RF PHOTO GUN STABILITY MEASUREMENT AT PITZ

I.V. Isaev*[†], G. Asova[‡], H.J. Grabosch, M. Gross, L. Hakobyan,Y. Ivanisenko,
M. Khojoyan[§], G. Klemz, W. Koehler, M. Krasilnikov, M. Mahgoub,D.A. Malyutin,
A. Oppelt, M. Otevrel, B. Petrosyan, S. Rimjaem, A. Shapovalov[†], F. Stephan,
G. Vashchenko, S. Weidinger, R. Wenndorff, DESY, 15738 Zeuthen, Germany
M. Hoffmann, H. Schlarb, DESY, 22607 Hamburg, Germany
I. Templin, I. Will, MBI, 12489 Berlin, Germany
D. Richter, HZB, 12489 Berlin, Germany

Abstract

The stability of the RF phase in the RF photo injector gun is one of the most important factors for the successful operation of linac based free-electron lasers. Instabilities in the RF launch phase can significantly reduce 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. The phase stability of the RF field is measured using the phase scan technique. Measurements were performed for different operating conditions at the Photo Injector Test facility at DESY, location Zeuthen (PITZ). Obtained stability measurement results will be presented and discussed.

INTRODUCTION

RF photo injectors are used as the high quality beam source for linac based free-electron lasers (FEL) like FLASH. Electron bunches are produced by interaction of pulsed laser radiation with a photo-cathode in the RF gun. The produced electron bunches are accelerated by a high gradient RF fields in the gun cavity to energies up to 6.9 MeV. The amplitude and phase stability of the RF field and also the laser pulse energy stability sensitively influence the beam quality. It is therefore mandatory to control these parameters. The Photo Injector Test facility at DESY in Zeuthen (PITZ) develops and optimizes high brightness electron sources for linac based FEL‘s. One of the main research programs at PITZ is stability of the photo electron source. This paper presents the RF gun stability measurement results for different working conditions at PITZ.

PHOTO INJECTOR IN ZEUTHEN

The PITZ setup is based on a normal-conducting standing wave RF gun cavity. The gun consists of 1.6 copper L-band cells with a Cs_2Te photocathode and two solenoids for generation of a constant external magnetic field which compensates the space charge induced emittance growth. Electron bunches are accelerated during the RF flat-top pulse. The gun operates with a RF field resonance frequency of 1.3 GHz and the electric field strength is 60 MV/m max at the cathode.

The gun RF power supply system consists of a 10 MW multibeam klystron with two arms for power output, two SF_6 filled waveguides, an in-vacuum T-combiner to combine fields from the waveguides, phase shifter to adjust RF phase, RF vacuum windows to separate UHV and SF_6 parts of the power supply system and three directional couplers for monitoring and controlling RF fields in the gun. The layout of the RF system is shown in Fig. 1

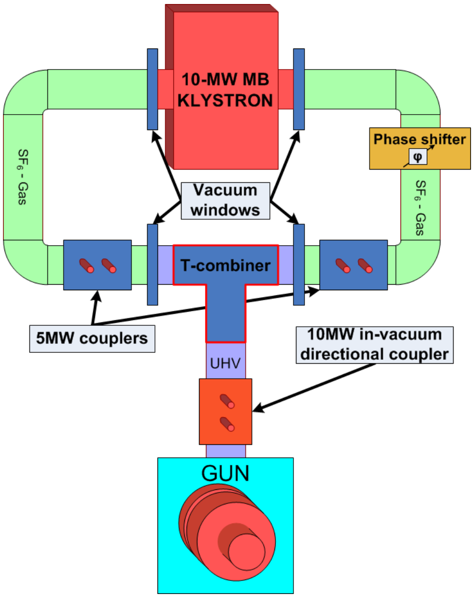

Figure 1: Layout of the RF system for the gun.

The control of incoming power to the gun is realized through analyzing forward and reflected wave signals from directional couplers near the T-combiner because no directional field pickup inside the gun is realized in the current cavity prototype.

The 2009 configuration of the power supply system [1] had just two 5 MW directional couplers on the SF_6 side before the T-combiner for control and adjustment of incoming power to the gun. An efficient feedback system based on two 5 MW couplers could not be realized because of cross-talk between the two waveguides and power reflections from RF vacuum windows. As a result, the large

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[*] igor.isaev@desy.de
[†] On leave from NRNU MEPhI, Moscow, Russia
[‡] On leave from INRNE, BAS, Sofia, Bulgaria
[§] On leave from YerPhI, Yerevan, Armenia

phase jitter could not be reduced to the sub degree level.

Measurements of the combined wave and the realization of a feedback system have been possible after the successful commissioning of the new 10 MW directional coupler [2] in the spring of 2010. The 10 MW directional coupler is installed in a vacuum waveguide after the T-combiner in front of the RF gun (Fig. 1). The 10 MW coupler allows to measure the forward wave going into the gun and the wave reflected from the gun cavity.

The cathode laser system [3] generates UV pulse trains with 1 to 800 bunches at 1 MHz frequency with a 10 Hz repetition rate. The laser pulses hit the cathode surface via a UV vacuum mirror which is mounted in the beampipe downstream of the gun. The laser pulse energy control is realized by a variable attenuator using a half-wave plate and a polarizer.

TECHNIQUES TO MEASURE THE RF PHASE STABILITY IN THE GUN

The gun RF phase stability is measured with two techniques.

One technique is a direct phase measurement. This technique is based on monitoring the forward wave signal from the directional couplers (Fig. 1). To measure phase jitter a single point on the gun phase distribution signal is selected. The gun phase distribution signal is calculated from the forward and reflected waves from 10 MW or signals combination from two 5 MW couplers.

Another technique is the beam based phase stability measurement. This technique is based on the dependence of the beam charge on the launch phase (see Fig. 2). Choosing a working point on the slope of the phase scan plot in Fig. 2, a jitter of the RF phase causes a jitter in the measured charge. If the laser pulse energy is stable enough, the charge fluctuation is a direct measure of the phase stability.

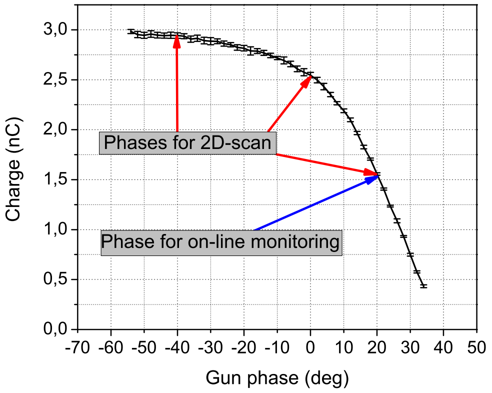


Figure 2: Phase scan for stability measurements.

The first tool is an on-line monitoring tool providing a fast measurement to control the low-level RF regulation for the RF photo gun [4]. This tool uses just one gun phase set point which should be on the linear slope of the charge-phase dependence. This tool assumes, that the jitter of the laser pulse energy is negligible. A typical phase stability measurement is shown in Fig. 3.

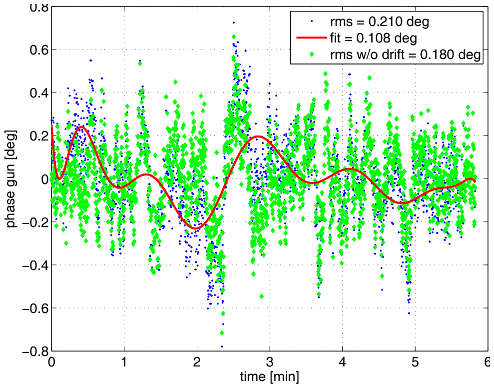
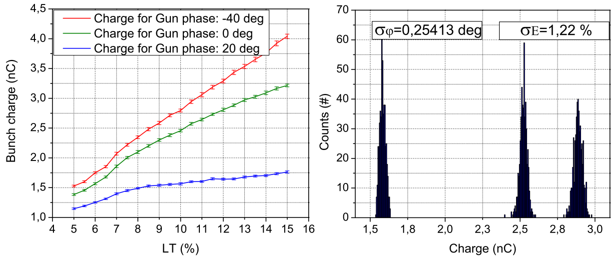


Figure 3: Phase stability measurement by the on-line monitoring tool. The rms phase jitter is 0.210 deg of 1.3 GHz RF.

The second tool uses a 2-D phase scan technique taking the laser energy jitter into account [5]. On the plateau of Fig. 2, the measured charge jitter is due to laser energy jitter and to a lesser extend, due to a phase jitter. The charge jitter histogram is obtained by mapping the 2D Gaussian probability function with a nonlinear surface $Q = G(\phi, E)$. The charge histograms are measured for different gun phases and cathode laser intensities for the analysis of the gun phase and laser energy jitters and therefore increasing accuracy of the measurements. The main assumption of this method is independence of the jitters of the RF launch phase and the cathode laser pulse energy. The laser transmission scans (Fig. 4 (a)) and the charge histograms (Fig. 4 (b)) were performed for three phases on the phase scan curve in Fig. 2, the chosen laser transmission is $LT = 10\%$.



(a) (b)

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

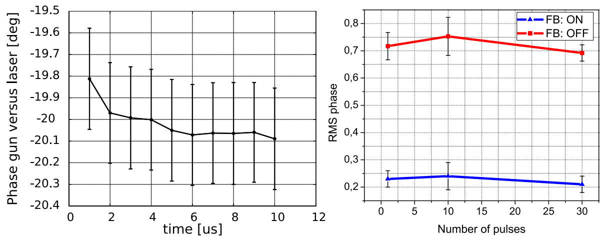
The gun phase stability measurement shown in Figures 3 to 5 were obtained for identical operating parameters of the gun. Rms phase jitter obtained from on-line monitoring tool is 0.210 deg and 0.254 deg obtained from 2D scan tool. From 2D scan tool obtained rms value of laser jitter is 1.22 %.

RF GUN PHASE STABILITY MEASUREMENT RESULTS

Stability measurement of the RF phase of the RF gun were performed for different working conditions to study the quality of the feedback system. During the study, measurements were performed by varying different parameters of the RF system such as power level, number of pulses, RF pulse flat length and for different resonance conditions.

The stability measurements based on the signals from the directional couplers only showed that the new feedback system improves the phase stability by an order of magnitude from $0.6\,\mathrm{deg}$ to $0.1\,\mathrm{deg}$ in respect to 1.3 GHz. The beam based phase stability measurement techniques shows almost the same results: the feedback system based on the new 10 MW coupler significantly improved the gun phase stability from $0.717\,\mathrm{deg}$ with feedback system switched off to $0.230\,\mathrm{deg}$ when feedback is on. The study shows that the dependence of the gun phase jitter on the peak power level in the gun is almost not measurable. For instance the rms phase jitter is $0.275\,\mathrm{deg}$ for the maximum level of 6.2 MW and it is $0.280\,\mathrm{deg}$ for 3.5 MW power with the feedback system switched on in both cases.

Increasing the number of pulses in a train does not improve the phase stability because the phase along a pulse train is not perfect constant and changes a bit from measurement to measurement. The measurements were performed for 1, 10 and 30 pulses per train. A typical phase stability along the pulse train is shown in Fig. 5 (a). The results for phase stability measurements with different number of pulses are presented in Fig. 5 (b).



(a) (b)

Figure 5: Phase along a pulse train (a), phase stability for different number of pulses (b).

Increasing the RF pulse length in the gun from $100\,\mu s$ to $300\,\mu s$ slightly increases jitter of the gun phase and results are $0.218\,\mathrm{deg}$ and $0.258\,\mathrm{deg}$ correspondingly.

In comparison with previous gun phase stability measurements [6] the rms value of gun phase jitter is improved from $2-4\,\mathrm{deg}$ to $0.2-0.3\,\mathrm{deg}$, one order of magnitude better.

STUDY OF THE GUN RESONANCE

The adjustment of gun cavity resonance is realized by precise changing of the temperature of the cooling water. The slope of the reflected power signals is an indicator of the cavity detuning. The gun cavity resonance is achieved if the mean value of reflected power signal slope is zero, but if the slope differs from zero than the gun is not in resonance. The resonant temperature for the gun is set according to the signal from the directional couplers near the T-combiner, but the signals from the 10 MW coupler and the pair of 5 MW couplers show different indications.

Tests to determine the gun resonance temperature and to study the reliability of signals from different directional couplers were performed. The tests implied beam momentum measurements while changing the gun temperature and scanning the gun phase simultaneously. The maximum beam momentum corresponds to the optimal conditions of resonance. The result shows that the gun set point temperature when set according to signals from 5 MW couplers is closer to the resonant condition than if the gun set point temperature is set according to the signal from the 10 MW coupler. The phase stability measurements for these temperature set points confirm these results. For example, the maximum power in the gun, flat length $100\,\mu s$ with feedback switched on and resonant temperature set according to signals from 5 MW couplers give a phase stability of $0.275\,\mathrm{deg}$ but for resonant temperature set according to the signal from the 10 MW coupler the phase stability is only $0.291\,\mathrm{deg}$.

SUMMARY

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

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

The new 10 MW in-vacuum directional coupler provides an efficient RF phase feedback resulting in a phase jitter of $0.2-0.3\,\mathrm{deg}$ rms which is a factor of 3 better than for the case with the feedback switched off and one order of magnitude better than results obtained with the previous gun RF system setup.

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