operation of the rf gun. Furthermore, these simulations may help to optimize the design of future electron sources.

Most of the mentioned subjects can be studied independent of the technical realization at PITZ2. Only the simulations on the booster and the new diagnostics beamline have to be finished in summer 2003.

### 4.4 Contribution of BESSY

In collaboration with the working group of INFN Milan, which has provided high quality photocathodes for PITZ and TTF up to now, BESSY intends to study and develop photocathode materials for FEL photoinjectors. Three main activities are planned, which will use photoelectron spectroscopy and microscopy at the high brilliance synchrotron radiation source BESSY II, and the corresponding scientific-technical know-how [8]:

- Characterization of existing photocathodes directly after the production and after specified use to study of quantum efficiency degradation processes; for this purpose, a setup compatible with the PITZ cathode system is necessary.
- Development of nanostructured cathodes.
- Study of the influence of laser pulse shape and spectrum on the quality of the electron beam.

Furthermore, contributions to the development of the optical and electronical beam diagnostics for PITZ2 are foreseen. BESSY will take care of the development and will continuously support the following diagnostics systems:

- Streak camera for the beam diagnostics.
- Commissioning of a bunch length measurement system; development, construction, and commissioning of a new diagnostics station for longitudinal phase space studies.
- Development and construction of a beam position measurement system for extremely short electron bunches and pulse trains.
- Participation in the construction of the new diagnostics beamline, especially the phase space tomography section; for that, the beam optics layout design and the procurement of the necessary magnet power supplies is foreseen.

In addition, the following activities are planned:

- Cooperation with the MBI for development of a photocathode laser for CW-, or quasi-CW operation.
- High power tests of the current PITZ cavity and of a new high duty cycle gun cavity which will be developed by BESSY in cooperation with DESY. The power tests will be done with the rf system being available at PITZ, in order to verify the thermal possibilities of such electron sources.
- Supply staff for the systematic characterization of the photoinjector.
5. Time Schedule

2003
until 09/2003: full characterization of Gun 2 (transverse emittance and beam size, momentum and momentum spread, bunch length) using the laser system optimized for PITZ1
09/2003: delivery of Gun 2 to the VUV-FEL at TTT2 in Hamburg
until 06/2003: simulations on the booster cavity at TUD
from 09/2003: installation and characterization of Gun 3 for PITZ
until 09/2003: simulations on the new diagnostics section at TUD
until 12/2003: setup and commissioning of the second rf system for the booster
10-12/ 2003: installation and rf commissioning of the TESLA prototype cavity as a preliminary booster (without diagnostics)
in parallel: development of a gun cavity for high duty cycle operation under the direction of BESSY (this gun might be reproduced and used for TTF2); studies on photocathodes with X-ray photoelectron spectroscopy (XPS) and photoelectron emission spectroscopy (PEEM)

2004
01-04/ 2004: power test of the high duty cycle gun cavity
05/2004: setup of a beam dump for the high energy beam
until 06/2004: installation of the diagnostics for the high energy beam in collaboration with TTF and BESSY
from 07/2004: commissioning of the preliminary booster and the new diagnostics section
until 10/2004: installation of the improved laser system providing rectangular micro pulses in time
from 10/2004: first measurements of the high energetic electron beam using the preliminary booster; study of emittance optimization and the minimal emittance conservation principle
in parallel: development and construction of Gun 4 (either BESSY-Gun with high duty cycle or conventional FEL-Gun); production and optimization of the nanostructured photocathodes; setup of a device for electron pulse length measurement with modulated laser pulses in the laboratory at BESSY

2005
until 06/2005: setup and commissioning of a booster cavity specially designed for PITZ in collaboration with INR Troitsk
afterwards: detailed measurements at higher energies, optimization of electron beam parameters, analysis of the results
in parallel: study the influence of the laser profile and frequency modulation on the electron beam properties in the laboratory at BESSY
6. Costs and Manpower

<table>
<thead>
<tr>
<th>Investment and Administration Costs (in kEUR)</th>
<th></th>
</tr>
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<tbody>
<tr>
<td>investment for laser system development (MBI)</td>
<td>421</td>
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<tr>
<td>material for laser system development (MBI)</td>
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<tr>
<td>rf supply and rf control (DESY)</td>
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<td>booster (DESY)</td>
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<tr>
<td>vacuum, girders, and infrastructure for booster und beamline (DESY)</td>
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<td>magnets (DESY)</td>
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<td>beam diagnostics components (DESY)</td>
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<td>extension of the accelerator control system (DESY)</td>
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<td>construction of Gun 4 (DESY)</td>
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<td>cavity development (BESSY)</td>
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<td>laser system development (BESSY)</td>
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<td>diagnostics (BESSY)</td>
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<td>photocathodes (BESSY)</td>
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<tr>
<td>computer power (TUD)</td>
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<td>Sum (kEUR):</td>
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<table>
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<tr>
<th>Manpower (in PY):</th>
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<th>Engineers</th>
<th>Technicians</th>
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<tr>
<td>laser development (MBI)</td>
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<td>installation, operation, and further development of the rf system (DESY)</td>
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<td>laser beam transport and commissioning of the MBI laser system at PITZ (DESY)</td>
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<td>operation of the facility and measurements of the electron beam properties (DESY)</td>
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<td>preparation for future research topics: flat beams, polarized electrons, bunch compression, CSR (DESY)</td>
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Sums:

investment costs 6048 kEUR
manpower and travel costs DESY 6966 kEUR
manpower and travel costs MBI 1407 kEUR
manpower and travel costs BESSY 1883 kEUR
manpower and travel costs TUD 337 kEUR

Total costs: 16641 kEUR

- DESY contribution 5722 kEUR
- MBI contribution 0 kEUR
- BESSY contribution 883 kEUR
- TUD contribution 0 kEUR

(Remark: the contributions contain materials and personnel costs)

Requested Support 10036 kEUR

cost allocation (in kEUR) | DESY | MBI | BESSY | TUD | Sum
--- | --- | --- | --- | --- | ---
2003 | 1703 | 1208 | 618 | 190 | 3719
2004 | 1543 | 1208 | 1030 | 113 | 3894
2005 | 1059 | 838 | 414 | 112 | 2423
Sums | 4305 | 3254 | 2062 | 415 | 10036

7. References