INVESTIGATIONS ON ELECTRON BEAM IMPERFECTIONS AT PITZ.


Abstract

Since more than a decade, the photo injector test facility at DESY, Zeuthen site (PITZ), has developed and optimized high brightness electron sources for modern Free Electron Lasers like the FLASH and the European XFEL. Despite a very high performance of the photo injector it was experimentally demonstrated, several discrepancies between measurements and beam dynamics simulations have been revealed. Although the optimized measured values of the projected transverse emittance are close to those obtained from the beam dynamics simulations, the corresponding experimental machine parameters show certain systematic deviations from the simulated optimized setup. As a source for these deviations, electron beam imperfections were experimentally investigated. This includes studies on bunch charge production, electron beam imaging using the RF gun with its solenoid, and investigations on the transverse asymmetry of the electron beam generated in a rotationally symmetric gun cavity. Experimental studies were supplied with corresponding beam dynamics simulations. The paper reports on results of these studies.

Motivation – High Brightness Photo Injector Optimization

The transverse phase space of the electron beam from the 11-cell I-Band RF-gun was measured in details while tuning numerous parameters, like gun gradient (Ecath) and phase, main solenoid current (Imain), cathode laser pulse temporal profile and spatial intensity distribution. The 2015 measurement program was mainly dedicated to the emittance minimization for 500 pC electron bunches for Ecoath=5 MV/m applying photocathode pulses with Gaussian temporal profile of ~11 ps FWHM [2].

For each laser spot size the main solenoid current was optimized. Corresponding measured emittance curves are shown below for each size of the electron beam. Results of simulations are shown as well while applying the optimized laser intensity distributions.

Photoemission

Experimental evidence optimization for fast bunch charge yield in a transverse spot size of the photocathode laser which corresponds to a strong space charge effect during the production. The working point for this has been the nominal operation of the electron beam gun with cathode laser pulse energy of 1.7 mJ/nm using the laser with 0.2 mm mm spot size.

Electron beam asymmetry studies: „Larmor angle experiment”

In order to investigate the origin of the electron beam X asymmetry, several dedicated experimental studies have been done. One of them is the so-called Larmor angle experiment [8]. The electron beam was tracked in a PITZ solenoid with a magnetic field of 5 mT and a length of 276 mm. By changing the orientation of the main solenoid a phase shift of ~90° or ~-90° relative to the cathode laser was applied. As a result the electron beam was deflected by 45° away from the central trajectory and in the opposite direction of the cathode laser. The asymmetry of the electron beam was clearly observed in the transverse beam position profiles. This measurement was done with the electron beam from ~0.3 mm at the cathode (~1.2 mm diameter) bunch charge of 650 pC. The measured beam profiles and the control bunches were switched off for these measurements.

Beam dynamics simulations using ASTRA code [9] applying laser pulse with radially homogenous distribution of pulse area corresponding to the measured ones result in a stronger emission of the simulated electrons. In order to explain this discrepancy an “loss plus beam model for the focal plane of the cathode laser was suggested. Analysis of the laser transverse distribution measured with a CCD revealed that the electron beam profile was strongly deviated from the radial symmetry of the laser beam. These distortions of the laser focal plane can be associated with a beam imperfection in the laser used for the experiment. Simulations show a significant improvements of measurement-simulation comparison. Despite further agreement between measurements and calculations, there still remain some discrepancies between experiment and simulation, which may be related to the phase differences of the laser pulses. Nevertheless, these results also better refer to the asymmetry simulations.

Electron Beam Imaging

Electron Beam Imaging is enabled by reducing the space charge effect (low charge density) and acquiring a laser pulse length short enough to reduce chromatic effects. Under these principle, experimental and simulation studies on beam dynamics of RF and solenoid fields of the PITZ gun without space charge were performed, by which the calibration of the main solenoid can be cross checked together with RF field properties. Magnetic field measurements with a real pulse yielded the main solenoid calibration formula 

\[ B_{z}(r) = 0.889 \times 10^{-7} + 7.102 \times 10^{-9} \times r \]  \( (1) \)

For the experiment, a gold foil is inserted in the laser beam line at the beam shaping aperture. The laser beam passes through the grid and is absorbed and being imaged onto the photocathode. The electron beam leaves the pit with a position determined by the gun RF field Astra simulation is used to determine the coordinate and to simulate the laser field. The simulation results are shown at (a) and (b). The laser focal plane is shown at (c) and (d). The simulation results are shown at (e) and (f).

The grid electron beams change from experiment and simulation at these screens with different space charge fields. The grid electron beams change from experiment and simulation with different space charge fields. The grid electron beams change from experiment and simulation with different space charge fields. The grid electron beams change from experiment and simulation with different space charge fields. The grid electron beams change from experiment and simulation with different space charge fields. The grid electron beams change from experiment and simulation with different space charge fields.

For 5 MHz peak power in the gun the magnification factor and the rotation angle show good agreement between experiment and simulation, but there are some discrepancies between experiment and simulation for other screens and different gun power levels. More studies and experiment for different gun powers and full charged current scans are ongoing.

Conclusions

Experimental studies and simulations have been performed at PITZ in order to explain the discrepancy between measured and simulated properties of electron beams. The “core plus halo model” in the modeling of the transverse cathode laser pulse distribution yields better agreement for the bunch charge production. A beam based check of the main solenoid calibration was done using the electron beam imaging technique. Electron beam X-asymmetry investigations revealed a possible location of a kick onto the transverse phase space at ±0.2 m from the cathode. Detailed studies to quantify the kick are ongoing.

References