PHOTOINJECTOR LASER INTENSITY AND POINTING POSITION MONITORING SYSTEM

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This work contains the description of a laser intensity and a laser beam pointing stability monitoring system, which was created for the Photo Injector Test Facility at Zeuthen, PITZ. The measurements are based on the usage of three detectors: a photomultiplier tube, a quadrant diode, and a coupled charge camera. Investigations were done for the nominal operation conditions: up to 800 laser pulses (20 psec duration) with a repetition rate of 1 MHz, a pulse energy of up to 30 microJ (wave length 262 nm), and a pulse train repetition rate is 10 Hz.

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1. INTRODUCTION

The radio frequency electron photo injector is a type of injectors, where the formation of the electron bunch is based on the photocathode illumination with short light pulse followed by electrons photoemission and acceleration by a rf-field. For the purpose intensive laser radiation is used.

The injector operation stability is investigated at PITZ (Photo Injector Test facility in Zeuthen) in Zeuthen, DESY, Germany [2]. The repetitional rate of the RF-power pulses is 10 Hz, and of the laser pulses is 1MHz. The RF-power flat top pulse duration is 0.8 ms (klystron output power 4 MW), that gives opportunity to produce up to 800 bunches.

2. DIAGNOSTICS SYSTEM

The role of the photoinjector is the generation of high brilliance and small emittance electron bunches for FEL application. For this purpose the generation is based on the photoemission of the Cs2Te cathode [4] induced by the incident light of 262 nm wavelength. Formation of the 18 psec flat-top laser pulse is an initial process [6]. Then the laser light is transmitted from the laser table to the tunnel through a 22 m optical line and enters the vacuum through the input window. It is directed by the vacuum mirror to the cathode. Just before the entrance to the vacuum there is a beam splitter, which directs 2% of the light to the laser beam diagnostics system.

Before the entrance to the laser beam diagnostics there is a beam limiting aperture, which makes the laser spot fixed at the cathode. The transverse displacement of the laser beam before the aperture will result in the laser beam center of gravity movement. This change is detected then by the quadrant diode - one should observe the repartition of the quadrant diode signals.

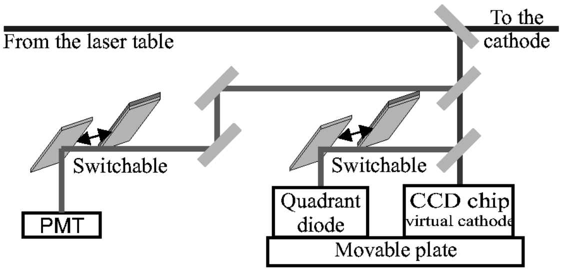

Fig.1. *Optical scheme of the laser beam stability diagnostics*

The measurement system scheme is shown in Fig.1. The quartz beam divider plates are inserted before the detectors in order to match the input intensity range and the linear response range of the devices. CCD matrix chip is situated the way, that optical path for the laser radiation is the same as the path to the cathode. The camera is used for the transverse laser beam profile measurements. The quadrant diode is used for the laser beam pointing position monitoring - the software analyses the transverse profile together with the quadrant diode signals and calculates the laser beam position. Photomultimplier (PM) is involved in the laser beam intensity measurements. There is a possibility to reduce the light intensity on the photomultiplier to measure PM response function parameters using single photoelectron method.

3. INTENSITY MEASUREMENTS

The structure of the pulse train defines that the response time should be much less than 1 μsec, and there is a 10^4 dynamical range to cover. That is why photomultiplier (PM) was chosen for the intensity measurements. Moreover it was not suggested to use some special features of reconfiguration of the field defining divider circuits, that is why complete

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PM module H6780 (Hamamatsu) with intrinsic high-voltage converter was chosen.

This PM module has a bialkali type cathode with quantum efficiency of 0.8 % at 260 nm and an effective area diameter of 8 mm. Another UV-sensitive type H6780-03 has quantum efficiency $\approx 4.5\%$. The high-voltage converter should have +12V of power supply. The gain of the PM can be regulated externally in range from 100 to 10^6. Maximal linear mode output current is 100 μA. The cathode saturation current is 0.1 μA for the bialkali. If the gain is less then 10^3 the linear output is limited by the cathode saturation, otherwise by the space charge forces in the dynode system during the multiplication.

To analyze the PM response function and noise level a single photoelectron measurement was done. The idea of the single photoelectron method of PM characterization lies in measuring the response of PM to light levels near to the one-electron creation level. As far as the light source, such as LED, produces number of photons in a pulse distributed by Poisson law, one can lower the intensity to suppress the probability of two and more photoelectrons events, but still have single photoelectrons. It means that the probability of zero will be much higher and it leads to a significant statistics of the noise events. A good PM should easily resolve the single photoelectron signal level. Let's consider, that this signal value is distributed by the Gauss law. Then it is defined with two parameters: mean output charge Q_1, standard deviation of the distribution σ_1 as a width parameter. Then a probability to have charge x at the cathode caused by one photoelectron event is formulated [3]:

$$G_1(x) = \frac{1}{\sigma_1\sqrt{2\pi}} \cdot \exp\left(-\frac{(x-Q_1)^2}{2\cdot\sigma_1^2}\right). \tag{1}$$

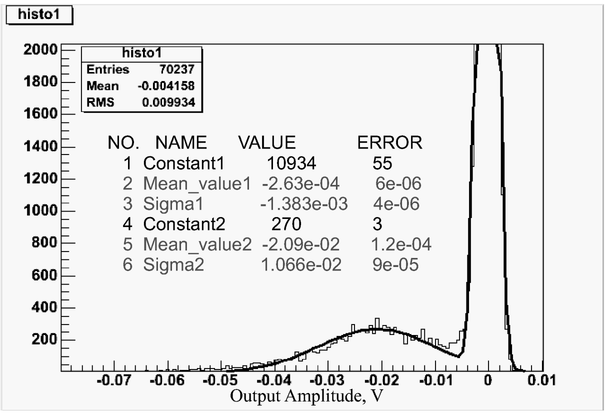
Finally total PMT response is expressed by a sum of different photoelectron quantity responses weighted by the possibility of occuring C_n.

$$R = \sum_{n=1}^{\infty} C_n \cdot \exp\left(\frac{-(x-n\cdot Q_1)^2}{2\cdot n\cdot\sigma_1^2}\right). \tag{2}$$

On the Fig.2 there is a thin high peak, that corresponds to "zero" events distribution. On the left side there is obviously the assymetric distribution and it is clearly separated from the zero-distribution. It is not Gaussian, because of more probability of low charge noise events. One of them is autoemission from the last dynodes. It can be seen comparing zero peak of high voltage supplied not illuminated PMT and much lower voltage supplied without illumination. The zero-peak of the first one has a "tail".

Result analysis is shown in Fig.2. For the PM gain $2\cdot10^6$ the mean response signal is $\approx 21mV$ and the standard deviation is 10 mV.

Due to the adjustable gain it is possible to cover interesting intensity range with the linear response of the PM. It is important for the correct definition of the intensity variations. One should remember that internal PM noise level also depends on gain. Gain change should be accompanied by the noise distribution measurement.



```
histo1
Entries      70237
Mean     -0.004158
RMS       0.009934
```

```
NO.  NAME          VALUE         ERROR
  1  Constant1      10934          55
  2  Mean_value1  -2.63e-04       6e-06
  3  Sigma1       -1.383e-03      4e-06
  4  Constant2       270           3
  5  Mean_value2  -2.09e-02      1.2e-04
  6  Sigma2        1.066e-02      9e-05
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Fig.2. *Single photoelectron spectrum*

4. POINTING POSITION MEASUREMENTS

Light beam position measurement devices are based on position sensitive PM or position sensitive photodiodes. For PM method one exchanges the anode by two perpendicular non electrically contacted wire arrays, which create a grid, and the current is measured for each wire. The position of the light beam center of gravity is obtained. Position sensitive photodiodes have additional uniform resistive layer, two side electrodes connected to the p-layer (one dimension) and the central point electrode connected to the n-layer.

The current passing the resistance layer depends on the distance to the electrode. If one can measure two currents independently then the position of the gravity center is obtained.

The first one is expensive and the second one is not fast enough to measure position of each pulse at 1MHz repetitional rate. There is also charge coupled discrete elements detector which is used for the transverse laser beam intensity distribution measurements. It is not sensitive and fast enough, to satisfy demands for parallel to facility operation measurements.

There are two examples when fast controlling of the incident light beam position is required: automatic alignment of the laser beam lines [5], the position detectors for wavefront sensors of adaptive optics. Both of them use a quadrant diode application. The quadrant diode is essentially a usual photodiode split into four quadrants, output current of each is measured. Since the current is proportional to the incident energy one can easily do alignment or measure cylinder-symmetric beam spot, if the dimensions of the spot are smaller than the detector.

The idea of the hybrid detector was proposed for the first time and the equipment was developed for PITZ. The main thing, that differs this approach from the laser beam auto-alignment or adaptive optics wave front detectors, is taking into account the transverse laser beam intensity distribution. The distribution is measured by the CCD matrix. From the distribution it is possible to find relation between the geometric center and the gravity center of the laser beam, which is measured by the quadrant diode. In such method there is no demand on the laser beam transverse profile cylindric symmetry. The cathode laser beam at PITZ should have a flat-top transverse intensity distribution, which can be distort enough on practice (Fig.3).

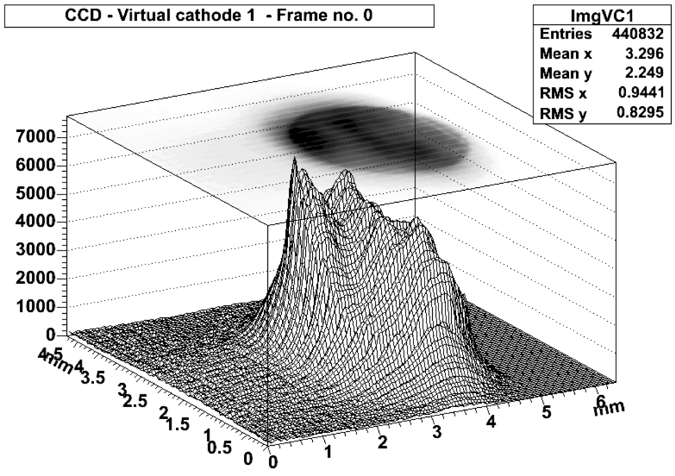

Fig.3. *An example of the laser beam transverse intensity distribution*

For the measurements in our case the PIN quadrant photodiode S4349 (Hamamatsu) was chosen. The response time is ≈ 100 ns. The QD has 40% quantum efficiency at 262 nm. Four signals are transmitted to the electronics racks room, integrated, digitized and stored at a hard drive. The sensitive area is a square with 3 mm side. The gap between the quadrants is 0.1 mm. Separating gaps of the CCD matrix are parallel or perpendicular to the gap lines, which divides the quadrant photodiode on four parts. For the position measurements it is important to have symmetry of the four channels of the quadrant diode. If the condition is not matched at the level of the equipment then it can be corrected by the analysing software. To check this a test was made for indentity of the quads and their electronic circuits. The integrator channels after the test and the recalibration(is done in the analysis software) are found to be with the accuracy of 1%. Test of the quads showed equality with the same accuracy as the previous test, what means if difference exist it is much smaller than the value of 1%.

Linear response of the quadrants are limited by the electronic interference at low intensities and by the saturation at high intensities. That is why it was decided to make a switchable quartz to mirror reflector before the quadrant diode. The mirror reflects ten times more light than the quartz plate does.

Each quadrant integrates the light signal over its surface. The same is done in the software for the four parts of the spatial intensity distribution, which is divided by the virtual gap cross. The cross can be moved with the resolution of 8.3 μm - the dimension of the square pixel of the CCD. The quadrant diode signals are simulated by the software and compared with the normalized real ones. The position of the cross relatively to the intensity distribution corresponds to the minimal discrepancy between the real and simulated values, defined as:

$$X = \frac{S_1 + S_2}{S_1 + S_2 + S_3 + S_4}, \tag{3}$$

$$Y = \frac{S_1 + S_4}{S_1 + S_2 + S_3 + S_4}, \tag{4}$$

where X and Y are independent and define the position on the surface. S_i - is a signal from the i^{th} quadrant. Quadrants are numbered clockwise.

5. LASER BEAM TRANSVERSE PROFILE MEASUREMENTS

The algorithm of the quadrant diode signals analysis involves a transverse laser beam intensity distribution, which is measured by the camera (Jai CV-M10CX). The active area is 575x767 pixels, pixel dimensions is (8.3 x 8.3) μm. The minimal exposition is 1/917000 sec. The camera is surrounded by the lead wall to avoid bremsstrahlung illumination of the semiconductor electronics of the camera. All of the pixels are supposed to have equal quantum efficiency and have noise level much smaller than the signal.

6. RESULTS

The single photoelectron measurements were done and found, that for the gain of $2 \cdot 10^4$ and the average signal of 100 photoelectrons (10 mV) the response function standard deviation equals 1 mV. For the case of performed measurements one obtained standard deviation of the signal 2.4 mV - the convoluted distribution standard deviation of the intensity variations, noises and PM response function. the deconvolution gives in average 14 ± 1% standard deviation of the intensity variation distribution (Fig.4), what will be treated as an intensity stability characteristic.

The pointing position measurements results are presented in Fig.5. Each pulse position in the 800 pulse train is averaged over 300 trains. Standard deviation of a laser beam pulse positions distribution is regarded as a pointing position stability characteristic and equals 18 $\pm 1.3 \mu m$ for the measurement. The observed position change (drift) during the train (Fig.5) presents also in the measurements made with the CCD matrix. It is thought the position drift is connected to the laser elements heating - the drift corresponds to the pointing angle devation inside the laser system of about 10^{-5} rad. That is a topic for the laser development at the moment. Inspite of the camera short enough exposition for capturing any laser pulse from the train, it was not possible to determine the drift in series of the different pulse positions during the train, because the type of camera has films covering active area, which excited by the ultraviolet give afterglowing. This effect is called shadowing.

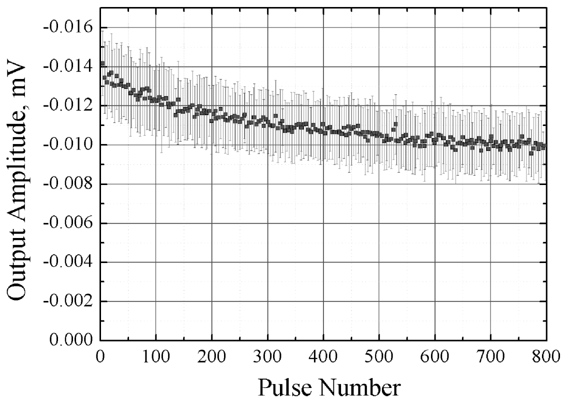

Fig.4. *Averaged over 300 trains pulse intensities (800 pulses train)*

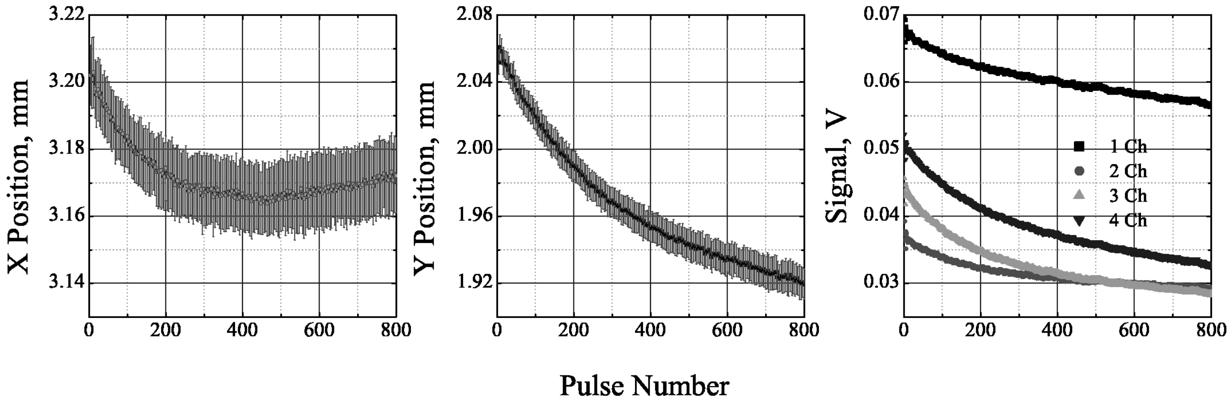

Fig.5. *Averaged over 300 trains pulse positions (800 pulses train): along the X axis, along the Y axis and the quadrant diode signals*

For the emittance measurements up to 100 pulse trains are used. If the bunch center of gravity is floating from pulse to pulse during the measurement, it causes the error of the size determination. ASTRA simulation software was used to find out how the electron beam size and position on the cathode is projected by the system into the screens. The software tracks the initial particle distribution through the user-defined electro-magnetic field configuration.

7. CONCLUSIONS

The system is fully implemented and ready to become a tool for the facility investigations. The intensity measurements have shown the laser beam intensity stability at level of 14%. This will be a subject for the laser system development. In the pointing position measurements one has obtained position jitter, position stability characteristic, of 18 μm. The jitter and drift cause less than 1% error in electron beam emittance measurements. It was shown in ASTRA simulations for the current electron beam line configuration of PITZ facility.

Before there were two widely spread approximationsof the measured beam profile: gaussian or uniform distribution. Actually any cylindrically symmetric beam position could be measured with the quadrant diode only. It is the first system to determine the position of the light beam with arbitrary transverse intensity distribution. Mostly the error of the new hybrid position detector comes from the discrete matrix element (camera), which measures the profile.

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СИСТЕМА НЕПРЕРЫВНОГО МОНИТОРИРОВАНИЯ СТАБИЛЬНОСТИ ИНТЕНСИВНОСТИ И ПОЛОЖЕНИЯ ПУЧКА КАТОДНОГО ЛАЗЕРА ФОТОИНЖЕКТОРА

Е.Е. Иванисенко

Рассмотрена система, созданная для мониторинга стабильности положения и интенсивности импульсов излучения лазерной системы фотоинжектора PITZ. Измерения осуществляются с использованием трех детекторов: фотоэлектронного умножителя, квадрантного фотодиода и ПЗС камеры. Основное внимание уделено работе установки в номинальном режиме: 800 лазерных импульсов (длительность 20 пс) с частотой повторения 1 МГц, энергия в одном импульсе до 30 мкДж, частота последовательностей 10 Гц.

СИСТЕМА БЕЗПЕРЕРВНОГО МОНІТОРИНГУ СТАБІЛЬНОСТІ ІНТЕНСИВНОСТІ ТА ПОЗИЦІЇ ПУЧКА КАТОДНОГО ЛАЗЕРА ФОТОІНЖЕКТОРА

Є.Є. Іванісенко

Описана система безперервного мониторингу стабільності інтенсивності та позиції катодного лазера фотоінжектора на установці випробування фотоінжекторів у Цойтені, DESY. Вимірювання здійснюються фотоелектронним помножувачем, квадрантним фотодіодом та ПЗС. Вимірювання проводилися при нормальному режимі: 800 лазерних імпульсів тривалістю 20 пс з частотою слідування 1 МГц, енергія кожного імпульсу до 30 мкДж, частота цугів 10 Гц.