Beam based monitoring of the rf photo gun stability at PITZ.

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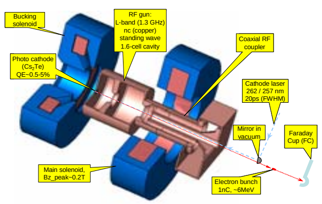
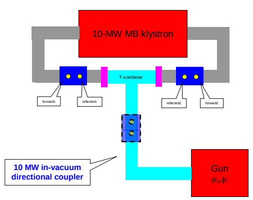
Abstract

The stability of the photo injector is a key issue for the successful operation of linac based free electron lasers. Several types of jitter can impact the stability of a laser driven RF gun. Fluctuations of the RF launch phase and the cathode laser energy have significant influence on the performance of a high brightness electron source. Bunch charge measurements are used to monitor the stability of the RF gun phase and the cathode laser energy. A basic measurement is the so called phase scan: the accelerated charge downstream of the gun is measured as a function of the launch phase, the relative phase of the laser pulses with respect to the RF. We describe a method which provides simultaneous information on RMS jitters from phase scans at different cathode laser energies. Fluctuations of the RF gun phase together with cathode laser energy jitter have been measured at the **Photo Injector test facility at DESY in Zeuthen (PITZ)**. Obtained results will be presented in comparison with direct independent measurements of corresponding instability factors. Dedicated beam dynamics simulations have been done in order to optimize the method performance.

PITZ RF Photo Gun

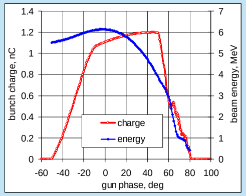


RF System for the PITZ Gun



The RF gun cavity is a 1½-cell normal conducting copper cavity, operated at a resonance frequency of 1.3 GHz with a peak power of up to ~7 MW. The RF power to the gun is supplied by a 10 MW multibeam klystron through two equal output ports. In front of the gun the RF pulses from both waveguides are combined using a custom T-shape combiner. No field pickups are available for the current gun cavity design. Before 2010 the control of the RF feed to the gun was realized via two directional couplers installed before the T-combiner. Cross-talking of both directional couplers under not well-known resonance conditions of the gun cavity made the control of the RF field in the gun practically impossible. So, no routine feed back was available and only the feed forward had been used. After the facility upgrade in spring 2010 a **10 MW in-vacuum directional coupler** has been installed after the T-combiner. Measurements of the combined RF pulses should provide a possibility for better control on the field in the gun closing a feedback loop for the amplitude and phase stabilization.

Phase scan for the gun stability measurements (ASTRA simulations)

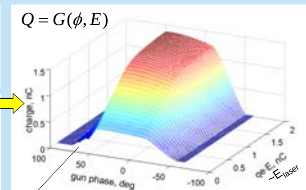


Simulated phase scans (ASTRA)

Standard PITZ gun conditions have been applied:
- Ecath=60 MV/m
- Cathode laser: flat-top temporal profile with 20 ps FWHM and 2 ps rise and fall time, ~0.4 mm RMS laser spot size.
- Schottky constant of 0.005 nC/(MV/m)

2D phase scan
simulated charge vs. RF phase and laser pulse energy

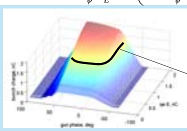
The value used for one of horizontal axis can be treated as a charge which could be extracted from the cathode if no space charge or Schottky-like effects would be applied. Zero RF phase on these plots refers to the gun phase with maximum mean momentum gain.

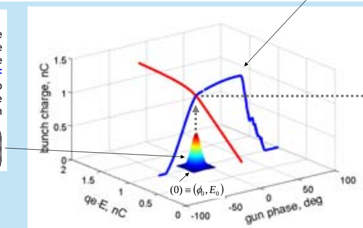


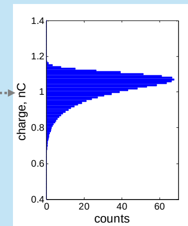
Technique to monitor gun stability

The dependence of the bunch charge on the gun phase and the laser energy can be used to determine gun phase and laser energy jitters. The main assumption of the method is an **independence of the jitters of the RF launch phase and the cathode laser pulse energy**, so the distribution function of the RF launch phase and the laser energy can be presented by a 2D Gaussian distribution:

$$P_2(\Delta\phi, \Delta E) = \frac{1}{2\pi\sigma_\phi\sigma_E}\exp\left(-\frac{\Delta\phi^2}{2\sigma_\phi^2} - \frac{\Delta E^2}{2\sigma_E^2}\right)$$







Assuming a parameterization of the curve:

$$G(\phi, E) = Q \iff \begin{matrix} \phi = F_\phi(Q,\xi) \\ E = F_E(Q,\xi) \end{matrix}$$

The charge probability distribution

$$P_1(Q) = \int P_2\left(F_\phi(Q,\xi), F_E(Q,\xi)\right) \cdot \sqrt{\left(\frac{\partial F_\phi}{\partial \xi}\right)^2 + \left(\frac{\partial F_E}{\partial \xi}\right)^2}\, d\xi$$

Linear approximation:

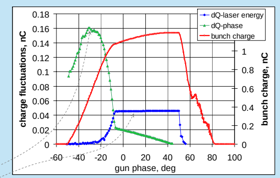
$$Q = \left.\frac{\partial Q(\phi,E)}{\partial \phi}\right|_{(0)} \Delta\phi + \left.\frac{\partial Q(\phi,E)}{\partial E}\right|_{(0)} \Delta E$$

Resulting charge distribution – Gaussian with RMS:

$$\sigma_Q = \sqrt{\left(\left.\frac{\partial Q(\phi,E)}{\partial \phi}\right|_{(0)}\right)^2 \sigma_\phi^2 + \left(\left.\frac{\partial Q(\phi,E)}{\partial E}\right|_{(0)}\right)^2 \sigma_E^2}$$

Two measured points are sufficient to resolve the linear system:

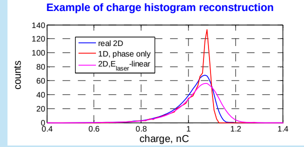
$$\begin{pmatrix} \left(\left.\frac{\partial Q}{\partial \phi}\right|_{01}\right)^2 & \left(\left.\frac{\partial Q}{\partial E}\right|_{01}\right)^2 \\ \left(\left.\frac{\partial Q}{\partial \phi}\right|_{02}\right)^2 & \left(\left.\frac{\partial Q}{\partial E}\right|_{02}\right)^2 \end{pmatrix} \times \begin{pmatrix} \sigma_\phi^2 \\ \sigma_E^2 \end{pmatrix} = \begin{pmatrix} \sigma_{Q1}^2 \\ \sigma_{Q2}^2 \end{pmatrix}$$



Simulated linear contributions to charge fluctuations from phase and laser pulse energy jitters

$$dQ\_phase = \frac{\partial Q(\phi,E)}{\partial \phi}\sigma_\phi; \quad dQ\_laser = \frac{\partial Q(\phi,E)}{\partial E}\sigma_E$$

Example of charge histogram reconstruction



real 2D	using full nonlinear charge dependence	=> goal histogram
1D, phase only	no laser pulse energy jitter assumed	overestimation of the phase jitter
2D, E_{laser}-linear	only linear slope of charge vs. laser energy assumed	underesimation of phase and laser energy jitter

General approach

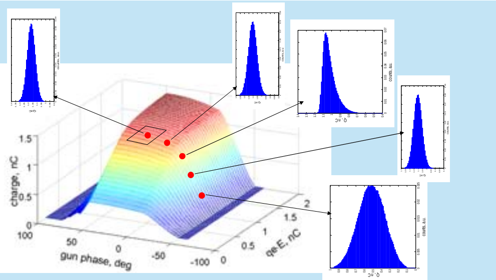
→simultaneous simulations of the measured charge histograms at various gun phases by minimizing the functional:

$$\Phi(\sigma_\phi, \sigma_E) = \sum_n w_n \cdot \int \left| QH_n^{meas} - QH_n^{sim} \right| dq$$

Where charge fluctuations histograms:

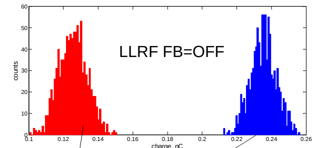
$QH_n^{meas}(q)$ - measured

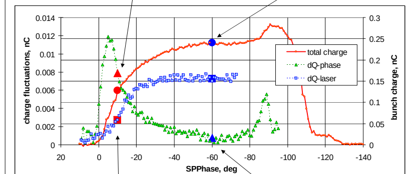
$QH_n^{sim}(q, \sigma_\phi, \sigma_E)$ - calculated

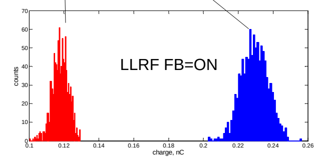


Experimental tests at PITZ

A new gun cavity is under conditioning now at PITZ. The full expected RF power (of ~7 MW) is not yet achieved, therefore some preliminary stability monitoring tests have been performed at reduced peak power in the gun (**~0.85 MW**). The gun temperature has been tuned in order to keep the gun cavity strictly at resonance. Gun solenoid was off for these measurements. Preliminary tests of the LLRF feed back (FB) system have been performed







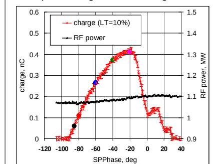
Feed Back (FB)	Laser pulse RMS jitter	RF phase RMS jitter	
		from charge measurements	from directional coupler
OFF	11%	0.82 deg	0.43 deg
ON	11%	0.32 deg	0.16 deg

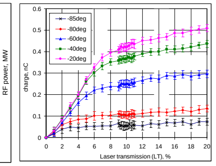
Tests of the general approach

Measurements have been performed using first FC (~0.8 m from the cathode) for **~1.09 MW** in the gun. The main solenoid current of 210 A has been applied to focus beams with high energy at the FC location. The **set point RF phase (SPPhase)** is used for the horizontal axis. It has an arbitrary (but fixed) offset to the mathematical phase of the gun cavity resonator.

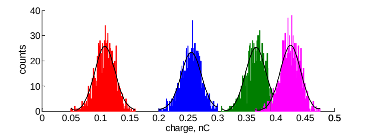
The shape of the phase scan is impacted from many parameters of the gun. The space charge density at the cathode due to the laser temporal and transverse profiles at the given laser pulse energy determines the charge dependence in the phase range from the field zero-crossing to the phase of the maximum beam energy gain from the gun (-90 deg to -40 deg). A Schottky-like effect – a charge production enhancement due to the presence of a high electric field at the cathode – contributes in an additional slope in the phase scan for the phases corresponding higher RF field during the photo emission (-40 deg to -20 deg).

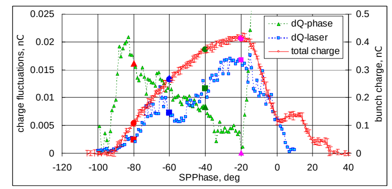
The control of the cathode laser pulse energy is realized at PITZ by means of a polarizer based attenuator. By its rotation the **laser transmission (LT)** can be tuned in order to adjust the energy of the laser pulse hitting the photo cathode. Initial (linear) parts of these curves are typically used for the quantum efficiency (QE) determination, their further (nonlinear) behaviour is strongly influenced by the space charge effects during emission.





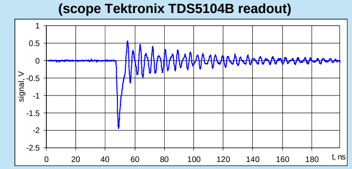
Charge histograms have been fitted at 4 phases (SPPhase=-80;-60;-40;-20 deg).





The applied method yielded an RMS jitter of 1.77 deg for the RF phase and 12.5% for the laser pulse energy. No feed back has been applied for these measurements. It should be also mentioned that these measurements have been done using short Gaussian laser pulses with ~2ps FWHM, which is significantly shorter the nominal value (20 ps). This can partially explain rather high laser energy jitter, PMT measurements of the laser pulse energy on the laser table are in good agreement with RMS value obtained from electron beam charge measurements.

Typical signal from Faraday Cup (scope Tektronix TDS5104B readout)



Systematic limitations on resolution of the technique

There are several sources of systematic limitations of the proposed method:

- The bunch charge measurements using FC or ICT with a scope readout is usually disturbed by the **noise of the scope base** line and by the jitter of the background due to the dark current fluctuations. A method to reduce the signal dependence on the dark current intensity can be based on a dark current envelope fitting corresponding to the actual peak power in the gun. This has to be tested in future when the nominal power level in the gun (7MW) will be achieved.
- A dependence of the extracted charge on the **RF gradient** in the gun is not included in the above described method. However for some conditions when the electric field at the cathode plays a significant role in the emission process the RF field jitter (e.g. due to the resonance temperature fluctuations) could contribute in the bunch charge jitter as well. This can also include the **klystron nonlinearity** – namely the dependency of the output RF power on the set point RF phase, which can be a substantial effect by the operation of the klystron close to saturation. If RF gradient in the gun is well controlled by the LLRF system these effects are assumed to be rather small.
- Another factor limiting the method performance is the laser **timing synchronization** to the **MO**, which are intrinsically included in the measured phase jitter. Using measurements from the directional coupler it should be possible to estimate this jitter as well.

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