RF PHOTO GUN STABILITY MEASUREMENT AT PITZ

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Abstract

High stability of the RF photo gun is one of the necessary conditions for the successful operation of linac based free electron lasers. Fluctuations of the RF launch phase have significant influence on the beam quality. Investigation on the dependence of different gun parameters and selection of optimal conditions are required to achieve high RF gun phase stability. Measurements of the gun RF phase stability are based on beam charge and momentum monitoring downstream of the gun. The stability of the RF gun phase for different operating conditions has been measured at the Photo Injector Test facility at DESY in Zeuthen (PITZ) and the results will be presented.

INTRODUCTION

A high quality beam is one of main requirements for linac based FELs.

The most important issue in this regard is to achieve a high phase stability in the RF photo gun. The RF launch phase stability is expected to be on the order of 0.1 degree for the phase [1]. The shot-to-shot stability in energy of the cathode laser pulses is expected to be 2% (RMS) for single pulses and 1% (RMS) averaged over a pulse train [1]. The Photo Injector Test facility at DESY in Zeuthen (PITZ) develops and optimizes high brightness electron sources for FELs like FLASH and the European XFEL, both in Hamburg (Germany). The stability of the photo electron source is one of the main programs of research at PITZ. This paper presents measurement results for different working conditions of the RF gun system.

PHOTO INJECTOR IN ZEUTHEN

The photo injector consists of 1.6 normal conducting L-band copper cells with a Cs_2Te photocathode and a solenoid system for compensating space charge. Operating resonance frequency is 1300 MHz and peak power up to ~7 MW. The RF gun is powered by a 10 MW multibeam klystron through two waveguides which are combined to one waveguide in front of the gun by a T-shaped combiner as shown in Fig. 1. The laser beam is coupled into the cavity with a small mirror mounted downsteam of the photo cathode in the beampipe.

The cathode laser system has been developed by the Max-Born Institute (MBI) [2] and it is able to generate flat-top pulse trains with the possibility to vary the number of bunches between 1 and 800 with 1 MHz frequency at 10 Hz repetition rate.

NEW 10MW IN-VACUUM RF COUPLER

The photo injectors for linac based FELs require an L-band RF photo gun with accelerating gradient of 60 MV/m at the cathode which necessitates a peak feeding power of ~7 MW. For transition of such high power waveguides filled with SF_6 –gas are needed but the gun must be under Ultra-High Vacuum (UHV), therefore vacuum windows are used for separate UHV and SF_6 parts of the power supply system as shown in Fig. 1. The klystron has to produce 10 MW peak power and transit it through two 5 MW arms. For combining power from the 2 arms in vacuum a T-combiner is used. No directional field pickup to control RF power inside the gun is realized in the current cavity prototype.

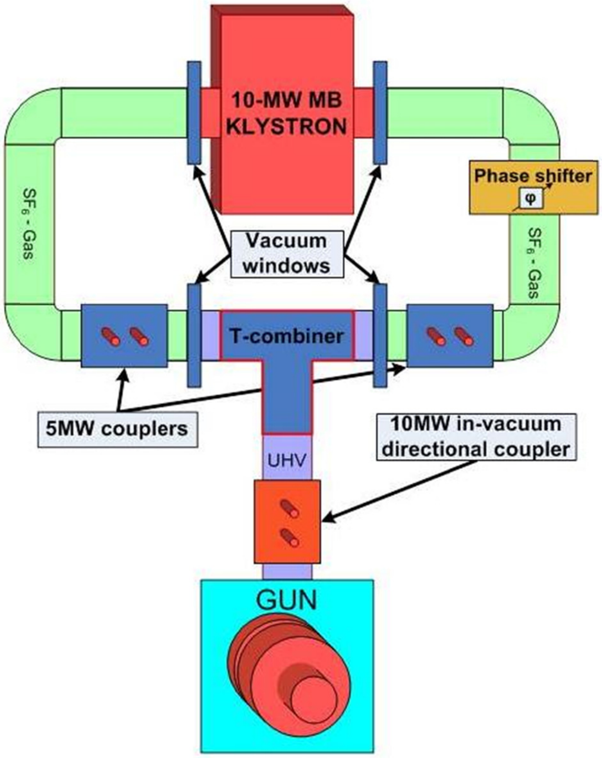

Figure 1: Layout of power supply system for the gun.

The power supply system of configuration 2009 [3] had just two 5 MW directional couplers in SF_6 side and phase shifter for control and adjustment of incoming power to the gun. Cross-talk between the two waveguides and

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power reflections from vacuum windows did not allow to realize an efficient feedback system based on two 5 MW couplers resulting in high gun phase jitter.

In the spring of 2010 a 10 MW in-vacuum directional coupler [4] was installed after the T-combiner. Measuring the combined wave and a feedback system to regulate incoming power are possible after installation of the 10 MW directional coupler.

METHODS FOR THE RF PHOTO GUN PHASE STABILITY MEASUREMENT

To measure phase stability of the gun we used two methods. The first is direct phase measurement which is based on monitoring signals from the 10 MW directional coupler and the combined signal from two 5 MW couplers (virtual probe). The second method is based on measurements of electron beam charge fluctuations.

The basis for the beam based monitoring method is beam charge using the Integrating Current Transformer or Faraday Cup which are located 0.9m downstream of the cathode. There are two different tools which are used for the beam based monitoring method: an on-line monitoring tool developed in DESY, location Hamburg [5] and a 2D-scan tool developed in DESY, location Zeuthen [6]. The beam based monitoring method uses the dependence of the beam charge on the launch phase, the dependence is shown in Fig. 2. This dependence is impacted from many parameters of the gun like the space charge density at the cathode, a Schottky-like effect, captured electrons in the full cell etc.

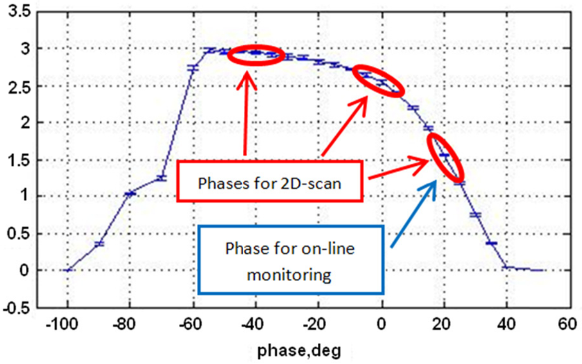


Figure 2: Phase scan for stability measurements.

The on-line monitoring tool has been developed to provide a fast measurement to control the low-level RF regulation for the RF photo gun. The tool measures the beam charge via a toroid, translates this to phase and shows the general phase stability, phase stability after removing slow drifts and phase stability across a macro pulse. The advantage of this method is fast phase jitter monitoring but without laser jitter incorporation. A typical phase stability result is shown in Fig. 3.

The second 2D-scan tool is based on a 2D phase scan which simulates accelerated charge after the gun as a function of the RF launch phase and the laser pulse intensity.

The main assumption of this method is independence of the jitters of the RF launch phase and the cathode laser pulse energy. Charge jitter histograms obtained at different gun phases and cathode laser intensities are fitted with the results of phase and laser intensity jitter distributions convolved with a measured 2D dependence $Q(\varphi,E)$. The main advantage of this method is simultaneous measurement of the gun phase jitter σ_φ and laser pulse energy jitter σ_E (or laser transmission LT) but this method requires additional analysis and detailed measurements. Typical laser transmission scans and charge histograms used for the 2D-scan tool are shown in Fig. 4.

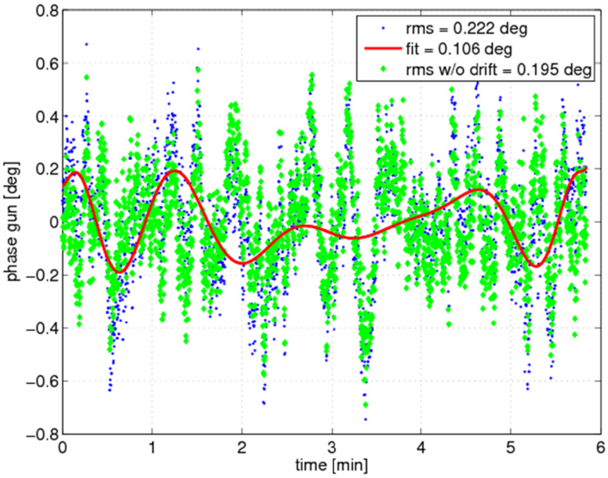
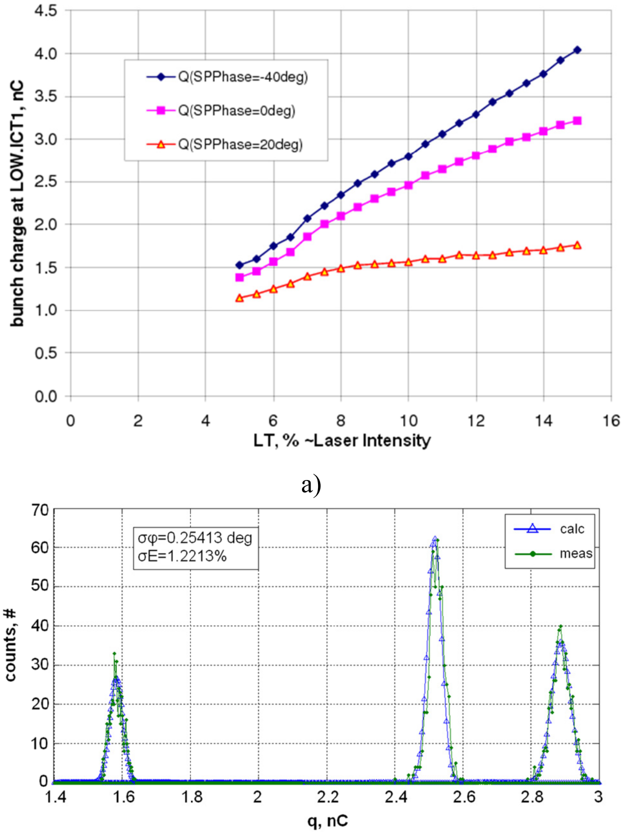


Figure 3: Phase stability measurement by on-line monitoring tool.



a)

b)

Figure 4: Laser transmission scans(a) and charge histograms(b) for 2D-scan tool.

RF GUN PHASE STABILITY

Photo gun phase stability measurements were performed for different working conditions such as different power level, number of pulses, RF pulse flat length and for different resonance conditions of the gun.

The measurement showed that the peak power level in the gun has almost no influence on the phase stability: for the maximum level of 6.2 MW the RF gun phase RMS jitter stability is 0.275 degree and it is 0.280 degree for 3.5 MW power when the feedback system is active. But for the case where the feedback is switched off the phase stability is systematically slightly better for the maximum power.

The assumption that measurement for higher number of pulses improves the result of phase stability because large number of pulses should average and decrease the result was not confirmed because phase along a pulse train is not perfect horizontally aligned as shown in Fig. 5. The results for phase stability measurements with different number of pulses are presented in Table 1.

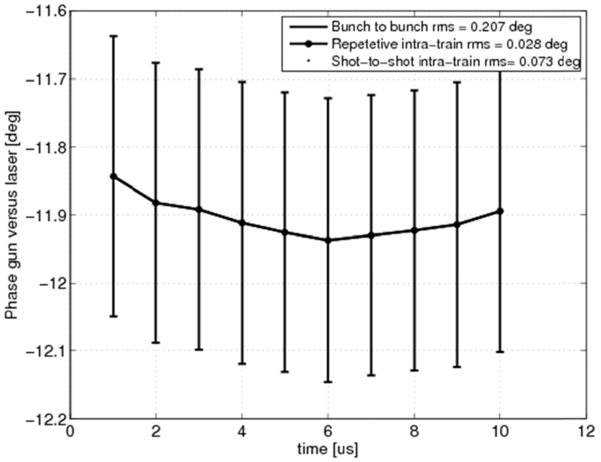


Figure 5: Phase stability along macro pulse.

Table 1: Phase stability for different number of pulses.

Feedback	Number of pulses	RMS phase
ON	1	0.230 deg.
ON	10	0.240 deg.
ON	30	0.210 deg.
OFF	1	0.717 deg.
OFF	10	0.753 deg.
OFF	30	0.692 deg.

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Increasing the RF pulse flat length in the gun slightly dilutes the phase stability and results are 0.218 degree and 0.258 degree for 100µs and 300µs correspondently.

The study shows that the feedback system based on the new 10 MW coupler significantly improved gun phase stability from 0.717 degree with feedback system switched off to 0.230 degree when feedback is on. The feedback improvement factor is about 3.

In comparison with previous gun phase stability measurements [7] the RMS value of gun phase jitter was decreased from ~2-4 degree to ~0.2-0.3 degree, one order of magnitude better.

STUDY OF THE GUN RESONANCE

The gun cavity resonance is achieved using precise adjustment of the temperature of the cooling water. The slope of the reflected power signals is an indicator of the cavity detuning.

The resonant temperature for the gun is usually set according to the signal from the direction couplers at the T-combiner in front of the gun but the 10 MW coupler and two 5 MW couplers show different signals. Tests to determine resonance gun temperature and to study the reliability of signals from different directional couplers were performed at PITZ. The tests implied beam momentum measurements while changing the gun temperature and scanning the gun phase simultaneously. The result (Fig. 6) shows that the gun temperature is set according to signals from 5 MW couplers closer to the resonant condition than temperature set according to signal from 10 MW coupler because at this point the maximum beam momentum. Analogous results are obtained for phase stability measurements. For example the maximum power in the gun, flat length 100µs with feedback switched on and resonant temperature set according to signals from 5 MW couplers give phase stability 0.275 degree but for resonant temperature set according to signal from 10 MW coupler phase stability is 0.291 degree.

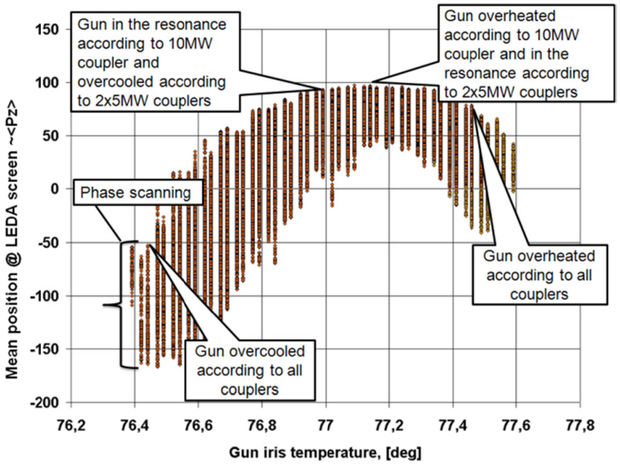

Figure 6: Beam momentum measurement for determine gun resonant condition.

SUMMARY

The RF gun launch phase stability measurement results at PITZ have been presented.

The results obtained by two methods for phase stability measurement are consistent.

The new 10 MW in-vacuum directional coupler has enabled an efficient LLRF feedback resulting in the phase

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jitter of ~0.2-0.3 degree RMS which is a factor of 3 better than for the case with the feedback switched off and one order of magnitude better than previous results.

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