LONGITUDINAL PHASE SPACE STUDIES AT THE PITZ FACILITY

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Abstract

The Photo Injector Test facility at DESY, location Zeuthen (PITZ), is a project to optimize photoelectron injectors for short wavelength Free Electron Lasers (FELs). Optimization of all injector parameters such as emittance and longitudinal properties of the electron bunch is needed. The Longitudinal Phase Space distribution (LPS) of the electron bunch was investigated using a streak camera system. Contradictory to the conventional way, IR radiation was used to recover some lenses which turned brown due to the radiation damage.

INTRODUCTION

Photoinjectors are a corner stone for short wavelength Free Electron Lasers (FELs) like FLASH and the European XFEL in Hamburg, Germany. The Photo Injector Test facility at DESY, location Zeuthen (PITZ), was built to develop and optimize such photoinjectors. The PITZ facility is capable to generate long trains of electron bunches. The photoelectric effect is utilized, where a UV laser pulse produces electrons from the surface of a Cs_2Te photocathode. A gun cavity and a booster accelerate the electrons up to 25 MeV/c.

Studying and optimizing the LPS of the electron bunch is an important topic at PITZ. A streak camera system consisting of Silica Aerogel radiators, Optical Transition Radiation screens (OTR), Optical Transmission Line (OTL) and a streak camera is used to study the longitudinal properties. Due to the high radiation level in the facility, many of the lenses in the OTL have turned brown, reducing the efficiency of the system. Some of the lenses were recovered by baking them in a normal oven. Few sensitive objective lenses, which can not be found in the market anymore, can not be baked in such simple way, rather they were recovered via exposure to IR radiation with the proper wavelength.

THE STREAK SYSTEM

A streak system is used to investigate the complete LPS distribution of the electron bunch with an accuracy of a few ps. The system consist of 4 screen stations equipped with radiators, an OTL and a streak camera.

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Silica Aerogel or OTR are used as radiators. They produce light pulses when they exposed to the electron beam bunches. Those light pulses include time resolved distributions of the electron bunch.

The produced light is transported over about 27 m OTL to a streak camera, which is based in a separate room far away from the PITZ tunnel. The OTL is a chain of telescopes consisting of over 50 optical elements like lenses and mirrors. A conus box is based on the side of each screen station, it allows the selection of a part or the full cone of the light pulses emitted from the radiator to be sent over the OTL. To obtain a direct view for the electron beam during PITZ operation, a TV system is based on the other side of each screen station [1].

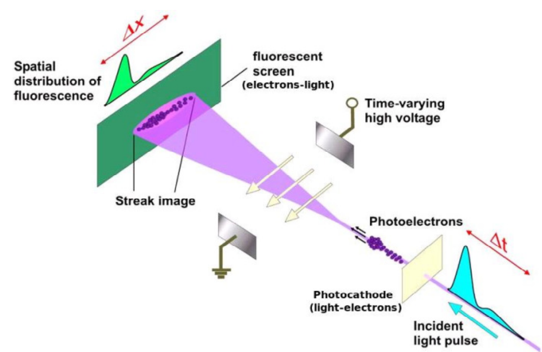


Figure 1: The working principle of the streak camera.

A Hamamatsu C5680 streak camera, is used to observe and record the LPS distribution of the electron bunch. The streak camera implies transforming the temporal profile of the light pulse into a spatial profile, figure 1 shows the working principle of the streak camera. By directing the LPS light pulse onto a photocathode, photons produce electrons via the photoelectric effect. The electrons are deflected by a time varying voltage produced by a pair of plates, which deflects the electrons sideways causing a time-varying deflection across the width of the detector. Then the electrons are converted again into photons by using a fluorescent screen. A CCD camera is used to measure the streak pattern on the fluorescent screen, and thus the temporal profile of the original light pulse [2].

PREPARATIONS AND MODIFICATIONS

Great care was taken during the alignments of the OTL, since a slight misalignment of any optical element can lead to a complete loss of the emitted light from the radiators. The alignment can be shortly summarized in the following steps. All the lenses of the OTL were dismounted. After dismounting the conus box and the TV-system, two optical arms were mounted on the both sides of the screen station. A high accuracy laser was mounted on one side of the screen station (the conus box side) then adjusted and centered to be perpendicular on the radiator inside the station, since the light pulse is emitted 90° or reflected 90° by a mirror, corresponding to the electron beam line in the case of OTR or the Aerogel, respectively. In this way the laser takes the same path as the emitted light pulse from the radiator. Two apertures were mounted on each optical arm to identify the laser path through the station. Another high accuracy Laser was mounted on the other side of the station and adjusted to go through the four apertures. So it is passing through and perpendicular on the radiator. The first optical arm was dismounted and the conus box was remounted. Mirrors in the conus box and the OTL were adjusted to drive the laser to the streak measurements room. All lenses were cleaned and remounted in their original position in the OTL. The last optical arm was dismounted and the TV-system was remounted.

IR Baking

Due to the high radiation level in the PITZ tunnel, many lenses in the OTL turn brown. This dimness reduces the signal at the streak measurements and caused a partial or total loss of the transmitted light. The damage is caused due to a shift of the electrons in the atomic lattice of the lens material. Fortunately such damage is reparable in most of the cases. Applying a proper heat on the lens can relocate the electrons back to the original position in the lattice.

Most of the brown lenses were recovered to an acceptable clearance by baking them in an oven for 1000 to 3000 min at temperature up to 473°K. Unfortunately, some objective lenses (Tessar) got damaged by applying such heat. The glue between the achromat doublet melts at 473°K, producing irregular spots in the lens. Baking at lower temperature (393°K) and longer temperature raising time, (0.1°K/min), did not result in a remarkable improvement.

Another way to recover the lenses was investigated, which is baking using radiation instead of normal heat. The proper radiation type was identified from the average kinetic energy relation $E = \frac{3}{2}KT$ and the Planck equation $E = h\nu$. The optimum IR baking wavelength can be obtained as,

$$\lambda_{\text{Averg}} = \frac{2hc}{3KT} \tag{1}$$

for the optimum baking temperature of T = 473°K, IR with a wavelength of λ_{Averg} = 20 μm is needed, which is lying in the mid IR region. Baking using IR radiation gave similar results to what was obtained using the normal baking method [3] and did not damage the lenses. Figures 2 and 3 show the results of the IR baking.

Figure 2: A lens from the Optical Transmission Line OTL before (left) and after the IR baking (right).

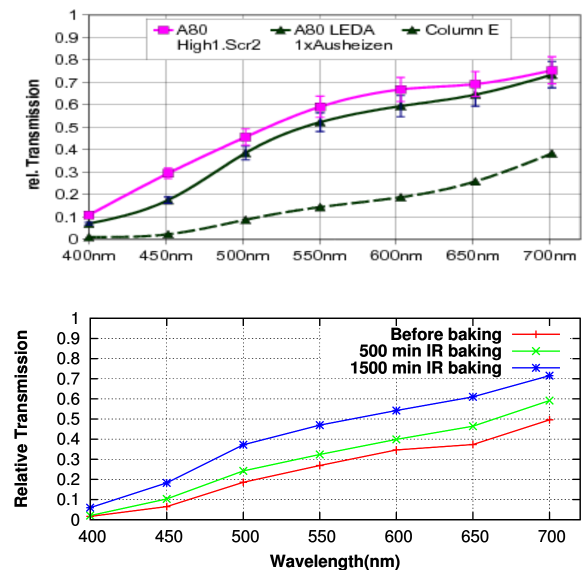
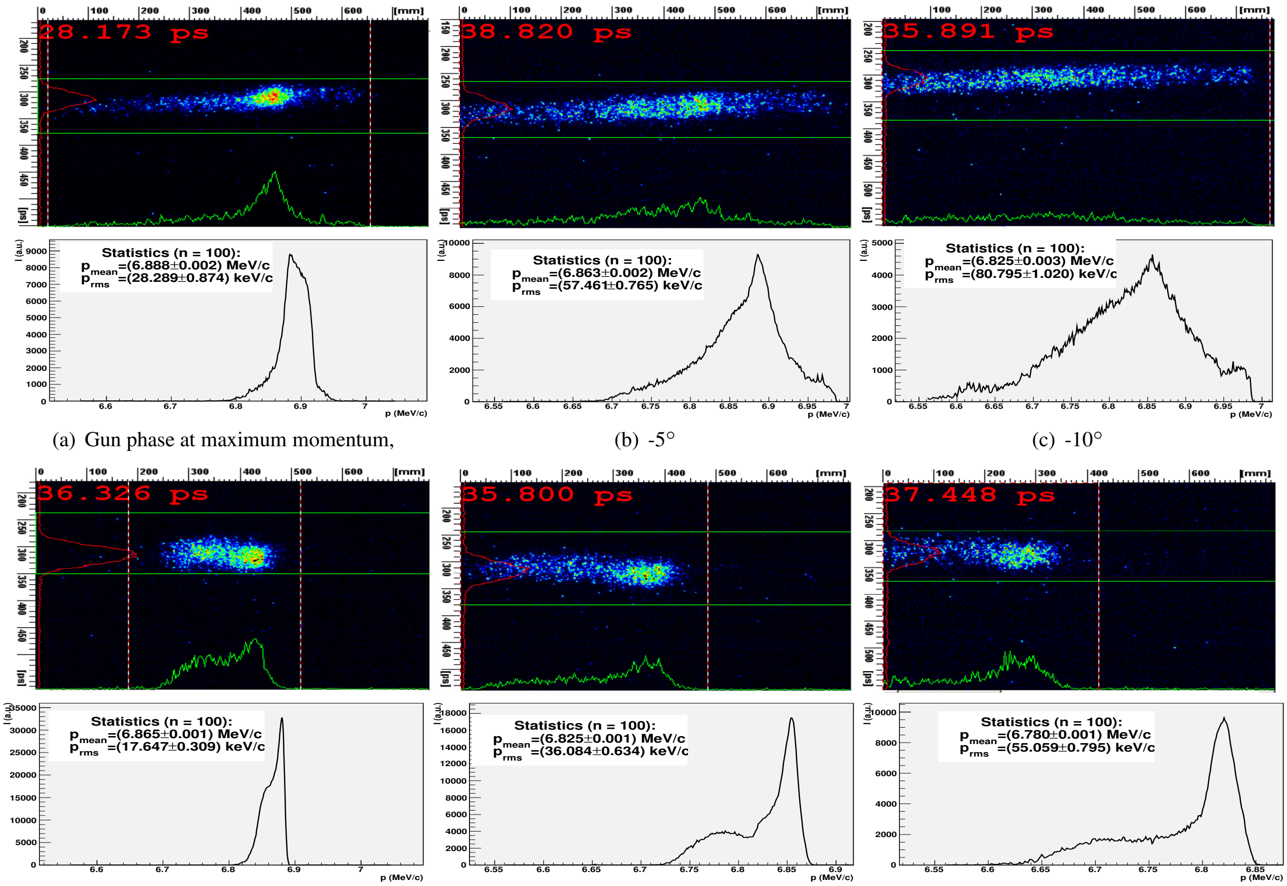


Figure 3: Relative transmission measurements obtained using IR baking (bottom) compared to the measurements obtained using normal baking (top) for similar lenses and with the same dimness.

MEASUREMENTS

The previously presented streak camera system was used to obtain a streak image of the electron bunch and to investigate its temporal distribution in the first dispersive arm (DISP1) of PITZ. The streak camera image was compared to the results obtained from the Mean Momentum And the Momentum spread Analysis (MAMA) program at PITZ. MAMA is a tool which uses a dipole to deflect the electrons into a dispersive arm where the electron beam distributions can be measured using a YAG screen [4]. The launch phase between RF and the UV laser is chosen such that the momentum gain in the gun is maximum (MMMG phase). The influence of the gun phase is studied by shifting the gun phase -10°, -5°, +5°, +10° and +15° from the MMMG phase (figure 4).The charge of the electron bunch was 500 pC. The laser pulse had a FWHM of 21 ps, rise time $\sim$ 2 ps and 11.5% modulation of laser flat-top.



(a) Gun phase at maximum momentum, (b) -5° (c) -10°

(d) +5° (e) +10° (f) +15°

Figure 4: The streak camera image of the electron bunch (top of each sub figure), compared to the results from MAMA (bottom of each sub figure) for the maximum momentum gun RF phase (a), maximum phase minus 5° (b), maximum phase minus 10° (c), maximum phase plus 5° (d), maximum phase plus 10° (d) and maximum phase plus 15° (d).

The projection on the horizontal axis presents the momentum distribution and the projection on the vertical axis presents the temporal profile of the electron bunch. The electron bunch length depends mainly one the momentum spread of the bunch and the influence of space-charge force, which is analyzed in more details in [5]. For maximum phase, Fig. 4 (a) the highest momentum mediates the bunch as expected. For phases less than the maximum momentum, Fig. 4 (b and c). The space-charge force within the bunch increase the momentum of the head particles and decrease the momentum of the tail particles, increasing the LPS distribution. For phases larger than the maximum momentum, Fig. 4 (d, e and f) the electron with highest momentum are located in the head of the bunch. The space-charge force decrease more the momentum of the tail particles resulting in increasing of the LPS distribution.

SUMMARY AND OUTLOOK

The maintenance of the OTL was performed in March 2012. The streak system suffered from aging and radiation damage of the lenses. Some lenses are not available in the market anymore, for that it was necessary to recover them by IR radiation. From the previous measurements it is found that the projection of the streak image for the electron bunch agrees in shape with the measurements obtained from MAMA.

A reflective optical system [6], based on parabolic mirrors under the study at the moment to replace the current system. The reflective optical system is expected to have a better spatial and temporal resolution and have higher resistance against the radiation damage.

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