# COMMISSIONING OF NEW DIAGNOSTIC DEVICES AT PITZ

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*Abstract*

The Photo Injector Test facility at DESY, Zeuthen site (PITZ) is the test stand of the electron source for the European X-ray Free Electron Laser (XFEL). The main goal of the facility is the detailed characterization of the electron bunch parameters produced by the RF photo-cathode gun. Characterization of the bunch longitudinal properties such as bunch length or longitudinal phase space earlier was done using a streak camera, which measures the Cherenkov light produced by electron bunches passing through aerogel radiators. Recently, a Transverse Deflecting Structure (TDS) and a Second High Energy Dispersive Arm (HEDA2) were installed in the PITZ beamline. They will enable time resolved measurements of the electron bunch with much better time resolution than the streak camera system.

The first results of the commissioning of the HEDA2 section at PITZ are presented in this contribution.

## INTRODUCTION

PITZ develops and optimizes electron sources for Free-Electron Lasers (FELs) like FLASH and the European XFEL in Hamburg (Germany). The main goal is to produce high brightness electron bunches whose quality fulfills the stringent requirements of these FELs [1].

A schematic layout of the current PITZ beamline is shown in Fig. 1. The main components are: the RF photo gun as electron source, an accelerating cavity Cut Disk Structure – CDS booster, three dipole spectrometers, three Emittance Measurement SYstems (EMSYs), a transverse deflecting structure (TDS) and a phase-space tomography module (PST). The three dipole spectrometers are located in the low energy section downstream the gun (Low Energy Dispersive Arm – LEDA), in the high energy section downstream the booster cavity (First High Energy Dispersive Arm – HEDA1) and at the end of the PITZ beam line (Second High Energy Dispersive Arm – HEDA2). A slit scan [2] is the standard technique for the projected emittance measurement at PITZ. The longitudinal phase space of the electron bunch is measured at PITZ with Cherenkov radiators in dispersive sections [3] up to now. The most recent upgrade of the PITZ facility included the installation of the TDS and the HEDA2. The TDS cavity is a multipurpose device, which is expected to provide a significant improvement in time resolved measurements. Beside measurements of the bunch length, the TDS is planned to be used in combination with HEDA2 for measurements of the longitudinal phase space. The main goals and working principles of the TDS and the HEDA2 are described in this paper. First results of the HEDA2 commissioning at PITZ are presented.

## TRANSVERSE DEFLECTING STRUCTURE

The TDS cavity was designed and manufactured by the Institute for Nuclear Research (INR, Troitsk, Russia) as a prototype for the European XFEL [4]. The basic operation principle of the TDS is illustrated in Fig. 2.

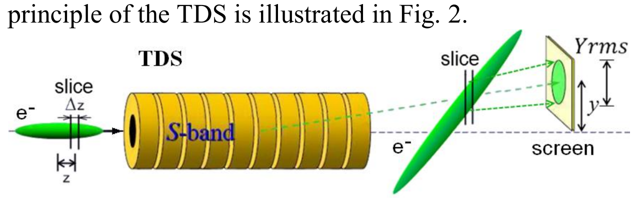


Figure 2: TDS working principle.

The structure deflects electrons vertically in linear dependence on their longitudinal coordinates within the bunch, which as a result enables measurements of the longitudinal bunch properties. An electron bunch propagates from left to right, passing through the deflecting structure. After a drift space, it is imaged on a screen. In case the bunch length is much shorter than the RF wavelength and if the bunch center propagates through the structure in the “zero” RF phase, then the

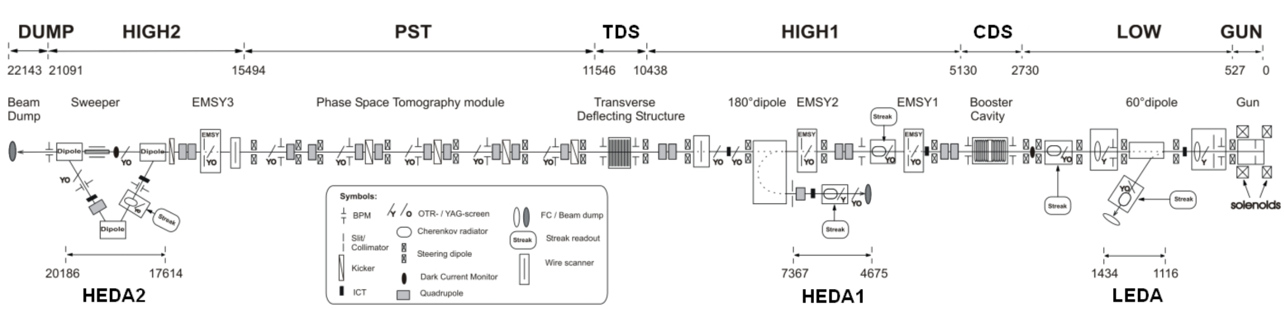


Figure 1: Current PITZ beamline layout.



ISBN 978-3-95450-125-0

deflection angle of each electron depends linearly on its longitudinal coordinate inside the bunch. As a result the mean vertical position $y$ of the bunch longitudinal slice on the screen can be obtained from the following equation [5]:

$$y = \theta \cdot l = \frac{eV_0 k}{pc} z \cdot l = S \cdot z, \quad (1)$$

where $\theta$ is the deflection angle, $l$ is the distance between the TDS and the screen, $V_0$ is the amplitude of the deflecting voltage, $k$ is the wave number ($2\pi f_{RF}/c$), $p$ is the bunch mean momentum, $e$ is the electron charge, $c$ is the speed of light, $z$ is the slice longitudinal coordinate within the bunch and $S$ is the TDS shear parameter.

The vertical size $Y_{rms}$ of the bunch slice on the screen (see Fig. 2) can be calculated as [5]:

$$Y_{rms}{}^2 = \beta_y \varepsilon_y + (S \cdot \Delta z)^2, \quad (2)$$

where $\varepsilon_y$ is the bunch vertical geometrical emittance at the screen position, $\beta_y$ is the vertical beta function and $\Delta z$ is the slice length.

Two slices of the electron bunch can be resolved on the screen if the vertical distance between their images is bigger than the vertical size of each of them. As a result, the minimum resolution length can be estimated for an infinitesimally small slice length as follows:

$$\delta z_{\min} = \frac{\sqrt{\beta_y \varepsilon_y}}{S}. \quad (3)$$

For typical PITZ operation conditions with $\beta_y$ equals 5 m, $\varepsilon_y$ equals $2 \cdot 10^{-8}$ mm·mrad and a TDS shear parameter $S$ of 4 the resolution length $\delta z_{min}$ is expected to be about 0.1 mm (0.3 ps).

## SECOND HIGH ENERGY DISPERSIVE ARM

The HEDA2 is designed and manufactured in a collaboration between LAL (Orsay, France) and DESY (Germany). The main goals of this section are [6]:

1. High resolution beam momentum measurements up to 40 MeV/c.
2. Longitudinal phase-space measurements with a slice momentum spread resolution down to 1 keV/c (screen imaging system resolution).
3. Transverse slice emittance measurements.
4. Long pulse train monitoring.

A sketch of the HEDA2 section is shown in Fig. 3. It consists of three dipole magnets – Disp3.D1, Disp3.D2 and Disp3.D3, two screen stations – Disp3.Scr1 and Disp3.Scr2, a quadrupole magnet – Disp3.Q1, three beam position monitors (BPMs) and two Integrating Current Transformers (ICTs) for bunch charge measurements.

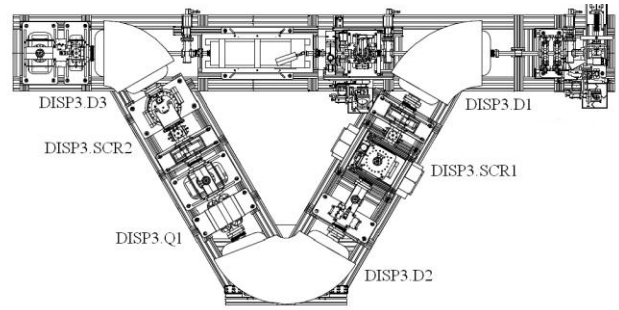


Figure 3: Sketch of the HEDA2 section, the electron bunch propagates from right to left.

Each screen station has two types of screens – a YAG (Ce-doped Yttrium Aluminum Garnet powder coated screen) and an OTR (Optical Transition Radiation screen). The screens are fixed on movable actuators. In addition, the first screen station has an aerogel radiator for streak measurements and a horizontal slit to select a longitudinal slice for vertical slice emittance measurements.

### *Momentum Measurements*

For measurements of the electron beam momentum the first dipole Disp3.D1 and the screen Disp3.Scr1 are used (Fig. 3). The entrance of the dipole is 17.14 m downstream the gun, the bending angle α and radius $\rho$ are 60° and 0.6 m, respectively. The distance $L$ between the dipole exit and the screen is 0.7 m.

The horizontal size of the electron bunch on the Disp3.Scr1 screen is defined by the bunch transverse phase space at this position and momentum spread [7]:

$$X_{rms}{}^2 = \beta_x \varepsilon_x + (D \cdot \delta p)^2, \quad (4)$$

where $X_{rms}$ is the rms bunch size on the screen, $\beta_x$ is the horizontal beta function, $\varepsilon_x$ is the horizontal geometrical emittance, $D$ is the dispersion as $D = \rho(1-\cos(\alpha))+L\sin(\alpha)$ and $\delta p = \Delta p/p$ is the relative rms momentum spread of the electrons in the bunch. For the parameters mentioned above $D$ = 0.905 m.

The horizontal bunch size corresponds to the momentum spread when the contribution of the last term on the right part of Eq. (4) is dominating. This means, the minimum achievable momentum resolution is defined as the momentum spread when the contributions from both terms on the right side of Eq. (4) are equal. Therefore, one gets the following limitation for the relative momentum resolution [7]:

$$\delta p_{\min} = \frac{\sqrt{\beta_x \varepsilon_x}}{D}. \quad (5)$$

For typical PITZ operation conditions with $\beta_x$ equals 5 m, $\varepsilon_x$ equals $2 \cdot 10^{-8}$ mm·mrad the minimum relative momentum resolution $\delta p_{min}$ is about $3.5 \cdot 10^{-4}$ or 8 keV/c for 25 MeV/c beam.

ISBN 978-3-95450-125-0

### *Longitudinal Phase Space Measurements*

The longitudinal phase space can be measured on the Disp3.Scr1 screen using the TDS cavity (see Fig. 1). The cavity center is located at 10.985 m downstream the gun, its length from flange to flange is 0.7 m, the distance between the cavity and the entrance of the dipole Disp3.D1 is 6.155 m. The beam image measured on the screen corresponds to the longitudinal phase space, where the image along the horizontal and vertical axes corresponds to the momentum and the longitudinal coordinate inside the bunch [8], respectively.

### *Slice Emittance Measurement*

Vertical slice emittance measurements can be performed with a quadrupole scan technique using the quadrupole magnet Disp3.Q1 and the second screen Disp3.Scr2. A horizontal slit at the Disp3.Scr1 screen station will be used to select a longitudinal slice of the energy chirped beam. The energy chirped beam will be realized with off-crest acceleration using the CDS booster. The horizontal slice emittance is measured with the same technique in the HEDA1 section upstream [9].

The third dipole Disp3.D3 is used to bend the beam back to the common beam dump at the end of the beamline of the straight section.

## RESULTS OF MOMENTUM MEASUREMENTS AT HEDA2

The first HEDA2 commissioning was done at PITZ in May 2012 with the following electron beam and PITZ parameters:

- Electron bunch charge – 0.8 nC (1 bunch in train).
- Beam momentum after the gun – 6.7 MeV/c.
- CDS Booster RF power – 4.5 MW.

As a test measurement, momentum measurements as a function of the booster RF phase were performed and results are shown in Fig.4.

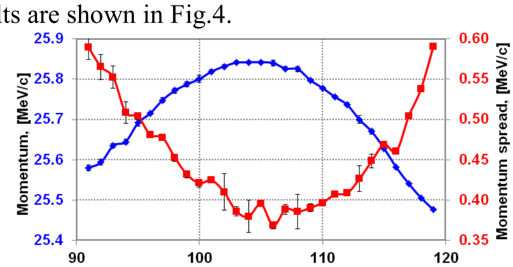


Figure 4: Beam momentum and momentum spread measurements performed at HEDA2.

The blue curve shows the mean beam momentum and the red curve shows the rms beam momentum spread as a function of the RF phase of the booster. The error bars show the standard deviation of 10 measurements for each RF phase.

An example of a beam image on the Disp3.Scr1 screen is shown in Fig. 5 together with the corresponding beam momentum distribution. The color code corresponds to the light intensity measured at the screen. The horizontal axis corresponds to the longitudinal beam momentum.

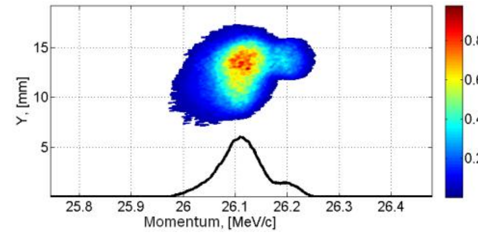


Figure 5: Beam image at the Disp3.Scr1 YAG screen and its corresponding momentum distribution.

## CONCLUSION AND OUTLOOK

The installed HEDA2 section enables momentum measurements of the electron beam up to 40 MeV/c. A beam momentum of up to 26 MeV/c was measured during the first commissioning in summer 2012. With the booster off-crest operation, it will be possible to perform vertical slice emittance measurements at the second screen station using a quadrupole scan technique. The TDS cavity will enable longitudinal phase space measurements with a minimum slice momentum spread resolution down to 1 keV/c. The TDS cavity was installed at PITZ in winter 2011. The klystron and high voltage modulator of the TDS were installed this summer. First tests with the cavity are planned for autumn 2012.

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ISBN 978-3-95450-125-0