SETUP AND COMMISSIONING OF THE DIAGNOSTICS BEAMLNE FOR THE SRF PHOTOINJECTOR PROJECT AT ROSSENDORF

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Abstract

A superconducting radio frequency photo electron injector (SRF injector) has been developed by a collaboration of BESSY, DESY, FZD and MBI and is in operation since late 2007. After the initial commissioning in late 2007 with a Copper photocathode a Caesium-Telluride cathode was installed early 2008 to allow for high charge production. The longitudinal and transverse electron beam parameters are measured in a compact diagnostics beamline. This paper describes results from beam commissioning of the main diagnostic tools. Special emphasis is given on the bunch length measurement system for the 15 ps FWHM electron bunches. The system is based on the conversion of the electron pulses into radiation pulses by Cherenkov radiation. These radiation pulses are transported in a novel fully-reflective, relay imaging optical beamline to a streak camera, where the temporal properties of the pulses are measured.

EXPERIMENTAL SETUP

The setup for the SRF photoinjector consists of the SRF gun and a diagnostics beamline as depicted in Fig. 1. Fore more details on the SRF gun cavity and operational results see [1, 2]. The two operation modes of the SRF photoinjector are summarized in Tab.1. During the commissioning of the SRF cavity, the gun was operated with a copper cathode, which has a quantum efficiency three orders of magnitude lower than Cs₂Te. The motivation for this is to separate the different commissioning stages and be able to fully test one subsystem after the other. The axis peak field of the accelerating mode is \( E_{\text{peak}} = 50 \text{ MV/m} \) (design value). The current cavity is able to produce an accelerating field of \( E_{\text{acc}} = 6 \text{ MV/m} \), due to problems encountered during the cleaning process of the cavity [1].

BEAM CHARACTERIZATION

In order to characterize the performance of the photoinjector, the following beam parameters need to be considered:

- The energy distribution of the beam – the kinetic energy of the electrons and the energy spread. The beam momentum will vary between a few and 9.5 MeV. The minimum momentum spread as expected from simulations will be 36 keV for the low charge operation mode. These quantities will be measured in a 180 degree dipole spectrometer.

- The total beam intensity, together with the time structure. The bunch charge can vary between a few pC during initial operation with the Copper cathode and 1 nC at the high charge operation mode. The bunch charge is monitored with integrating current transformers and Faraday cups, the bunch length is measured with a Cherenkov monitor.

- The optical properties, which can be described in terms of the transverse beam emittance. The normalized beam emittance is expected to vary between 1 and 10 mm mrad. The electron beam generated in the injector is in all nominal operation modes space-charge dominated. For this reason a double slit-based phase space sampling method is considered, where an actuator-mounted slit mask is moved perpendicular across the beam.

| RF frequency | 1.3 GHz | 1.3 GHz |
| Beam energy | 9.5 MeV | 9.5 MeV |
| Operation | CW | CW |
| Drive laser | 263 nm | 263 nm |
| Photocathode | Cs₂Te | Cs₂Te |
| Pulse length FWHM | 5 ps | 16 ps |
| Repetition rate | 13 MHz | 500 kHz |
| Bunch charge | 77 pC | 1 nC |
| Trans. emittance | 1.5 μm | 2.5 μm |

Table 1: Design beam parameters of the two main operation modes of the SRF injector: for the ELBE FEL replacing the thermionic gun (ELBE FEL) and at high bunch charge (High Charge).

For a complete description of the individual elements see [3]. In the following the tools to measure the transverse and temporal profile are described with more details. Furthermore initial experience gathered during commissioning is given.

TRANSVERSE PROFILE

Thin Yttrium-Aluminum-Garnet (YAG) crystal sheets doped with the visible light scintillator Cerium can be in-
serted into the beampath to produce an image of the transverse charge distribution. This beam image is detected by a CCD camera. The screen material has to be robust and UHV-compatible as the first screen is located in close proximity to the SRF cavity. To provide for the best image fidelity, the screens are mounted at normal incidence to the electron beam. An Aluminum mirror is placed downstream to deflect the fluorescent light out to the camera. Outside the vacuum beam pipe the light is deflected again by a mirror and then focused onto the sensitive area of a CCD camera. The optical focus and magnification can be calibrated by inserting a calibration target at the location of the screen. The cameras are GigE compliant, data transfer is done through standard ethernet cable in a dedicated camera network. The trigger for image acquisition is derived from the ELBE timing system. Standard photographic objective lenses with a focal length of $150\text{ mm}$ are used to image the screen image onto the sensitive area of the CCD camera. The minimum object size generated by the crystal screen is dominated by multiple scattering for beam energies below $10\text{ MeV}$. At $2$ to $3\text{ MeV}$ beam momentum the minimum resolution is around $40\mu\text{m}$ and at $9.5\text{ MeV}$ the resolution is around $10\mu\text{m}$.

During commissioning, the viewscreens were able to withstand operation conditions with several thousand nC per hour without any visible degradation of the beam image. Fig. 2 shows a beam images obtained during commissioning.

**TEMPORAL PROFILE**

*Cherenkov Monitor*

The first temporal profile monitor is located after the spectrometer magnet in straight direction. Inside the Cherenkov monitor [4] the electron bunches pass a thin sheet of radiator. The radiator emits a Cherenkov radiation pulse with the same time structure as the electron bunch. A streak camera can be used to measure the shape and length of this radiation pulse with ps resolution. Silica aerogel plates of small dimensions with refractive index of $n = 1.008$ and $1.028$ are available [5] and considered as Cherenkov radiator. The threshold energy for $n = 1.008$ is $4.1\text{ MeV}$, for $n = 1.028$ is $2.2\text{ MeV}$. The refractive index of the material was measured with samples in parallel plate setup. A test plate of thickness $d$ was put perpendicular into the light path of a laser beam. The plate was rotated and the resulting parallel shift of the laser beam measured. From the measured parallel shift versus rotation angle data the refractive index could be retrieved. The thickness of the plate was chosen to be $6\text{ mm}$ to balance the amount of emitted photons with the time resolution due to dispersion. The Cherenkov light is then transported with mirrors to the streak camera [8] over a distance of roughly $20\text{ m}$. The Cherenkov light exits the radiator with large divergence, therefore a relay imaging with focusing elements is necessary to achieve a high photon collection efficiency. Using lenses for this can cause dispersion related pulse broaden-
ing of the short photon pulse. For setups with lenses pulse 
broadening by a factor of 2.5 was measured for bunches 
of 20 ps FWHM length [6]. Therefore only reflective optical 
elements, plane and off-axis parabolic mirrors, were 
considered for the light transport. The pulse is broadened 
due to dispersion in the light beamline by 2.2 ps for wave- 
lengths between 300 and 600 nm, caused to almost equal 
parts by the two viewports and the air in the light beamline. 
These effects can be minimized by using bandpass filters.

**Laser Pulse Measurements**

First tests with the streak camera were performed to 
check the photocathode laser (see [7] for full description) 
pulse length and the synchronisation of the streak camera 
to the master oscillator. For the direct measurement an 
optical transport line with mirrors and beamsplitters was 
set up to transport the laser light from the laser hutch to 
the neighboring streak camera hutch. Synchronization be- 
tween laser and streak camera is achieved by a 250 MHz 
phase-locked loop synthesizer driven by a 13 MHz refer- 
cence signal from the laser itself. The synchronization accu- 

racy between laser and streak camera was measured to be 
better than 2 ps. The photocathode laser oscillator deliv- 

ers pulses in the infra-red (1053 nm), which are amplified 
and finally in converted in two second harmonic generators 
to green (526 nm) and finally ultra-violet (263 nm). During 
the data taking, the pump current of the photo diodes of 
the laser amplifier was changed and the average power and 
pulse length of the output pulses was measured. For mea- 

curement of the green pulses, the second conversion stage 
was removed. The average laser power was measured with 
a powermeter, the pulse length with the streak camera as 
described above. For each pump current setting, the light 
intensity was entering the streak camera was regulated, for 
the green pulses by low-reflectivity optical flats and neutral 
density filters, for the UV only with low-reflectivity flats. 
In Fig. 3 the results for these measurements are shown. For 
each data point five streak images were taken. Each im- 
age was analyzed by applying a Gaussian fit to the time- 
projection axis data. For the green pulses the average out- 
put power increases with increasing pump current. Above 
a pump current of 15.5 mA a sudden drop in laser inten- 
sity was observed. The laser intensity recovered soon, but 
due to time constraints the data point for this pump current 
could not be taken again. For the UV output pulses, the 
sequence started at high pump current. Here also the laser 
intensity dropped, this time at the data point for a pump 
current below 18.5 mA. The intensity for the measurement 
on the streak camera was consequently very low leading to 
a small signal to noise ratio and thus to an underestimation 
of the pulse length. It is planned to do the measurements 
again. The pulse length of the electron bunches after ex- 
traction out of the cathode as measured with a phase scan 
is \( \Delta z = 18.1 \pm 7.3 \) ps FWHM.

**SUMMARY AND OUTLOOK**

The diagnostics beamline currently under construction 
plays a vital role in the commissioning and successful run- 
nings of the SRF injector. Results from first beam tests at 
low bunch charge indicate the efficiency of the individual 

devices.

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**REFERENCES**