# CONDITIONING STATUS OF THE FIRST XFEL GUN AT PITZ

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*Abstract*

The paper describes the recent results of conditioning and dark current measurements for the photocathode RF gun at the photoinjector test facility at DESY, Zeuthen site (PITZ). The aim of PITZ is to develop and operate an optimized photo injector for free electron lasers and linear accelerators which require high quality beams. In order to get high gradients in the RF gun extensive conditioning is required. A data analysis of the conditioning process is based on data saved by a Data Acquisition system (DAQ). Conditioning results of the first gun cavity for the XFEL is presented. The events which occurred during the conditioning are briefly described.

## INTRODUCTION AND OVERVIEW

The photo injector test facility at DESY, Zeuthen site (PITZ) has been built for the development, testing and optimization of high brightness electron sources for FELs like FLASH and the European XFEL.

The 1.6 cell normal conducting (copper) cavity with the $Cs_2Te$ photocathode serves as an electron source at PITZ for its subsequent application at superconducting linac based FELs. Several gun prototypes were conditioned and characterized at PITZ and successfully operated at FLASH. Recently the first gun (Gun 4.3) for the European XFEL [1] was conditioned in Zeuthen as well.

The gun life cycle includes following stages: production (fabrication) → tuning → dry-ice cleaning → RF conditioning → characterization.

Conditioning was done from the end of spring to the middle of summer 2013. The main goal of the conditioning was to reach 6 MW peak power in the gun at a 650 $\mu$s RF pulse length and a 10 Hz repetition rate. This corresponds to the average RF power of 39 kW. The gun was conditioned and tested together with the upgraded RF waveguide distribution system, which close to the gun is similar to the one to be installed at the European XFEL. The previous setup of two 5-MW vacuum windows was replaced by one of the 10-MW THALES [2] vacuum windows which was installed downstream the 10-MW directional coupler for power measurements and low level RF control.

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The gun was built in 2012 and later the new RF cathode spring design was applied. Afterwards the gun was dry-ice cleaned [3]. On the 18th of March 2013 the gun was installed in the PITZ tunnel and RF conditioning was performed from the $10^{\text{th}}$ of April to the $15^{\text{th}}$ of July 2013. A Molybdenum (Mo) cathode plug was inserted during the RF conditioning instead of the $Cs_2Te$ cathode plug, used for photoelectron production, in order to prevent destruction of the $Cs_2Te$ coating on the cathode surface. This coating is very sensitive to the vacuum pressure. Also effects like the field emission of electrons from rough surface, multipacting or sparks can damage it. In the case of such events, the gun interlock system (IL) [4] consisting of different detectors will switch off the RF feed to the gun.

The gun conditioning setup consisting of a 10-MW klystron, an upgraded RF waveguide distribution system, a 10-MW THALES vacuum window, directional couplers, Ion Getter vacuum Pumps (IGP) and Pressure Gages (PG), photomultipliers (PMT) and electron detectors (e-det) located around the gun coupler is presented in Fig. 1.

## CONDITIONING PROGRAM AND DATA ANALYSIS

The main goal of the conditioning process is the cleaning of the in-vacuum surfaces to get rid of residual contamination from previous production and cleaning steps. This process is accompanied by the increased vacuum pressure level at the beginning of the conditioning. The vacuum pressure later decreases, but single vacuum spikes happened up to the end of the conditioning. The vacuum activity is a normal conditioning behavior and means that the conditioning process as long as there is no leak in the vacuum system.

The applied conditioning procedure is based on the conditioning requirement of the THALES window includes following principles:

- RF pulse length: 10 – 650 $\mu$s.
- RF power increase in steps of max 0.2 MW every 15 min for each new RF pulse length.
- Vacuum pressure must be below $10^{-7}$ mbar.
- In the case of significant vacuum events or other trips:
  - restart with the shortest RF pulse length (10 $\mu$s).
  - increase the pulse length in reasonable steps.
- Initially, the RF gun solenoid is off.



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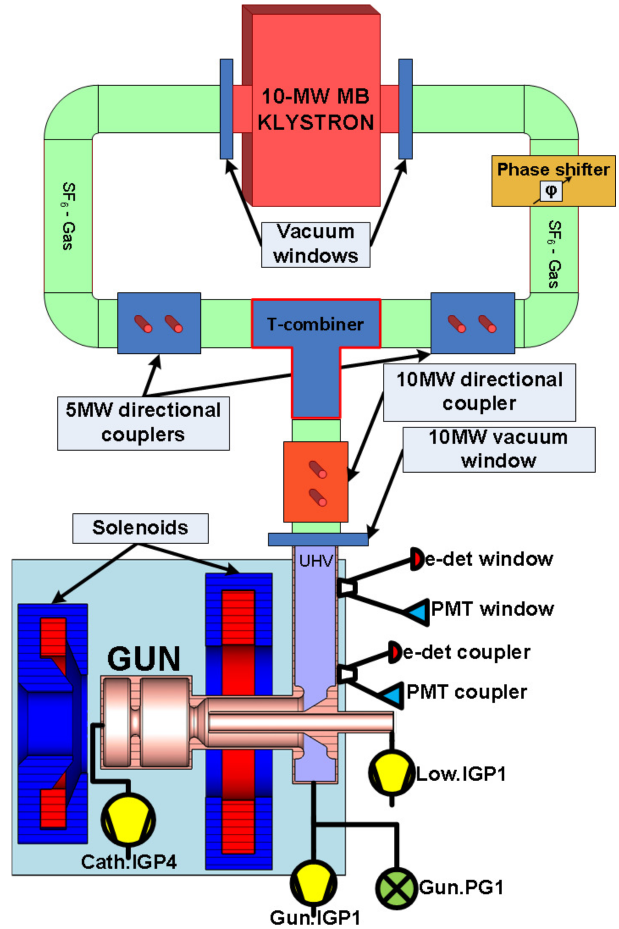


Figure 1: Gun conditioning setup: gun and RF system overview, vacuum pumps and IL detector locations.

- When conditioning without solenoid is finished repeat conditioning with solenoid sweeping.
- A good trip rate is less than 1 interlock per week.

The maximum operated forward power was 6 MW for a RF pulse lengths above 200 $\mu$s and 6.5 MW for pulse length less or equal to 200 $\mu$s. This restriction is driven by the installed THALES vacuum window which was preconditioned only up to 6 MW forward power (almost without reflected power).

All important information about the gun operation such as power, vacuum pressure, machine parameter settings, spectra of interlock detectors etc. was recorded to a special storage via the Data Acquisition (DAQ) system. The PITZ DAQ system allows saving all of possible events and data with the required repetition rate for each parameter. For example, all spectra must be saved with a repetition rate of 10 Hz, whereas it is sufficient to save the value of the RF pulse length with a repetition rate of 1 Hz only. The DAQ system provides an opportunity for the combination of different types of data to a single file making data analysis easier. Recorded data were analyzed by means of tools which are developed in the numerical computing environment MATLAB [5]. Data analysis allowed not only the collection of the gun operation statistics but also the observation of particular gun subsystems and a running problem investigations.

## RF CONDITIONING

According to the applied conditioning procedure, the following steps were completed:

- The maximum power was achieved at 10 → 20 → 50 → 100 $\mu$s RF pulse length for a 5 Hz repetition rate
- The maximum power was achieved at 10 → 20 → 50 → 100 → 200 → 400 → 650 $\mu$s RF pulse length for a 10 Hz repetition rate

### *Power History and Statistics*

Total run time can be divided into three periods:

- slow conditioning progress at the beginning of the run (5 Hz repetition rate)
- good conditioning progress (switched from 5 to 10 Hz repetition rate)
- bad conditioning progress (almost no progress) after the cathode was exchanged for first time from Mo to $Cs_2Te$

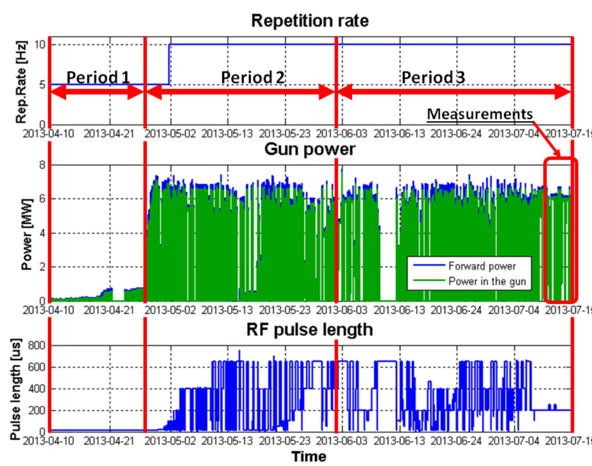


Figure 2: History of the Gun 4.3 conditioning. Top – Repetition rate, middle – forward power and power in the gun, bottom – RF pulse length.

The power history of the conditioning of Gun 4.3 is presented in Fig. 2. The first period of the conditioning is typical: progress in power increase is small, approximately 50kW per week. Such a process takes about 1–2 weeks. In case of Gun 4.3 it was around 15 days. At this time conditioning was ongoing with a 5 Hz repetition rate and the shortest RF pulse length (10 $\mu$s). The second period of the conditioning process started with extremely high growth of the power in the gun (4–5 MW within 18 hours) but still at a 5 Hz repetition rate and at 10 $\mu$s pulse length. After all steps at 5 Hz repetition rate were finished and the system was switched to 10 Hz. The conditioning process was continued normally. It takes about 1–2 months to reach

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the goal parameters. For Gun 4.3 conditioning has taken around 30 days (in Fig. 2 the time for this part is from 28$^{th}$ of April 2013 to 30$^{th}$ of May 2013). The third period of the run started from the time when the cathode was exchanged from Mo to $Cs_2Te$ for the first time, for production of photoelectrons. After this time, conditioning has not shown any further progress. The main reason was interlocks caused by the photomultiplier located in the gun RF coupler.

Most of the time the gun was running at a peak power level above 4 MW peak power and up to 14 kW in average power the gun. Results of statistical analysis of Gun 4.3 run time at different power levels are shown in Fig. 3 (for peak power) and Fig. 4 (for average power). The bottom plots show the RF power exposure time, i.e. the time the cavity has been operating at the given power or higher.

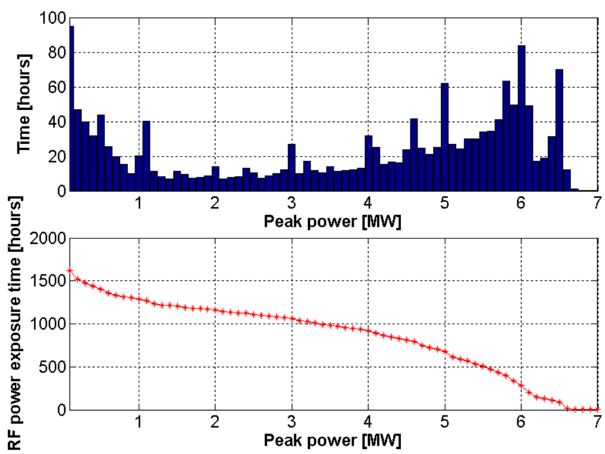


Figure 3: Gun 4.3 run statistics for peak power in the gun cavity.

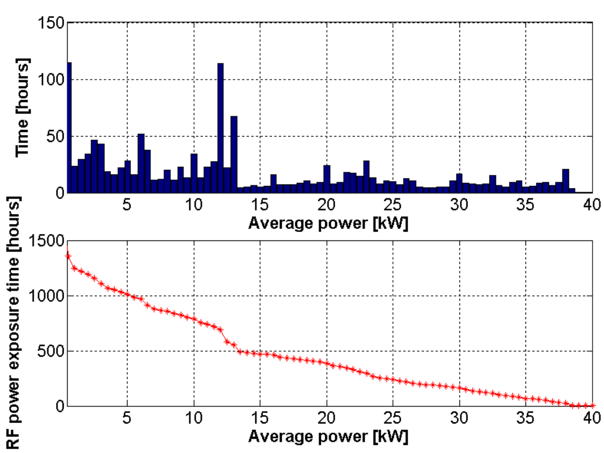


Figure 4: Gun 4.3 run statistics for average power in the gun cavity.

A comparison of the normalized statistics of Gun 4.3 with guns (Gun 3.1 and Gun 4.1) which were previously installed at PITZ [6, 7] is presented in Fig. 5. The plot shows that, as opposed to Gun 3.1 and Gun 4.3, Gun 4.1 was operated mainly at power level of 5.5–6.5 MW in the gun.

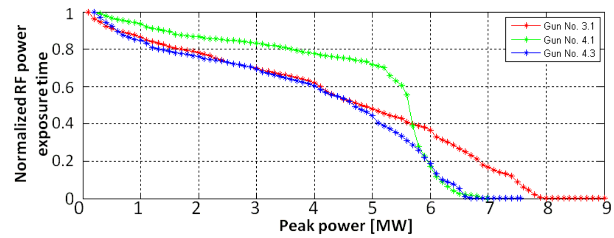


Figure 5: Comparison of the normalized RF exposure time for Gun 3.1, Gun 4.1 and Gun 4.3.

### *IL Statistics*

In Fig. 6 the percentage ratio of different interlock signals for different parts of the conditioning process is presented. The sum of percentages for the different interlocks is larger than hundred percents because some of the interlocks were recorded by a few IL detectors simultaneously. The statistics show that the main reason for interlocks was e-det coupler and PM coupler detectors for the 2$^{nd}$ and the 3$^{rd}$ run periods correspondingly. However, during the 1st run period, together with PM coupler and e-det coupler interlocks, the Gun IGP1 interlock was observed in 25 % cases of all events.

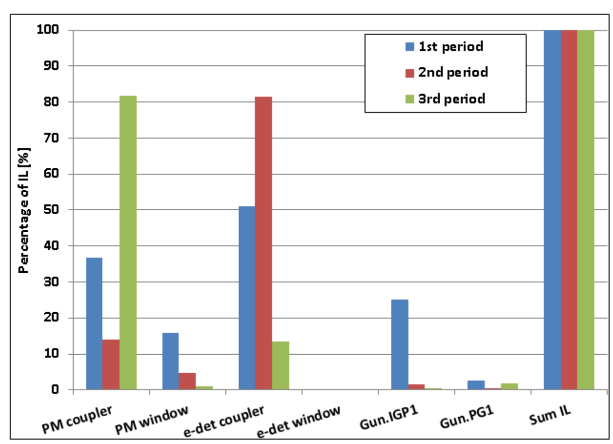


Figure 6: Percentage of interlocks for different periods of the gun conditioning.

### *Operation with Solenoid*

The final goal of the gun conditioning was the achievement of the maximum power level in the gun with solenoid fields. Solenoid sweep maps were applied for different combinations of the solenoid current, pulse length and power in the gun, in order to complete conditioning for all possible gun operation conditions.

The history plot of the main gun solenoid current is presented if Fig. 7. All possible regions of the solenoid current for different power levels were successfully conditioned. Only in one region (30–50 A main solenoid current and 0–2 MW power) a slight increase in the vacuum activity was



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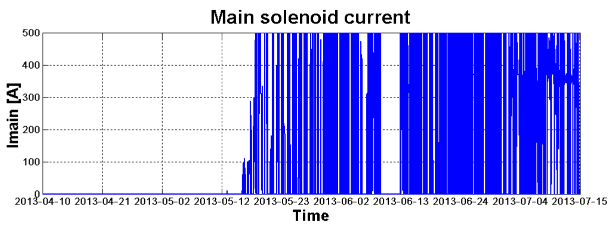


Figure 7: Main solenoid current history during gun conditioning.

observed. However, this activity is far below the vacuum IL threshold level.

### *Vacuum Activity*

The history of the gun vacuum activity for vacuum pumps around the gun cavity is presented in Fig. 8. The gun conditioning process started with high vacuum activity which fell towards the end of the 2nd part of the conditioning (Fig. 8 blue line – gun PG and green line – gun IGP 1). After exchanging the cathode the vacuum level in the gun was spoiled. Also, at that time, activity behind the cathode started (Fig. 8 orange line – cathode IGP 4). This activity depended strongly on the cathode insertion.

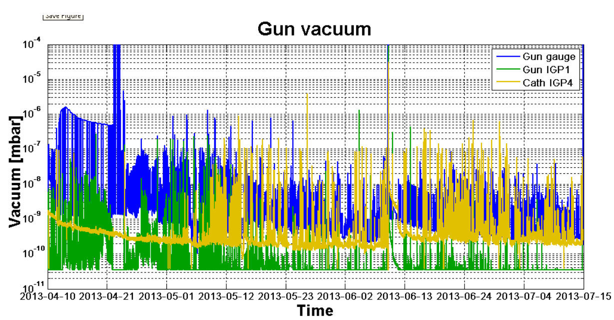


Figure 8: Vacuum activity during gun conditioning.

## DARK CURRENT MEASUREMENTS

The main gun dark current sources are in different parts of the gun cavity surface, such as the photocathode area, gun cavity walls, and irises. The biggest part of the dark current which could be observed at the first screen, located 0.8 m downstream of the cathode, comes from the area around the cathode. Fig. 9 shows a dark current image for 6.5 MW power in the gun at 200 $\mu$s and a main solenoid current 450 A.

The dark current has been measured using the Faraday Cup, located at the same position as the first observation screen. The maximum value from a solenoid scan curve was taken as the measurement result for the given power level and RF pulse length. For a several days the dark current was observed in order to see how it developed in time (Fig. 10). The final measurement, which was done on the last run day, showed a dark current of 80 $\mu$A that is comparable with values from former guns of the same type (Gun 4.1 [7] and Gun 4.2 [8]).

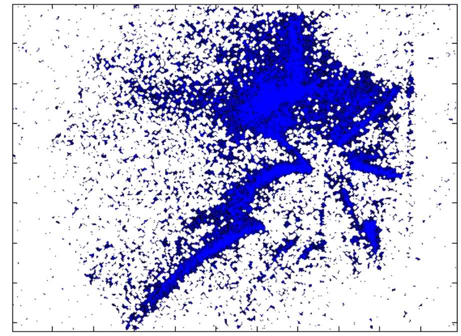

Figure 9: Dark current at the first observation screen.

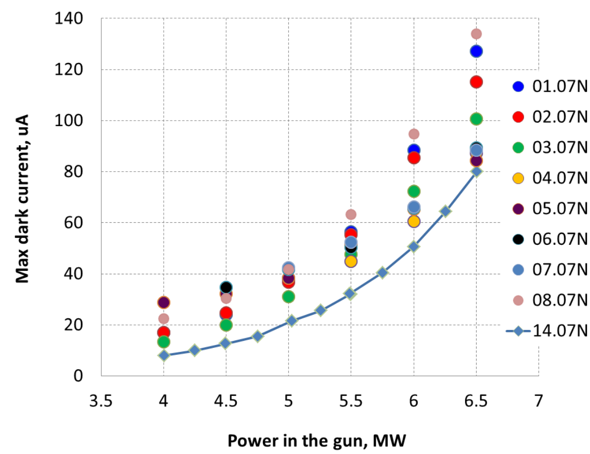


Figure 10: Maximum dark current dependence on the peak power in gun on different days.

The dark current measurements at different peak power levels in the gun as a function of the main solenoid current, which have been performed on the last day of the run, are presented in Fig. 11.

## SUMMARY

The start-up gun cavity (Gun 4.3) for the European XFEL project has been conditioned at PITZ. A new conditioning procedure was tested and applied. Results of the conditioning and dark current measurement results have been presented in this paper. The gun has been delivered to Hamburg end of July 2013 to perform tests on the new waveguide distribution system at the injector of the European XFEL in autumn 2013.

The maximum peak power reached was 6.5 MW in the gun at 200 $\mu$s RF pulse length and 6 MW at 650 $\mu$s RF pulse length, 10 Hz repetition rate in both cases. The main reason for interlocks is the photomultiplier located in the RF coupler. The dark current measured at the end of the run showed values comparable with previous measurements for the same type of guns.

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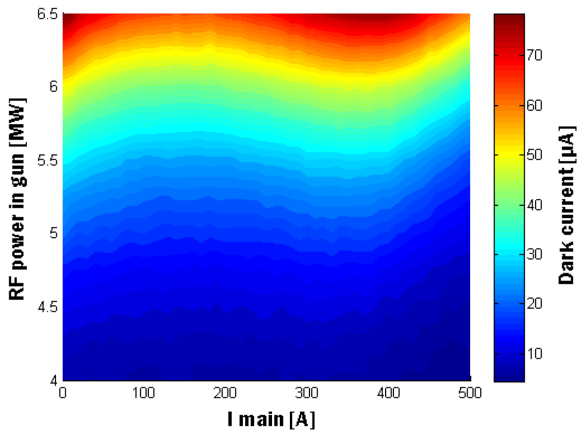


Figure 11: Dark current measurements at different peak power level in the gun vs. main solenoid current.

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