DIAGNOSTICS AT PITZ 2.0 BEAMLINE: STATUS AND NEW DEVELOPMENTS

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Abstract

The main aim of the Photo Injector Test Facility at DESY, Zeuthen (PITZ) site is to develop and test an FEL photo injector system capable of producing high charge short electron bunches of lowest possible transverse emittance to allow optimum FEL performance. The last major beamline upgrade realized in the second half of the year 2011 completed the evolution of the PITZ setup ongoing since 2005. The most recent upgrades include the installation of a new RF deflecting cavity - a prerequisite for longitudinal emittance and high resolution slice emittance measurements and installation of a new dispersive section for longitudinal phase space diagnostics of the high energy electron bunches. The paper will give an overview on electron beam diagnostics at PITZ, including the above mentioned upgrades.

INTRODUCTION

The performance of linac based 4th generation sources of high brightness short wavelength coherent radiation is very sensitive to the quality of the driving electron beam. The measures of the beam quality are its peak current, energy spread and normalized transverse slice emittance. Whereas the beam peak current can be increased by a staged bunch compression [1], the transverse phase space could only degrade in linear accelerators. This makes a small emittance electron sources a key issue for the FEL performance.

The Photo Injector Test Facility at DESY, Zeuthen site (PITZ), is dedicated for development and testing of high quality laser-driven RF photoinjectors for the European XFEL project [1] capable of providing every second 10 electron bunch trains as long as 650µs, each containing about 3000 bunches of 1nC charge and transverse projected emittance not higher than 0.9mmmrad. The PITZ photo injector is an L-band 1.6 cell normal conducting water cooled RF gun cavity equipped with a solenoid to compensate space-charge induced emittance growth. A high quantum efficiency (QE ~ 10% [2]) Caesium Telluride (Cs_2Te) photo-cathode is used for electron production. The 4th generation PITZ gun, which is currently in use, is already capable to produce 1nC bunches with an emittance considerably lower than 0.9mmmrad [3,4]. The maximum kinetic energy of an electron beam accelerated by this gun is ~6.5MeV. Further acceleration up to ~25MeV is realized by using a Cut Disk Structure booster cavity (CDS) [5].

BEAM DIAGNOSTICS AT PITZ

Since the full experimental characterization of an electron beam is the fundamental aim of the PITZ research program, the beamline is equipped with a large variety of diagnostic devices:

Beam charge is measured either by using one of two installed Faraday cups (FC) or by using up to 6 available integrating current transformers (ICT) [6]. An ICT is a passive transformer designed to measure the charge of a very fast pulse. It is a non-destructive but resolution-limited device suitable for monitoring of medium to high charge beams (200pC – 5nC). For very low charges one of two FC's has to be used.

Beam transverse distribution, size and position can be determined by observing the beam on a Ce-doped Yttrium Aluminium Garnet screen (YAG, $Y_3Al_5O_{12}$) or on an optical transition radiation (OTR) screen. After hit by the electron beam, both screens emit visible light: the YAG screen by means of scintillation, the OTR screen by means of transition radiation. In both cases, an optical system images the light onto a CCD camera. The screens can be inserted to or removed from the beam-path by

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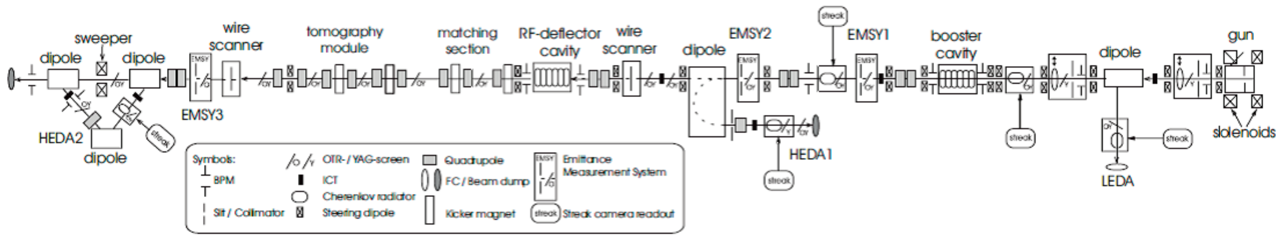

Figure 1: Schematic diagram of the current PITZ beamline. (The electron beam propagates from right to left.)

means of a remotely controlled actuator. In addition to the standard stations a new screen station using CVD (chemical vapour deposition) diamond has been installed in the upgraded beam line for long pulse trains monitoring.

Besides the screen stations, two wire scanners for beam-profile measurement [7] and several beam position monitors (BPM) for beam position measurements are installed.

Beam momentum and longitudinal phase space are analysed at dispersive arms (dipole spectrometers), where the beam is first deflected by a dipole magnet and afterwards collected and analysed at an observation screen station. The momentum and momentum spread are determined from a momentum-distributed beam image collected on a YAG screen. The complete longitudinal phase space is measured by analysing Cherenkov light produced by a same-treated beam on an aerogel radiator using a streak camera [8].

In the current PITZ setup (PITZ 2.0) there are three dispersive sections. The first one (DISP1), called as the low energy dispersive arm (LEDA in Fig.1), is equipped with a 60º vertically-bending dipole magnet and is placed ~1.1m downstream the gun. It is dedicated to momentum measurements and to longitudinal phase space reconstruction. The beam momentum after the gun is up to 7MeV/c, the resolution of the setup is 3keV/c [9])

The second dispersive arm (DISP2) is denoted as the first high-energy dispersive arm (HEDA1 in Fig.1). It is used to measure momentum, momentum spread, longitudinal phase space and the transverse slice emittance after the beam being accelerated by the booster. The DISP2 arm is able to measure electron beams having momentum up to 40MeV/c [10]. It is based on a 180º vertically-bending dipole and includes a slit for cutting of a beam part of a certain momentum range, a screen station dedicated to momentum analysis, a quadrupole magnet and a second screen station [11]. Beside that each screen station has its reference counterpart placed on the straight section which allows, together with the 180º dipole design, a simple reconstruction of the momentum distribution by means of de-convolution of beam shape (collected at the reference screen) from the momentum distribution measured in the dispersive arm. The resolution of the setup is ~8keV/c [9].

The third dispersive arm (DISP3) is one of the major upgrades of the PITZ setup and will be described later in a separate section.

Transverse phase space and transverse projected emittance are measured either with the single-slit-scan method [12] at a so-called emittance measurement system (EMSY) stations or via tomographic reconstruction using the tomography module (TOMO).

An EMSY station consists of two orthogonal actuators mounted perpendicularly to the direction of beam propagation. Each actuator consists of a YAG or an OTR screen for transverse RMS beam size determination and a pair of single-slit masks. The masks cut small portions out of the beam such that space charge effects during the drift from the slit to a screen for the divergence measurement are negligible. The 1mm thick tungsten slits have openings of 10µm and 50µm and are used for measurements of high and low charge density beams, respectively. The summary of measurements results from year 2011 can be found in [3,4]

The tomography module consists of four observation screens separated by three FODO cells. The other upstream quads of the beamline serve as the matching section for the TOMO. The phase space (both planes x-x' and y-y' simultaneously) can be reconstructed by means of modified inverse Radon transform. For details of the physical design of the tomography section, the analysis method and measurement results see [13].

A more comprehensive description of the PITZ diagnostics and measurement procedures can be found in [12]

RECENT BEAMLINE UPGRADES

The 3rd Dispersive Arm – DISP3

The third dispersive arm DISP3, also denoted as the second high-energy dispersive arm (HEDA2 in Fig.1) is a device serving a number of purposes. First, like the DISP2 it is designed for high resolution measurements of momentum distribution up to 40MeV/c and for measurement of the vertical slice emittance of energy-chirped beams. (The horizontal slice emittance of energy-chirped beams can be measured using the DISP2.) In addition to that the DISP3 system can be used together with the transverse deflecting cavity for diagnostics of the longitudinal phase space with resolution as good as 1keV/c [14]. The DISP3 arm has been designed and manufactured in collaboration between DESY and the Laboratoire de L' Accelerateur Lineaire (LAL, Orsay) [15]. Two ICTs and three BPMs integrated in the diagnostic section are used to monitor charge and vertical position within a bunch train as well as shot-to-shot.

Since the purpose of DISP3 is to analyse electron bunches in a high duty cycle of about 30k bunches per second a large beam dump is required. However the constraints of the PITZ tunnel do not allow a separate dump of that kind. Therefore, the deflected beam has to be brought back by the second and third dipole towards the dump located at the end of the straight section. In addition, the DISP3 arm has two screen stations and one quadrupole magnet.

The first multi-purpose screen station located between the first and the second dipole is dedicated for momentum distribution measurements (using a YAG and an OTR screen), bunch length and longitudinal phase space measurements and also contains a vertical slit (30mm times 60mm opening, 10mm thickness) needed for the measurements of the vertical transverse slice emittance at the downstream second station. Because of vertical space limitations in the PITZ tunnel and the need to use a bulky clean-room during assembly, the screen holder is placed as a whole inside a DN160 welded bellow. This reduces the height and improves the stability of the system. The choice of such a large bellow size poses extreme demands for the screen actuator (produced by the AXMO company), which is capable of dealing with forces as high as 3000N [14].

The second screen station is located between the second and the third dipole and serves as the observation screen for the vertical transverse slice emittance measurements and also for observing the beam before it reaches the third dipole. It consists of one YAG and one OTR screen. The design of this station is based on the second screen of the second dispersive arm DISP2 (that one dedicated for the transverse slice emittance measurements), which performed well in the past run periods.

The Transverse Deflecting System (TDS)

The TDS is designated for longitudinal beam diagnostics of ultra-short electron bunches. An electron beam travelling through the deflecting structure will be subjected to a time dependent vertical deflection, which will introduce a strong z-p_y correlation, resulting in z-y position correlation after a finite drift. A TDS is foreseen at three locations in the European XFEL setup. The XFEL TDS structures have been designed and now are in manufacturing by the Institute for Nuclear Research (INR), Moscow, Russia [16]. A prototype of the XFEL TDS is now being installed at PITZ to test its feasibility to satisfy the European XFEL performance requirements and to serve as an important diagnostic tool for PITZ. At PITZ it will be used in combination with the tomography module or with the EMSY3 station for slice emittance phase space reconstruction, and with the DISP3 arm for the longitudinal emittance measurements [17].

The PITZ TDS travelling wave structure is an S-band disc-loaded waveguide with two mode-locking holes for deflecting plane stabilization. The structure has 16 cells and operates in a deflecting TM11-like travelling mode with a very short filling time < 120ns. The unloaded Q-factor has been measured to be Q = 11044, which is 94% of the simulated value [18]. The RF station provides an RF pulse up to 3.1μs temporal length.

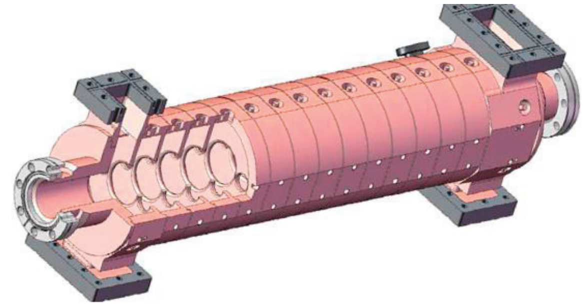

Figure 2: Sketch of the transverse deflecting cavity installed at PITZ. [18].

SUMMARY AND CURRENT STATUS

During the last shutdown in 2011, a major upgrade of the PITZ diagnostics has been carried out. The main upgrades were the installations of the third dispersive arm DISP3 and of the transverse deflecting structure. The TDS cavity has been already installed, mounting of the RF station and waveguides have been started recently. First tests are expected in summer 2012.

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