PHOTOCATHODE LASER PULSE DIAGNOSTICS AT PITZ*

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Abstract

The main objective of the Photo Injector Test facility at DESY in Zeuthen (PITZ) is the development of electron sources that meet the requirements for existing and future FELs such as FLASH or the European XFEL. The goal is the minimization of the transverse emittance of the produced electron bunches. In this respect one of the key issues is the cathode laser system, which should provide longitudinal and transversal flat-top pulses with an excellent long-term stability. In this work we present the full system of laser diagnostics that is currently used at PITZ to monitor the laser pulse parameters.

INTRODUCTION

Laser systems of photo injectors play a crucial role for generating electron bunches with optimum transverse emittance. In our case the laser must produce pulse trains with a repetition rate of 10Hz consisting of up to 800 micro pulses with 1MHz repetition rate. The laser pulses wavelength is 262nm and they have a temporal flat-top shape (FWHM 20ps, rise-/fall-times 6-8ps) as well as a transverse flat-top profile. To extract the required charge of 1nC from the photocathode (Cs_2Te) the laser must provide pulses with an energy of at least 1μJ (for 0.5% quantum efficiency). For further details on the laser system which was developed by the Max Born institute Berlin see [1].

In this paper we present the diagnostics system that is used to monitor the key laser parameters accompanied by recent results.

TEMPORAL LASER PROFILE

The currently used laser system is able to produce flat-top pulses (FWHM 20ps, rise-/fall-times 6-8ps) in the UV utilizing a pulse shaper which consists mainly of a grating stretcher and two birefringent crystals. The effects of the pulse shaper, the subsequent amplification stages, and the conversion of the infrared light into the UV combine to generate flat-top pulses. For tuning the temporal laser shape one can adjust the rotation angles of the birefringent crystals as well as their temperatures. For a detailed description on this pulse shaping technique see [2].

To measure the temporal profile of the laser pulses, a streak camera is used which has a temporal resolution of about 2ps in the UV (Hamamatsu C5680). In addition the measurements of the streak camera can be evaluated using a Matlab script which provides key parameters of the pulse from a fit procedure, i.e. the FWHM, rise- and fall-times as well as the depth of the modulations on the flat-top. Long-term observations show that this method of pulse-shaping is very robust due to its simplicity.

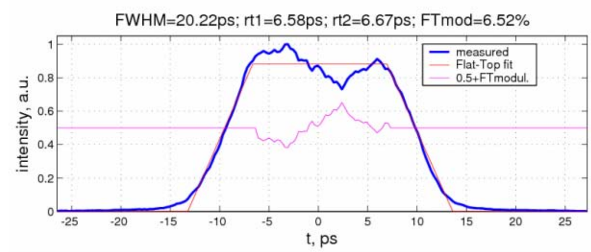

Figure 1: Typical temporal laser pulse shape used during 2007 run period evaluated by the mentioned Matlab script

SPATIAL LASER PROFILE

The spatial flat-top shape of the laser pulses is generated by cutting out a round spot from the center of the widened Gaussian intensity distribution which is produced by the laser. To provide various spot sizes a plate with several apertures of different diameters is mounted on a motorized stage which is remotely controllable. This almost flat-top distribution is then relay imaged onto the photocathode.

For monitoring the transverse profile three different virtual cathodes are used each having the same optical path length as the pulses to the real cathodes have. Two of these virtual cathodes are cameras with a rest-sensitivity in the UV so that the pulses can be shone directly onto the CCD chip. These cameras can be used in different intensity regimes due to different attenuations. The third virtual cathode consist of a Ce:YAG plate which converts the ultraviolet light to visible light. This virtual cathode was introduced recently to develop a method of measurement which does not rely on the rest-sensitivity of the CCD cameras in the UV. Experience shows that this sensitivity rapidly becomes inhomogeneous across the CCD chip. The method using Ce:YAG plates is described in a separate section.

In figure 2a one can see a typical image of the transverse laser profile shown in false colors. Figure 2b displays the same profile in a more intuitive 3D-representation. These images were taken using the direct measurement by shining the laser on the CCD chip. This method has a great disadvantage. Using standard settings for the shutter speed (1/60s) results in smear out effect for the profile. Instead of the one shown in figure 2 one meas-

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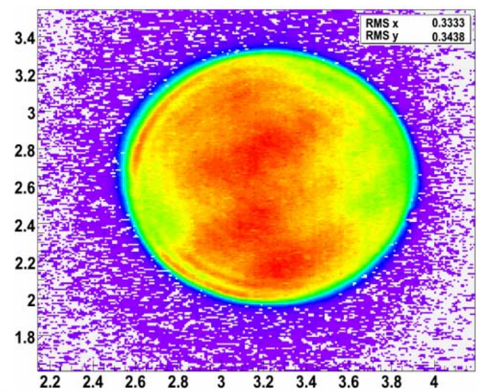
ures a profile with less structure and a big halo around the center spot which makes it hard to determine the correct beam size. The reasons for this behavior are not clear and will be investigated.

Because the smear out effect appears to be a slow process the shown profile was measured using a shutter speed of 2µs and the timing was set such that only the first pulse of the train is captured. The shown image is the average over 100 frames.

For this measurement an aperture of 1.2mm diameter was used. The RMS values for x and y differ due to the non symmetric distribution and are slightly higher than the real one because of the position jitter (see corresponding paragraph). The RMS of the flat-top intensity distribution is 7.5%.



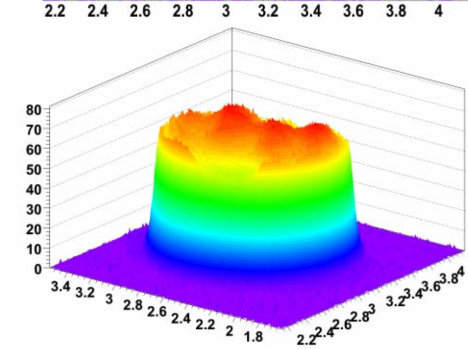


Figure 2a (upper): Transverse laser profile as seen by one of the virtual cathodes.
Figure 2b (lower): The same profile in 3D-view values on the x and y axes are in mm, z axis is arbitrary intensity.

Measurements with Ce:YAG - plate

The optical scheme for measuring the transverse profile of the laser pulses using the fluorescence properties of Ce:YAG is depicted in figure 3. The laser is directed onto the plate and a part of the ultraviolet light is converted to a broadband signal in the yellow-green wavelength region. The profile in the Ce:YAG plate is imaged onto a CCD-chip by use of a commercial objective. The remaining ultraviolet light is absorbed by the lenses of the objective (BK7).

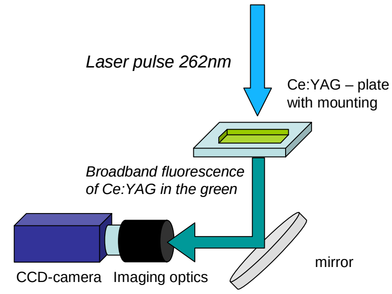


Figure 3: optical setup for the measurement of the transverse laser shape using Ce:YAG

The measurements were performed with three Ce:YAG plates all having the same geometric shape. The surfaces were uncoated. In figure 4 transverse profiles for different plates and positions on the plates are displayed. On every picture pronounced interference structures are visible. These structures vary with position and are different for every Ce:YAG plate. From these pictures one can conclude that it is not possible to get reliable information about the transverse pulse shape by use of this method.

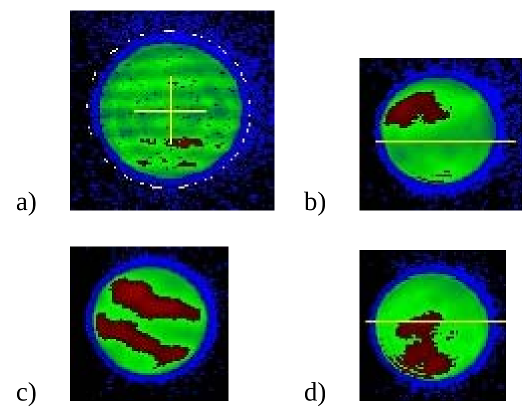


Figure 4: images of the transverse profile for two Ce:YAG - plates and different positions on the plate
a) 1.8mm aperture, 1st plate, pronounced horizontal interference stripes are visible due to non parallel surfaces
b) - d) 1.2mm aperture, 2nd plate, same conditions of the laser but different positions on the plate

The next step is to provide the Ce:YAG plates with an antireflective coating on each surface for further investigation.

LASER PULSE ENERGY JITTER

Besides possibilities to measure the laser pulses energies at the laser output it is more important to know how much energy is actually impinging on the photo cathode. This energy is less than 20% of what the laser produces due to the losses in the beam line which are mainly introduced by the beam shaping apertures. Therefore a photomultiplier tube is used which measures a strongly attenuated part of the beam that is coupled out before the laser enters the vacuum of the gun. Photomultiplier tubes have several advantages. They can provide a linear response over a large range of laser pulse energies, they are able to measure at 1MHz repetition rate and by changing the drive voltage the actual amplification can be chosen from several orders of magnitude.

To be able to calibrate the signal of the photomultiplier another measurement device is used. This is based on a commercially available UV sensitive photo diode together with an energy-meter which are externally calibrated and can be read out remotely via RS232 connection (Ophir NOVA II, PD10-pJ-SH-V2). This photo diode is only capable of measuring a repetition rate of 10kHz at maximum. Therefore it cannot be used directly to measure the laser pulse energies within the train. Averaging the signals of both devices for one pulse per train gives the calibration factor.

In Figure 5 the laser pulse energy distribution within a pulse train consisting of 40 pulses is displayed. Every data point represents the averaged energy for the corresponding pulse. The mean value is 54.34 in this case arbitrary units.

As a general criterion for the energy stability one can

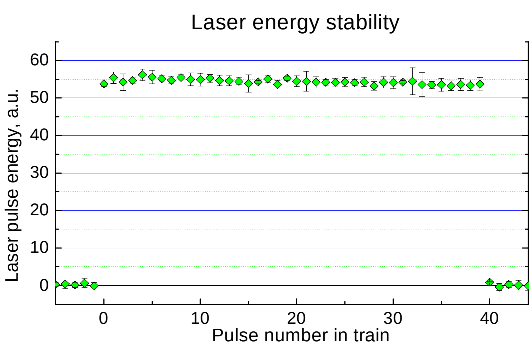


Figure 5: Laser pulse energy for every single pulse in a train of 40 pulses evaluated over 50 trains. The dots show the mean value and the error bars represent the RMS value of the energy for each single pulse.

calculate the overall RMS for all pulses in all measured trains. This turns out to be 1.46 and corresponds to 2.7% pulse energy jitter but contains also a possible slope within the trains. Therefore the average RMS jitter for a single pulse is smaller and was calculated to be 2%. The RMS of the mean values is 1.3%.

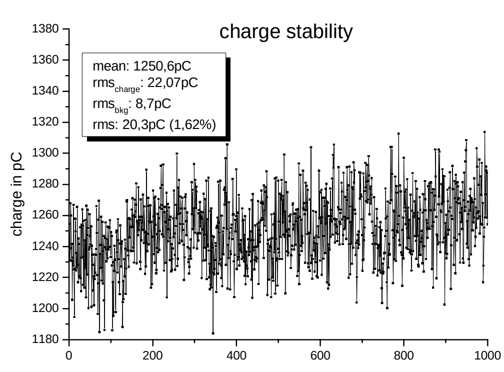


Figure 6: Charge stability measurement

The laser pulse energy is directly linked to a key parameter of the machine, i.e. the extracted charge. The measurement of the charge jitter using an ICT reveals a value of 1.62% (see Figure 6). For this measurement the charge of the first pulse in each train was determined.

At this charge level the slope of the charge vs. laser energy curve is 0.444pC/nJ and therefore a charge stability jitter of 1.62% translates to a laser energy jitter of 2.8% which is in good agreement with the measured one of 2% taking into account that besides the laser energy jitter also other sources exist for the charge jitter.

LASER POSITION JITTER

Another key parameter of the laser system is the position of the spot on the real cathode. While position changes in the order of 0.5mm can be easily measured using the virtual cathodes small scale movements must be monitored by a more sophisticated method. For this reason a procedure was developed which uses a fast quadrant diode. Knowing the transverse laser profile and the signals of the quadrant diode one can extract the actual position of each single laser pulse within the pulse train [3].
Figure 7 shows the measured x- and y-positions within a train of 40 pulses. The position of every pulse is averaged over 200 pulse trains and one can see that there is no significant systematic movement of the pulse position within one train. The error bars are the RMS values for the position of every single pulse. The overall jitter for all pulses in all trains is x_{rms} = 35µm and y_{rms} = 39µm.
There are different possible explanations for this rather

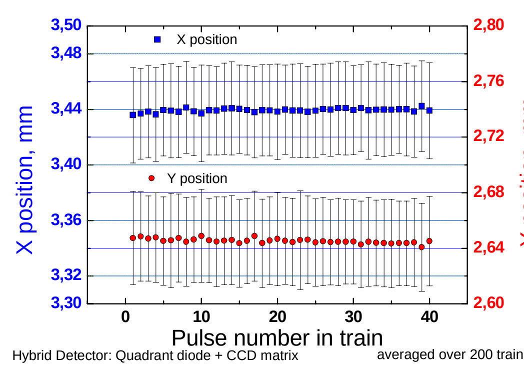


Figure 7: Analysis of the position jitter

high value. The main reason is vibrations of the optical elements in the tunnel. One can estimate that for an optical path length of about 7m in the tunnel the first mirror only needs to turn by 5nrad to introduce 35µm movement on the cathode.

SUMMARY

In this paper the key parameters of the used photo cathode laser system for the 2007 run period were presented.

The temporal profile of the laser pulses are in agreement with the design parameters (20ps FWHM, 6-8ps rise-/fall-times) and show a good long-term stability. The transverse profile has steep edges and exhibits a structure with an RMS of 7.5% on the top. A new system consisting of a Ce:YAG – plate as converter from the UV to visible light was tested and it was found out that this system currently does not meet the demands for this kind of measurement. The laser pulse energy fluctuations were characterized and the value of 2% is in good agreement with the charge stability. Finally the position jitter of the laser pulses on the cathode was determined and shows that the mean position within a pulse train is almost constant but the RMS-values of $x_{rms} = 35\mu m$ and $y_{rms} = 39\mu m$ are rather high.

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