PHYSICS AND TECHNICAL DESIGN FOR THE SECOND HIGH ENERGY DISPERSIVE SECTION AT PITZ*

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Abstract

Research activities at the Photo Injector Test facility at DESY, Zeuthen site, (PITZ) aim to develop and optimize high brightness electron sources for Free Electron Lasers (FELs) like FLASH and the European XFEL. To demonstrate the XFEL operation, an electron bunch train containing 3250 pulses of 1 nC charge at 10 Hz repetition rate is required. The spectrometers and related equipments for studying the longitudinal phase space for such long pulse trains do not yet exist at PITZ. Design and construction of a new high energy dispersive arm (HEDA2) is currently in progress. Besides the requirement to handle long electron bunch trains, the HEDA2 setup is designed to allow high resolution measurements of momentum distribution up to 40 MeV/c, a longitudinal phase space measurement with slice momentum spread down to 1 keV/c and transverse slice emittance measurements at off-crest booster phases. The status of the physics design and technical considerations of this dispersive section will be presented.

INTRODUCTION

The test facility PITZ was built and is developing as a pilot photo injector source for the FELs like FLASH and the European XFEL. The research goal is to produce, optimize and characterize the small transverse emittance electron beam of $\leq$ 1 mm-mrad with a bunch charge of 1 nC and an energy spread of smaller than 1%. In order to fulfill the characterization of high brightness electron beam, the PITZ beam line is continuously upgraded towards the final design (PITZ2) in parallel to the beam operation. The future PITZ2 set up (see Fig.1) will consist of a photocathode RF-gun, a booster cavity, and several diagnostics systems including 3 emittance measurement systems, 3 dispersive arms, an RF deflector, a phase space tomography module, and bunch length diagnostics. One of the key components which will be installed in the PITZ2 beamline is a new cut disk structure (CDS) booster cavity for emittance conservation corresponding to the peak field at the cathode of 60 MV/m [1]. The CDS booster can accelerate electron beams to reach higher energy than the current PITZ setup. This leads to the upgrade of the diagnostics components downstream the booster cavity for supporting the measurements with higher energy electron beams.

To fulfill the beam characterization, besides the intensive measurement program for the transverse phase space optimization the longitudinal phase space is studied using the low energy dispersive arm (LEDA) to measure beam momentum downstream the RF-gun, the first high energy dispersive arm (HEDA1) and the second high energy dispersive arm (HEDA2) to measure the beam momentum behind the booster. The upgraded LEDA and the new HEDA1 have been installed in the current PITZ setup [1]. The old high energy dispersive arm from the previous set up, which is able to measure the beam momentum up to about 16 MeV/c [2], was moved to the end of the beam line. Design and construction of the new HEDA2 is ongoing under the collaboration between DESY and LAL and it is planned to be installed at PITZ in the middle of year 2010.

SETUP

The HEDA2 setup is designed for high resolution measurements of momentum distribution up to 40 MeV/c, a longitudinal phase space measurement with slice momentum spread down to 1 keV/c, and a transverse slice emittance measurements. The contradictory between the measurements of the longitudinal phase space and the transverse slice emittance is the operation at different booster phases. The on-crest or nearly on-crest booster operation is required in the longitudinal phase space measurement for a small momentum spread, while in the transverse slice emittance measurement, the off-crest booster phases conduct the large momentum spread. Since the resolution of the transverse slice emittance measurement at the existing HEDA1 setup is expected to be very good [3], the good resolution of the longitudinal phase space measurement has higher priority in HEDA2 design.

To demonstrate an operation of electron bunches of 1 nC charge for the long bunch train up to 7200 pulses for the FEL at FLASH (720 μs pulse, 10 Hz) and 3250 pulses for the European XFEL (650 μs pulse, 5 Hz), the large beam dump with the size of about $2\times2\times2$ m^3 is required and the existing beam dump in the PITZ straight section is planned to be upgraded to fulfill this requirement. The same size of the beam dump is also needed at the end of the HEDA2 section, but the space in the PITZ tunnel is limited. Thus, the transportation of the beam back to the beam dump in the straight section is foreseen. Three dipole magnets are used for this purpose. The HEDA2 setup (see Fig.2) will consist of 3 dipole magnets, 2 screen stations, a quadrupole magnet, 3 beam position monitors (BPMs) and 2 integrated

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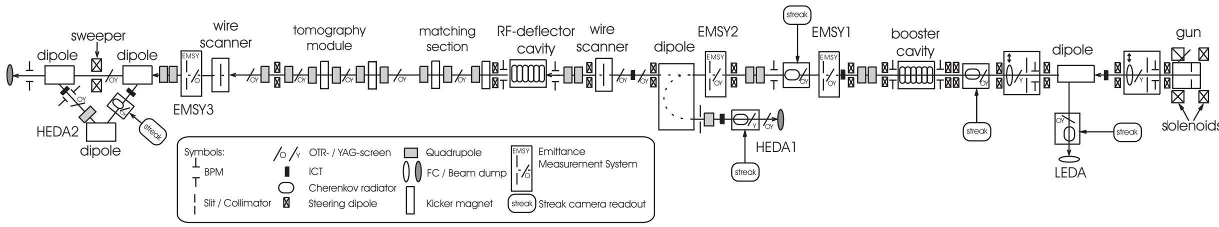

Figure 1: Layout of the future Photo Injector Test facility at DESY, Zeuthen site, (PITZ).

current transformers (ICTs). For characterization of a single bunch out of the long pulse trains, a kicker magnet will be placed in the straight section before the first dipole magnet. The longitudinal phase space will be measured at HEDA2 by using the combination of a spectrometer and a Cherenkov radiator equipped with a streak camera readout or an RF-deflector together with a screen in the dispersive section.

Since the RF-deflector deflects the beam in vertical plane, the first dipole (DISP3.D1) bends the beam in the horizontal direction and functions as the spectrometer for longitudinal phase space measurements using the first screen station (DISP3.Scr1). The second dipole (DISP3.D2) serves in transverse slice emittance measurements using a quadrupole (DISP3.Q1) and the second screen station (DISP3.Scr2) and transports the beam back to the straight section. The third dipole (DISP3.D3) transports the beam to the beam dump. The deflecting angle (α), the input and the output pole face rotation (β_{in}, β_{out}) and the bending radius (ρ) of these dipoles are listed in Table 1.

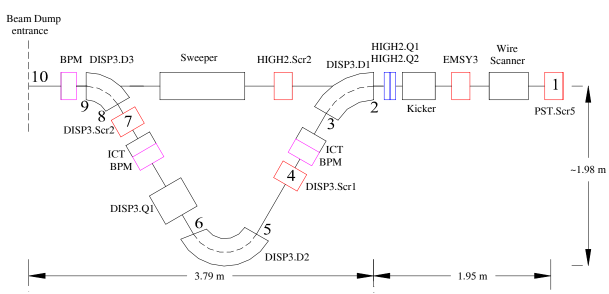

Figure 2: Layout of the foreseen HEDA2 setup.

Table 1: Specifications of Dipole Magnets in HEDA2 Setup

dipole	α (^{o})	β_{in} (^{o})	β_{out} (^{o})	ρ (mm)
DISP3.D1	60	0	0	600
DISP3.D2	-120	0	9	400
DISP3.D3	60	0	0	400

SIMULATIONS AND DESIGN

Reconstructed Longitudinal Phase Space

In momentum and momentum spread measurements, electrons with different momenta are deflected by a dipole magnet with different deflecting angles and resulting in different positions at the dispersive screen as $x = R_{11}x_0 + R_{12}x_0' + R_{16}\frac{\Delta p_0}{p_0}$, where the matrix elements R_{11}, R_{12} and R_{16} are defined by the matrix transportation from the initial position through the dipole magnet until reaching the dispersive screen. In order to have good resolution for momentum spread ($\frac{\Delta p_0}{p_0}$), the influence of the particle position (x_0) and divergence (x_0') should be small compared to the momentum contribution.

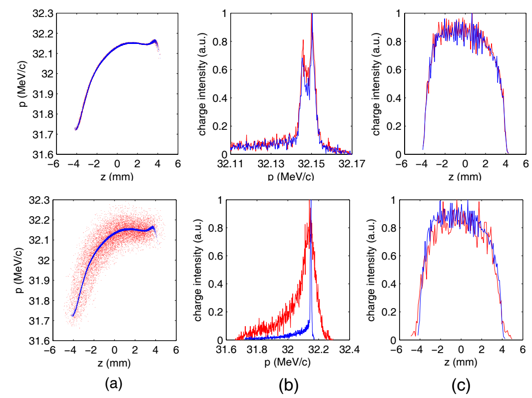

Figure 3: (a). Longitudinal phase space, (b). momentum spectrum and (c). charge profile of simulated particle distributions at the reference screen (blue) compared to its reconstructed distribution at the dispersive screen (red). Top-row pictures show the results from the simulated measurement using the quadrupole focusing at the reference screen and bottom-row pictures show the results in case of without the quadrupole focusing.

For the design of the first dipole as a high resolution spectrometer using the RF-deflector, a reference screen was defined to be the focus position in order to reduce the influence of the beam size. The last screen in the tomography module (PST.Scr5) was chosen to be the reference screen for the longitudinal phase space measurement at the dispersive screen (DISP3.Scr1). The drift lengths from the reference screen to the dipole entrance and from the dipole exit to the dispersive screen were optimized from simulations and they are chosen to be 1950 and 650 mm. The focusing optimization using the first three quadrupole magnets in the tomography module as the triplet quadrupole has been studied and the results are shown in Fig.3. It can be clearly seen that the measurement with the quadrupole focusing should have better resolution. The resolution of the measurement is affected mainly by the initial beam size and the vertical focusing of the beam on the dispersive screen before turning on the RF-deflector is required to gain a good resolution.

The reconstructed slice momentum spread ($p_{rms,slice}$) for different quadrupole focusings have been simulated for the initial particle mean momentum, momentum spread, minimum slice momentum spread and mean slice momentum spread of 32.07 MeV/c, 106.15 keV/c, 0.77 keV/c and 2.88 keV/c, respectively. The results in Fig.4 show that the focusing corresponding to the minimum horizontal beam size (0.06 mm, blue curve) at the reference screen gives better resolution than other cases. The reconstructed distribution fits very well in the center part of the bunch which contains the major part of charge. There is some discrepancy at the head and the tail of the bunch due to the focusing of a certain energy range at the required position. The minimum slice momentum spread of the simulated measurement using the RF-deflector down to 0.96 keV/c can be expected for this focusing condition.

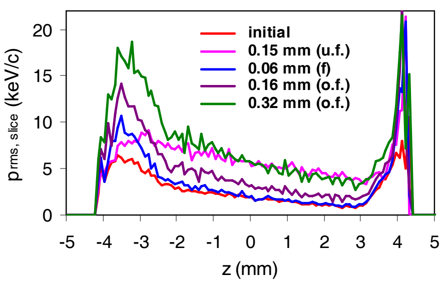

Figure 4: Simulated slice momentum spread compared to its reconstructed at the dispersive screen for different quadrupole focusing corresponding to the rms horizontal beam sizes at the reference screen. The abbreviations u.f., f, and o.f. present the under-focused, focused and over-focused conditions at the reference screen.

Beam Size Calculation

The beam size in the dispersive section will be large due to the large dispersion from the dipole magnet, especially in cases of far off-crest RF phases. Beam sizes along the dispersive section have been studied with the gun and the booster on-crest for the measurement with and without using the RF-deflector. The calculation results in Fig.5 conclude that the aperture of all the components in HEDA2 should be about or larger than 80 mm depending on the locations and the reasonable design for each component. The transverse beam size before and after the exit of the DISP3.D3 dipole can be controlled by using the DISP3.Q1 quadrupole magnet.

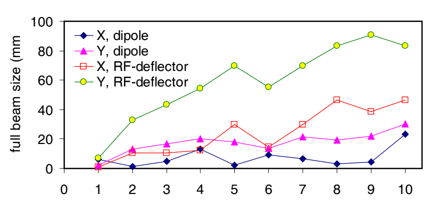

Figure 5: Calculated beam sizes along the HEDA2 section. The position numbers correspond to the numbers indicated in HEDA2 setup in Fig.2.

Dispersive Screen Stations

The DISP3.Scr1 is a multi-purpose screen station for momentum distribution measurements using a YAG and an OTR screen, bunch length measurements using an OTR screen and an aerogel radiator as Cherenkov radiators and a vertical slit for the transverse slice emittance measurements. The design configurations of this screen station are shown in Fig.6. Since the beam spot size in the dispersive section will be large due to the large dispersion, the large screen sizes are needed. The effective screen size of about 80 mm×60 mm for the YAG and OTR screens was chosen and this leads to the large screen actuator. The idea to include the screen actuator inside the actuator bellow has been studied. In order to keep the effort vacuum force that the linear translator needs to take (3000 N), the bellow size of 160 mm diameter will be used. According to this constrain, the OTR screens will have the off-set of about 50 mm from the desired position. Simulation results confirm that this off-set is acceptable for the high resolution in the longitudinal phase space measurements.

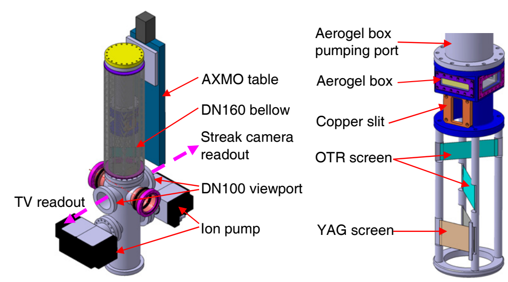

Figure 6: The first screen station in HEDA2 (DISP3.Scr1) including details of screens and slit configurations.

SUMMARY

The HEDA2 spectrometers and related diagnostics, which are foreseen to be installed at PITZ at about the middle of year 2010, will allow the analysis of long bunch trains including measurements of the longitudinal phase space and the transverse slice emittance. The slice momentum spread resolution down to 0.96 keV/c is expected to be resolved using this dispersive section diagnostics. The physics design for the dipole magnets and the simulated measurement conditions are ongoing in parallel to the technical design. An optical system for the longitudinal phase space measurements is under development.

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