REPORT ON GUN CONDITIONING ACTIVITIES AT PITZ IN 2013

M. Otevrel[1], P. Boonpornprasert[2], J. Good, M. Gross, I. Isaev, D. Kalantaryan, M. Khojoyan, G. Kourkafas, M. Krasilnikov, D. Malyutin, D. Melkumyan, T. Rublack, F. Stephan, G. Vashchenko, DESY, 15738 Zeuthen, Germany
F. Brinker, K. Floettmann, S. Lederer, B. Marchetti, S. Schreiber, DESY, 22607 Hamburg, Germany
S. Rimjaem, Chiang Mai University, 50200 Chiang Mai, Thailand
G. Pathak, Hamburg University, 20148 Hamburg, Germany
D. Richter, HZB, 12489 Berlin, Germany
G. Asova, INRNE BAS, 1784 Sofia, Bulgaria
M. Nozdrin, JINR, 141980 Dubna, Russia
Y. Ivanisenko, PSI, 5232 Villigen, Switzerland

Abstract

Recently three RF guns were prepared at the Photo Injector Test Facility at DESY, location Zeuthen (PITZ) for their subsequent operation at FLASH and the European XFEL. The gun 3.1 is a previous cavity design and is currently installed and operated at FLASH, the other two guns 4.3 and 4.4 were of the current cavity design and are dedicated to serve for the start-up of the European XFEL photo-injector. All three cavities had been dry-ice-cleaned prior their conditioning and hence showed low dark current levels. The lowest dark current level – as low as 60µA at 65MV/m field amplitude – has been observed for the gun 3.1. This paper reports in details about the conditioning process of the most recent gun 4.4. It informs about experience gained at PITZ during establishing of the RF conditioning procedure and provides a comparison with the other gun cavities in terms of the dark currents. It also summarizes the major setup upgrades, which have affected the conditioning processes of the cavities.

INTRODUCTION AND OVERVIEW

The PITZ facility has been established to test and optimize photo-injector based high brightness electron beam sources suitable mainly for high energy free electron lasers (FELs). The essential required property of such electron beams is low transverse slice emittance at the undulator inlet (1.0mm·mrad, 1nC bunch charge) and reasonably small longitudinal emittance in order to be capable of providing high-gain FEL operation.

The RF Setup

The RF system provides 10 times per second a flat-top 1.3GHz RF pulse of up to ~7MW peak power (corresponding to a field amplitude at the cathode of ~62MV/m) and of up to 830µs temporal length. The RF power is supplied by a 10MW multi-beam klystron through two equal output ports. The RF waveguide distribution setup has been changed recently. The power is like before distributed by two separated waveguide systems filled with SF_6 under absolute pressure of 1.3bar. In the previous setup however the gas sides were closed by two RF windows just upstream the combining waveguide (the T-combiner), then combined in vacuum and led into the coaxial coupler of the gun. In the current setup the waves are combined in gas and separated from the vacuum side by just single RF window (10MW Thales window [1]) designed to operate at higher loads. The new setup is sketched in the Fig. 1.

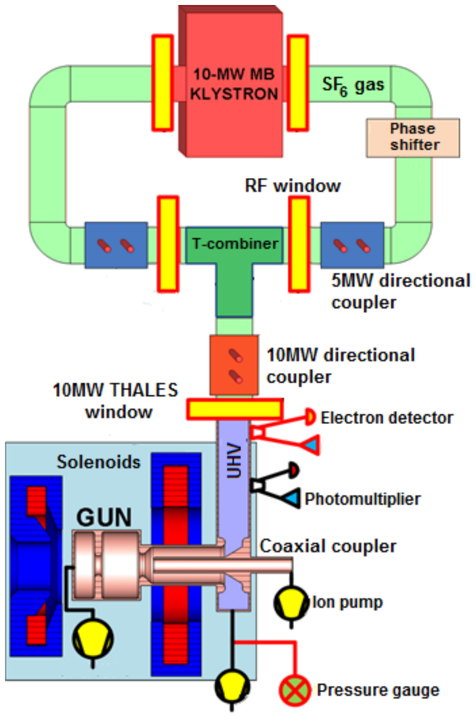

Figure 1: The PITZ RF setup.

The Gun

The RF-gun setups tested at PITZ consist of a 1.6 cell 1.3GHz normal conducting RF-gun. The RF field is fed into the cavity through an RF-window and further via a coaxial coupler. The cavity is surrounded by a main solenoid and a bucking solenoid for focusing purposes and in order to compensate space charge forces. To achieve the required ultra-high vacuum conditions the set-up is pumped via ion getter pumps (IGP) and a titanium

[1] marek.otevrel@desy.de
[2] On leave from Chiang Mai University, 50200 Chiang Mai, Thailand

sublimation pump. The interlock system which protects the RF-components from damages relies on readings of detectors like photomultipliers, electron detectors and pressure sensors.

The photo-electrons are generated from a Cs_2Te photo-cathode deposited on a Mo-plug. Cathode exchange under UHV is possible because of the usage of a load-lock system. The required RF-contact of the cathode to the RF-gun is made by an RF-contact spring positioned in the RF-gun backplane. In the past severe damages on the gun cavity occurred during operation at this place (Fig. 2 left). In order to avoid these damages a new design of the RF-contact was developed (Fig. 2 right) and tested with Gun4.3 and Gun4.4.

To keep the gun in resonance temperature there is also a water cooling system capable to control the gun temperature with a precision of 0.05K.

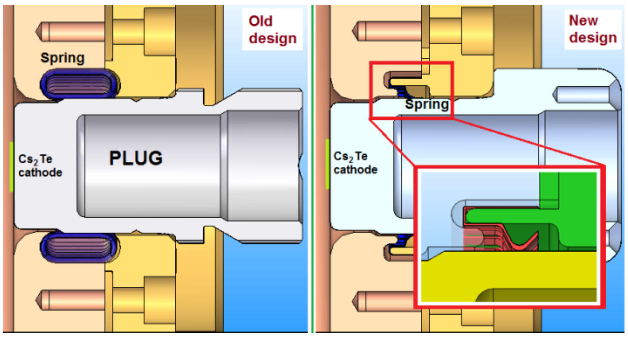

Figure 2: Cathode holding system design. Old design: left, new design: right.

Cleaning and Tuning

Due to unavoidable uncertainties during the manufacturing process, the resonant frequency and the electric field distribution inside the RF-gun has to be measured and tuned to match the goal resonant frequency and also to optimize the field ratio (E_1/E_2) between the field amplitude at the cathode plane and the field amplitude at the centre of the second cell. The optimal field ratio lies between 1.05 and 1.10 as a result of compromise between high momentum gain and enhanced peak gradient at the cathode plane causing swift initial acceleration and therefore supressing space charge effects. For that purpose there is a tuning apparatus available at DESY. (For details please see the ref. [2].)

Every newly produced and tuned RF cavity undergoes also a thorough cleaning process to remove all residuals which, if present, would cause discharges when subjected to high gradients. At DESY the so called dry ice cleaning method has been standardized. The particle and film contaminations are removed by impacting of high velocity carbon dioxide snow stream. The high-speed CO_2 particles have mechanical, thermal and chemical cleaning effects on the surface. The dry-ice cleaning method has significant advantage over the water cleaning method as it leaves no water residuals on the surfaces exposed to high gradient RF fields. This results in better vacuum parameters and allows the cavity to operate at higher gradients. More details on this subject can be found elsewhere [3].

Conditioning Process

Regardless how carefully the cleaning of the vacuum surfaces is performed, there are always some surface imperfections and contamination remaining. Therefore, before the gun can operate at its full specifications, it must undergo the so called conditioning process to remove remaining surface imperfections and contamination and to train the cavity with RF power. At the beginning of this process only a small fraction of the nominal power is loaded and then power (in peak and average) is slowly and carefully increased. This process is always accompanied with vacuum activity (increase of the pressure) inside the cavity as the contaminants and emitters are being removed from the in-vacuum surfaces. More details on the conditioning procedure may be found in [4].

Dark Current Measurements

Besides the desired photo-electrons there are also undesired electrons emitted from the gun surface caused by high gradient RF fields. At PITZ the dark current is measured using the first Faraday cup, located 0.803m downstream the cathode plane. For each RF power level (gradient amplitude) the dark current is scanned within the full range of solenoid fields and then the maximum value is taken. More details on the PITZ setup can be found elsewhere [5, 6].

GUN 4.4 TUNING AND CONDITIONING

The gun 4.4 was tuned in June 2013. The final parameters are summarized in the Table 1. The field profile of the π-mode after tuning is shown in the Fig. 3. The field ratio was tuned to be $E_1/E_2 = 1.09$.

Table 1: Gun parameters after tuning measured in air.

Parameter	π-mode	0-mode
Resonant frequency f_c [GHz]	1.300068	1.294925
Unloaded Q-value	14445	8464
Field ratio E_1/E_2	1.09	1.8
Δf_c (cathode in/out) [kHz]	292	-
Resonant temperature [ºC]	48.3	
$\Delta f_{0-\pi}$ [kHz]	5143	

The resonant frequency of the π-mode had to be modified by 1423kHz to reach the goal level of 1.3GHz. This results in predicted resonant temperature decrease by ca. 65K to the final level of 48.3ºC. The measured resonant temperature however proved to be not only higher and dependent on the average RF power, as usual, but also slowly increasing with operation time. The possible explanation of the measured resonant temperature drift may be either uncertainties in RF power measurements (as high as 10%) and/or by degrading of the cathode spring (by loosing some of the little stripes providing contact with the cathode plug) and/or by little deformation of the gun caused by non-homogenous heating and/or by uncertainty of the cathode plug axial position after re-insertion.

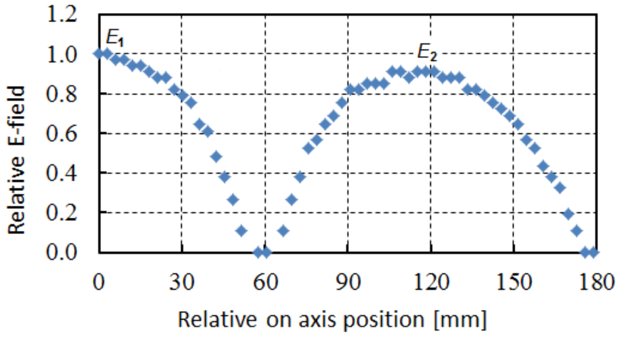

Figure 3: Measured electric field of the gun 4.4.

The Gun 4.4 has been conditioned at PITZ since October 8, 2013. The THALES window has been pre-conditioned in Hamburg before being installed at PITZ. The full specifications for the European X-FEL operation (60MV/m electric field amplitude at the cathode, 650µs RF pulse length, 10Hz repetition rate) have been met already on November 3rd, 2013 but only with a molybdenum cathode in the gun and for just ~1 hour of stable run. From December 2013 till January 2014 there were unperturbed run periods at or close to the specifications of up to 40 hours long for both Mo and Cs_2Te cathodes in the gun.

During a shutdown end of March the cathode spring was exchanged with a new one of an identical design but with gold plating and with an additional rhodium layer covering the stripes. Also a new set of cathodes with electro-polished side surfaces was installed. The motivation for the upgrade was expected better electric contacts between the spring and the cathode plug. This should result in lower level of damage in the cathode region and consequently in more stable run.

On Wednesday April 16th a pressure increase in the gun region by more than an order of magnitude was observed which later was identified as a leak between the vacuum side and the gas side of the Thales window. Due to the leak the SF_6 gas in the T-combiner section has been replaced by air at 1.3bar absolute pressure. This however resulted in increased rate of spark interlocks in the T-combiner waveguide which prevented stable operation at high average power levels.

GUN 3.1, 4.3, 4.4 COMPARISON

As many as three RF guns were conditioned and tested at PITZ in 2013 and 2014. Besides the above discussed gun 4.4 it was also the gun 4.3 (10.4.2013 - 15.7.2013) which both are meant to serve as start-up guns for the European X-FEL and finally the gun 3.1 (10.11.2012 - 21.2.2013) which is currently operating at FLASH. The gun 3.1 is of the older gun and spring design but dry-ice-cleaned.

Dark Current

Due to the dry ice cleaning method the dark current emitted from the discussed guns was more than an order of magnitude lower than for those in the past which did not undertake such treatment [7]. For fully conditioned cavities and cathodes dark current is in most cases below 100µA even at high field gradients exceeding 60MV/m. For comparison see the representative selection of dark current measurements for all three gun cavities in the Fig. 4.

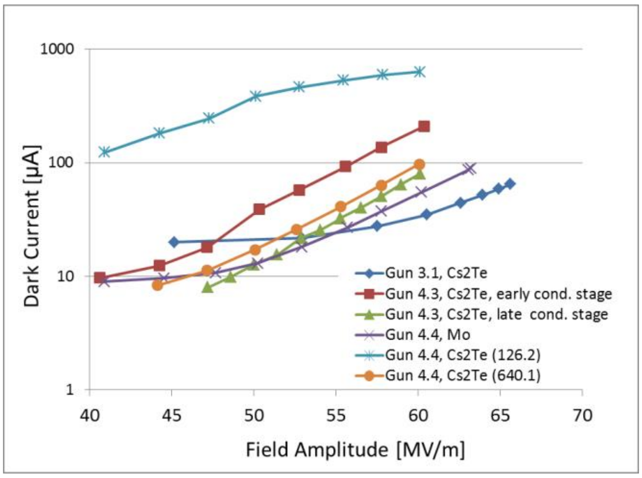

Figure 4: Comparison of the measured dark currents as a function of electric field amplitude.

REFERENCES

[1] Thales Group, 45 rue de Villiers, 92526 Neuilly-sur-Seine, Cedex, France, www.thalesgroup.com.

[2] A. Oppelt et al., "Tuning, conditioning, and dark current measurements of a new gun cavity at PITZ", FEL'06, Berlin, Germany, August 2006.

[3] D. Proch et al., "Dry ice cleaning for SRF applications", 10th Workshop on RF Super-conductivity, Tsukuba, Japan, September 2001.

[4] I. Isaev et al., "Conditioning status of the first XFEL gun at PITZ", FEL'13, New York, USA, August 2013.

[5] F. Stephan et al., Phys. Rev. ST Accel. Beams 13, 020704 (2010).

[6] M. Otevrel et al., "Conditioning of a new gun at PITZ equipped with an upgraded RF measurement system", FEL'10, Malmö, Sweden, August 2010.

[7] F. Stephan et al., "New experimental results from PITZ", LINAC'08, Victoria, Canada, 2008.