VIRTUAL CATHODE DIAGNOSTICS WITH A LARGE DYNAMIC RANGE FOR A CONTINUOUS WAVE SRF PHOTOINJECTOR*

E. Panofski#, A. Jankowiak, T. Kamps, G. Klemz, Helmholtz-Zentrum Berlin, Berlin, Germany

Abstract

In a laser driven electron gun the close relationship between the laser pulse parameters and the quality of the generated electron bunch requires a continuous monitoring of some of the laser parameters. A laser diagnostic system, called virtual cathode, controls the stability of the key laser parameters. Further, the virtual cathode allows to analyse the influence of laser instabilities on electron bunch parameters. The main challenge for the virtual cathode lies in covering the large dynamic range of the photocathode laser between commissioning at 120 Hz and operation at 1.3 GHz repetition rate. The design of the virtual cathode as well as first test measurements will be presented.

MOTIVATION

Future developments in such scientific fields as X-ray sources, particle physics or material science increase the demands on the performance of modern particle accelerators. The trend towards high brilliance beams with low emittance and high average current, calls for improvements in the present accelerator technology. Therefore, a new concept of a linear accelerator, a so-called energy recovery linac (ERL), is proposed [1]. Planned at the Helmholtz-Zentrum Berlin, bERLinPro (Berlin Energy Recovery Linac Project) represents a test facility to demonstrate and improve the ERL technology. The main goal is to generate and accelerate an electron beam with an average current of 100 mA and with a low emittance, i.e. smaller than 1mm mrad [2].

The 1.3 GHz SRF gun generates electrons by photoemission [Fig. 1]. In the photoinjector, the electron bunch parameters, like emittance or average current, are greatly affected by the photocathode quality (quantum efficiency) and the stability of the laser parameters. The close relationship between the laser pulse and the generated electron bunch requires continuous monitoring of the most prominent laser parameters by a diagnostic system. Especially, such a laser diagnostic system permits the alignment of the laser spot on the photocathode during commissioning. In addition, significant information about the relationship between laser and electron beam instabilities are expected. The proposed diagnostic system is called “Virtual Cathode”.

This paper presents the design, setup and testing of a laser diagnostic system used to control the key parameters of the photoinjector drive laser.

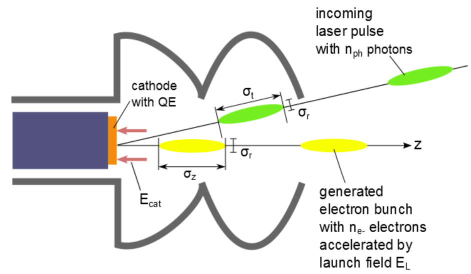

Figure 1: Photoemission inside gun cavity.

LASER PARAMETERS

In order to create a concept for the virtual cathode, the basic laser parameters are examined for their relevance regarding electron beam dynamics.

The laser spot size on the photocathode determines the transverse dimension of the electron bunch and hence the initial emittance. Further, the spot size contributes to space charge phenomena.

The bunch charge, and therefore the average current, is directly dominated by the laser pulse energy, while it is indirectly affected by the dependency of quantum efficiency from the photon energy.

Apart from generating an electron beam with high average current and low emittance, focusing and optimal acceleration of the electron bunch play an essential role. Electron scattering neglected, the electrons will escape at the same point at which the laser illuminates the photocathode. To achieve maximum electron acceleration, the exploitation of the launch field symmetry along the axis of the cavity is obligatory. Any deviation from this axis leads to reduced acceleration due to radial defocusing in the RF structure. The defocusing radial electric field, which increases with the distance from the axis of the cavity, arises from the strong electric field in the cavity structure.

At last, the temporal pulse length determines the electron bunch length. Besides the electron bunch length, the laser pulse length affects the peak current of the electron beam.

The transverse shape, the laser spot position as well as the pulse energy and the average power are monitored as key laser parameters in the diagnostic system. The change in the temporal structure of the laser beam along the 33m long beam path to the photocathode will be analyzed in a separate measurement. If there is only a small, constant change in the temporal shape, it is sufficient to control the pulse length close to the laser.

* Work supported by BMBF & Land Berlin
# eva.panofski@helmholtz-berlin.de

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DYNAMIC RANGE

The requirements for the dynamic range of the virtual cathode are determined by the used photocathode drive lasers. In the diagnostic mode (commissioning) the current 8 kHz laser is installed. The available repetition rates range from 120 Hz to 30 kHz (upgrade). The laser offers wavelengths of 515 nm (green) and 258 nm (UV) according to the two used photocathode materials cesium potassium antimonide CsK_2Sb and copper Cu. For an operation mode with high average currents up to 100 mA, a further laser with a repetition rate of 1.3 GHz will be developed and installed in a joint collaboration project by the Max-Born Institute. In this mode the CsK_2Sb cathode with high quantum efficiency is used. Therefore, the 1.3 GHz laser will provide 515 nm only.

The laser power in the diagnostic and operation mode covers a dynamic range of 80 dB. One of the main challenges of the virtual cathode is to select suitable measurement instruments with a sufficient dynamic range for monitoring the key laser parameters. Therefore, focus lies on the diagnostic mode in the presented concept of the virtual cathode, i.e. low laser power with a dynamic range of 35 dB. To avoid saturation of the devices in the operation mode the high average power will be attenuated by neutral density filters.

MEASUREMENT SYSTEMS

Measuring the laser spot size, a CCD camera is installed in the virtual cathode box, providing a spatial resolution of 659 pixels×494 pixels and a pixel size of 9.9 µm×9.9 µm. However, if the same camera is intended to be used in the UV mode, an additional YAG screen with fluorescent coating as well as a close-up lens would be necessary. In addition to the laser spot size, information on laser spot intensity as well as changes in its distribution are received.

The CCD camera also offers a solution for laser spot position measurements. However, if single shot measurements are required, a CCD camera may not be sufficient - depending on exposure time and laser intensity. A quadrant diode may offer a fast alternative to the camera. It consists of four photo-sensitive areas, arranged crosswise as in a coordinate system. The incident laser light will be converted into an output photocurrent in the quadrants. Using the current ratios, a relative spot position can be calculated, which must be calibrated, however. The selected quadrant diode model features an adequate sensitivity ranging from the UV to near IR spectral range. The radiant sensitive area covers 3.0 mm×3.0 mm.

A semiconducting photodiode is suitable for measuring the laser energy. The suggested photodiode model is UV enhanced. Providing an active area of 3.6 mm×3.6 mm, the sensor is sufficient for different laser spot diameters.

The quadrant- and photodiodes generate low level photocurrents. For further signal analyses, two transimpedance amplifiers convert the signals into voltages and amplify them.

CONCEPT AND SETUP

First Concept

A graphical overview of the concept is shown in Fig. 2. A wedged beam splitter reflects nearly 2% of the laser beam, directing the light into the virtual cathode. Due to the wedge boundaries of the splitter, the two decoupled beams diverge. Therefore, there will be enough space for mirrors and measurement instruments in both beam paths. Entering the gun vacuum, the laser light transmits through an optical window called viewport. Attenuating the laser power, this window has to be simulated in the virtual cathode (viewport dummy). The movable filter wheel ensures that the required dynamic range of 80 dB can be covered. It is implemented in the operation mode for 23 W to reduce the laser power onto the diagnostic mode level. Further, the photodiode and quadrant diode with their transimpedance amplifiers as well as the CCD camera are installed, monitoring the key laser parameters. In order to receive the values of the laser spot size and position on the real photocathode, the CCD camera and quadrant diode are arranged in the same distance to the beam splitter as the photocathode.

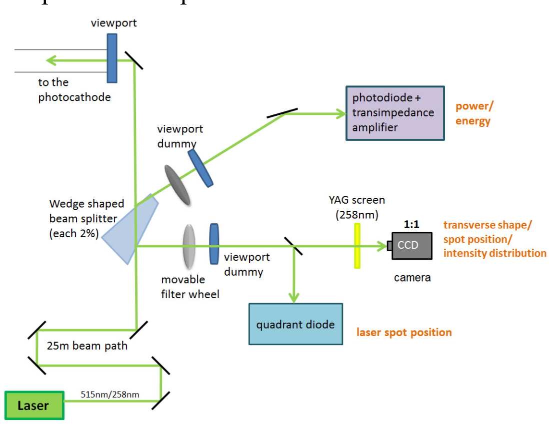

Figure 2: Concept of the virtual cathode.

Final Setup

The current setup with all sensors, optics, amplifier systems and an AD-converter is shown in Fig. 3. The beam paths of both wavelengths (515 nm and 258 nm) are confined to the virtual cathode box.

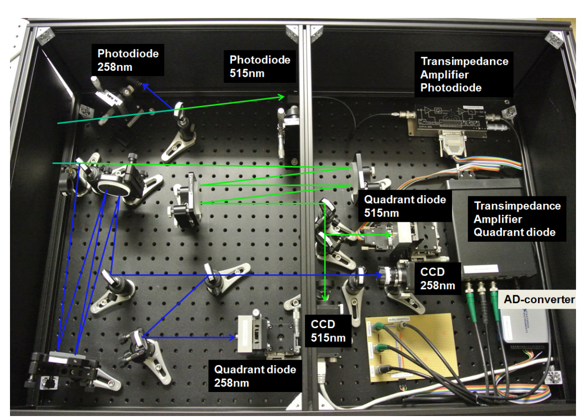

Figure 3: The final setup of the virtual cathode box.

FIRST TEST MEASUREMENTS

Calibration

The quadrant diode transimpedance amplifier is able to calculate a relative x- and y-position from the four quadrant signals. A calibration is required in order to give precise information on the exact laser spot position on the real photocathode. Since the quadrant diode is mounted on linear stages, the detector can be calibrated by moving the sensor active area across the optical beam path. The x- and y-position is subsequently determined from the micrometer-screws [Fig. 4].

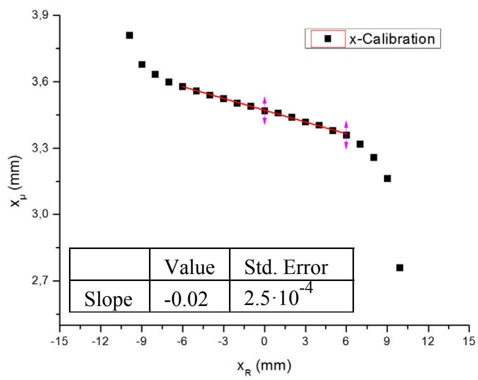

Figure 4: X-calibration of the quadrant diode.

As a result, one relative position unit of the amplifier corresponds to 20 µm. A spatial resolution of 200 nm is obtained. The linear range of the quadrant diode extends to the position at which the laser spot moves out of the active sensor area.

Dynamic Range of the Detectors

The dynamic range and the linearity of the photodiode and quadrant diode are tested. Therefore, the sensors are placed in a measurement set-up with a 1mW test laser (532 nm) and a variable attenuator. For further signal processing the sensor is connected to the transimpedance amplifier, which directs the measurement values trough an AD-converter into the computer. There the signals are recorded, saved and analysed in LabView programs.

The dynamic ranges of the sensors are measured at all adjustable gain settings of the transimpedance amplifiers. Fig. 5 represents a small excerpt from the dynamic range measurements of the photodiode for one gain setting.

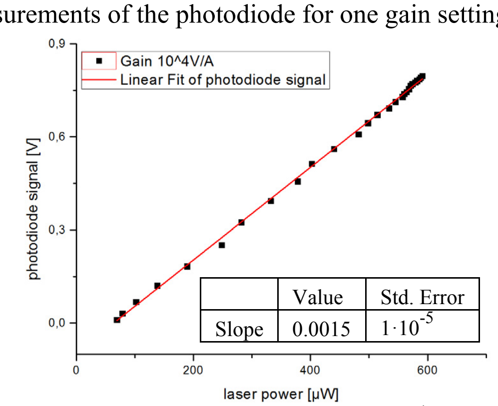

Figure 5: Photodiode signal (gain 10^4 V/A).

All measurement values indicate the linearity of the detectors and their transimpedance amplifiers. The dynamic range of the photodiode system covers 58 dB. For the quadrant diode-amplifier system a power range of 37 dB is obtained. The limits of the dynamic ranges are set by the transimpedance amplifiers, not by the sensors.

While the dynamic range of the photodiode meets the requirements of the virtual cathode for energy measurements, the amplifier system of the quadrant diode needs to be improved.

SUMMARY

In this paper a definition of the virtual cathode was provided. All laser parameters were checked on their relevance for beam dynamics and key laser parameters were determined: The laser spot size, laser spot position, pulse energy and average power. Suitable measurement devices like photodiodes, quadrant diodes and CCD cameras were discussed. After a first concept for the virtual cathode had been designed, the virtual cathode setup was implemented. Computer programs written in LabView enable to analyze and save the measured values. Finally, the quadrant diode was calibrated and the measurement instruments were tested for their suitability regarding the specific proposes of the virtual cathode.

OUTLOOK

This paper describes the first version of a laser diagnostic setup for bERLinPro, which needs to be improved and developed further.

The quadrant diode amplifier technique does not meet the requirements of the virtual cathode. A minimum gain of 10^7 V/A is necessary for correct position measurements at low laser power. One option for repetition rates up to the kHz-regime would be to replace the current transimpedance amplifier by a lock-in amplifier. Otherwise, the wedged beam splitter has to be exchanged at low laser power in order to extract larger fraction of beam power.

The current setup focuses on a wide dynamic range. In the next step, the virtual cathode will be developed further for single pulse measurements up to 30 kHz. Therefore, the signal processing technique and LabView programs need to be modified. The optics and selected sensors are suitable for single pulse measurements.

Finally, a feedback system will be implemented. The aim is to correct instabilities and deviations in the laser beam parameters as well as in the electron beam parameters.

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