

# LATEST NEWS ON HIGH AVERAGE RF POWER OPERATION AT PITZ

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## Abstract

The Photo Injector Test Facility at DESY in Zeuthen (PITZ) develops, tests and characterizes high brightness electron sources for FLASH and European XFEL. Since these FELs work with superconducting accelerators in pulsed mode, also the corresponding normal-conducting RF gun has to operate with long RF pulses. Generating high beam quality from the photocathode RF gun in addition requires a high accelerating gradient at the cathode. Therefore, the RF gun has to ensure stable and reliable operation at high average RF power, e.g. 6.5 MW peak power in the gun for 650  $\mu$ s RF pulse length at 10 Hz repetition rate for the European XFEL. Several RF gun setups have been operated towards these goals over the last years. The latest gun setup was brought into the PITZ tunnel on February 10th 2016 and its RF operation started on March 7th. This setup includes RF gun prototype 4.6 with a new cathode contact spring design and an RF input distribution which consists of an in-vacuum coaxial coupler, an in-vacuum T-combiner and 2 RF windows from DESY production. In this contribution we will summarize the experience from the RF conditioning of this setup towards high average RF power and first experience from the operation with photoelectrons.

## RF FEED SYSTEM AND GUN 4.6

The RF waveguide distribution system used with gun 4.6 is the two vacuum windows configuration as shown in Fig. 1. This two RF windows solution was installed in 2014 [1] after several break-downs of RF windows in the previous configuration where only one RF vacuum window was used. This solution has the particularity to have the 10 MW directional coupler and the T-combiner in vacuum. Along with the gun installation, two recoated and pre-conditioned DESY RF windows and a new T-combiner have been installed during the winter 2016. A short section with air under 3 bar pressure is realized between the SF<sub>6</sub> gas and the vacuum section, to have an easy exchange between two different setups and to be as close as possible to the XFEL and FLASH setups where there is no SF<sub>6</sub> but air waveguides. This section is also an additional safety, acting as a buffer in case of a leak in the gas vacuum windows, preventing any SF<sub>6</sub> to reach the vacuum system.

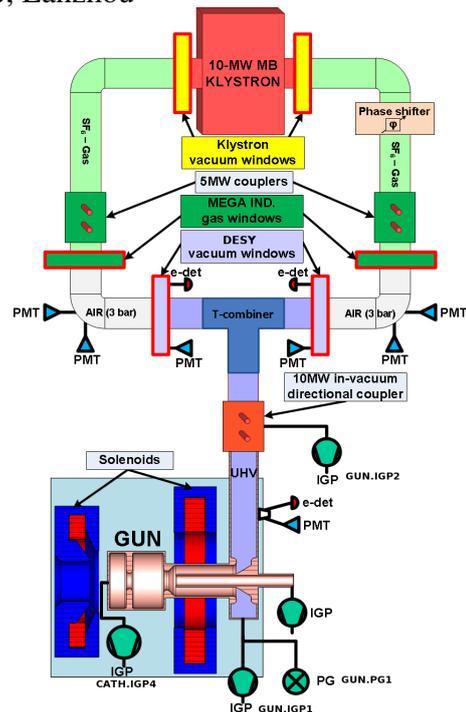


Figure 1: PITZ RF feed system in a two vacuum windows configuration.

The gun 4.6 is a new cavity and uses the new watchband-reloaded cathode spring design [2] where the cathode region has been optimized to avoid any sharp edges. In the original design, sharp edges could be damaged during cathode manipulations and high power operation. The cathode plug is electro-polished to avoid damages to the contact spring e.g. caused by bad contact with the cathode or by discharges. As usual, the gun is dry-ice cleaned to reduce the dark current [3].

## CONDITIONING

The standard procedure applied for conditioning of RF guns is described in [4]. The control system used is based on DOOCS [5]. Relevant properties are stored by the Data Aquisition system (DAQ). This data is then analyzed to get statistics on conditioning and operation.

The interlock (IL) system of gun 4.6 stops operation in a few microseconds (within the RF pulse) when signals from photomultipliers (PMTs), electron detectors or reflected

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power (measured by directional couplers) exceed their respective thresholds. Vacuum pressures (measured by IGP and PGs) are also monitored, but as they are slow signals (few Hz data rate), they only can interrupt operation between RF pulses. The position of the IL sensors are shown in Fig. 1.

Figure 2 shows the fractional operation time for a given pulse length and power in the gun 4.6 from the first day of conditioning (7.3.2016). The repetition rate was switched from 5 Hz to 10 Hz on 8.4.2016, the solenoid sweep started on 3.5.2016 and the first photo-electrons were produced on 9.6.2016.

It took 6 weeks to reach reliably full power at 100  $\mu$ s RF pulse length and 16 weeks to reach XFEL nominal parameters (6.5 MW at 650  $\mu$ s RF pulse length) with gun 4.6. This evolution is comparable to the previous guns.

## OPERATION

From the 18<sup>th</sup> week, the uptime (fraction of operation time over 6 MW at over 600  $\mu$ s RF pulse length) was above 40%. The goal is to reach an acceptable level for an FEL user facility (uptime  $\geq$  99%). The uptime has increased up to now, reaching 85% in the 24<sup>th</sup> week and 82% in the 26<sup>th</sup> week. The fact that the gun can be operated longer at high peak power and long RF pulse length shows that there is still a conditioning effect induced by the RF and that further improvement can still be expected.

IL data from the DAQ for the full run of gun 4.6 was also analyzed. Periods when there was less than 100 kW power in the gun are not taken into account neither for counting ILs nor for the operation run time. The interlock rate is calculated as the number of ILs divided by the total operation time during a given period. As several sensors can be triggered together during an IL, all signals from IL sensors switching to an active state within a 10 s window are accounted for the same IL event to avoid any double counting.

When looking at the type of interlocks and their rates for every week of gun 4.6 operation (as shown in Fig. 3), mainly vacuum trips and maximum reflection ILs were interrupting the operation during the first four weeks. From the 5<sup>th</sup> week of conditioning to the 12<sup>th</sup>, mainly the PMT looking at the vacuum window in waveguide 1 (its sensitivity was decreased in the 9<sup>th</sup> week) and vacuum ILs interrupted the conditioning. From the 13<sup>th</sup> week, PMTs in the air side of WG2 were the limiting factor (their threshold was decreased in the 15<sup>th</sup> week). On the 23<sup>rd</sup> week, after 2 weeks of shutdown, the number of interlocks from PMTs in the air side of WG2 increased a lot for a few days and then suddenly disappeared. We assume that a field emitter due to a micro-protrusion on the vacuum window had been conditioned away, but visual inspections were not conclusive. From the 15<sup>th</sup> week, there were only few vacuum trips, which indicates that the new watchband-reloaded design of the cathode region was successfully preventing strong discharges.

It has been possible to reach more than 80% uptime with close to the nominal parameters despite the quite high number of trips ( $>5$  d<sup>-1</sup>). The uptime could also be increased

by an improve start-up procedure. The rapid recovery technique [6] modulates the RF frequency to follow the cavity resonance during the ramp-up. This technique allows to reach the nominal power and pulse length in  $\sim$ 5 min instead of the usual  $\sim$ 40 min. It was demonstrated at FLASH in 2012 and since 2015 it has been improved at PITZ and XFEL. Its usage at PITZ for normal operation started during the 23<sup>rd</sup> week from startup. It is also planned to use it at XFEL.

## ELECTRON BEAM MEASUREMENTS

The emittance of the electron beam produced by the gun 4.6 has been measured using the slit scan technique [7]. A 11 ps to 12 ps Full Width Half Maximum (FWHM) Gaussian laser was used to extract a charge of 0.5 nC while the power in the gun was 6.5 MW (corresponding to a gradient at the cathode of 60 MV/m and a beam momentum of 6.5 MeV/c). For each measurement, the solenoid current has been optimized, then 10 consecutive measurements have been done to get statistics for the setup with the smallest emittance value. Table 1 summarizes the measurements made up to now.

$p_z$ boo (MeV/c)	BSA (mm)	$I_{main}$ (A)	$\epsilon_{xy}$ (mm.mrad)	FWHM bunch length (ps)
23.3	1.2	387	$0.87 \pm 0.03$	$17.1 \pm 0.4$
20.9	1.2	392	$0.80 \pm 0.04$	$16.3 \pm 0.4$
23.4	1.1	391	$0.90 \pm 0.07$	$18.3 \pm 0.6$

Table 1: Emittance and FWHM bunch length measured for different powers in the booster (resulting in different beam momentum  $p_z$  boo) and laser spot diameters at the cathode (Beam Shaping Aperture or BSA). The solenoid current ( $I_{main}$ ) has been optimized for the best emittance.

These emittance numbers are better than the specifications for the commissioning of the European XFEL (1 mm mrad@0.5 nC) and are comparable to previous guns [1]. The smallest emittance was obtained with a reduced booster power as predicted by simulations [8]. The smallest bunch length of 16.3 ps measured by the transverse deflecting structure [9] corresponds to a peak current of  $\sim$ 32 A.

## CONCLUSION

After  $\sim$  4 months of conditioning, gun 4.6 reached XFEL specification (6.5 MW@650  $\mu$ s RF pulse length and 10 Hz repetition rate). Despite the  $\sim$  5 ILs per day observed during the last weeks (e.g week 20, 24, 26 and 28), the rapid recovery technique used at PITZ is helping to increase the uptime. After 6 months of conditioning and operation, there were no problems anymore with the RF windows, proving that the 2 windows solution works. Also, as no signature of cathode spring failure has been observed, it seems that the new watchband-reloaded design of the cathode region works successfully.

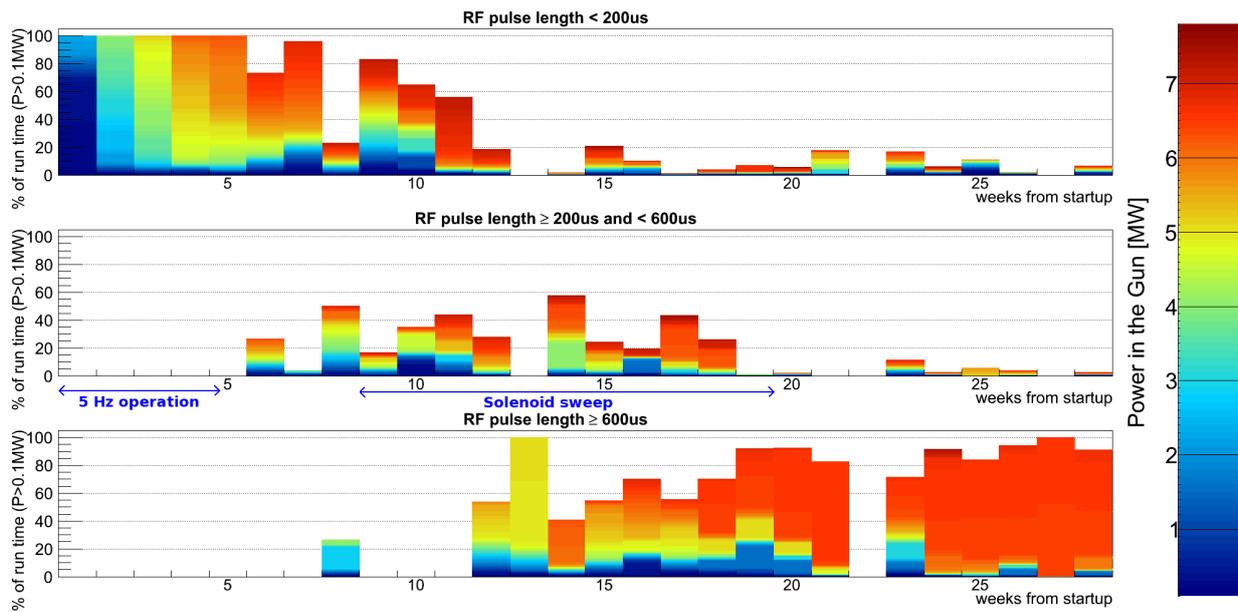


Figure 2: Weekly percentage of gun 4.6 operation time spent at different RF pulse lengths. The color code provides further information about the time spent at different power levels. Weeks 7, 13, 14, 21, 22, 25 and 27 have little operation time (shutdowns).

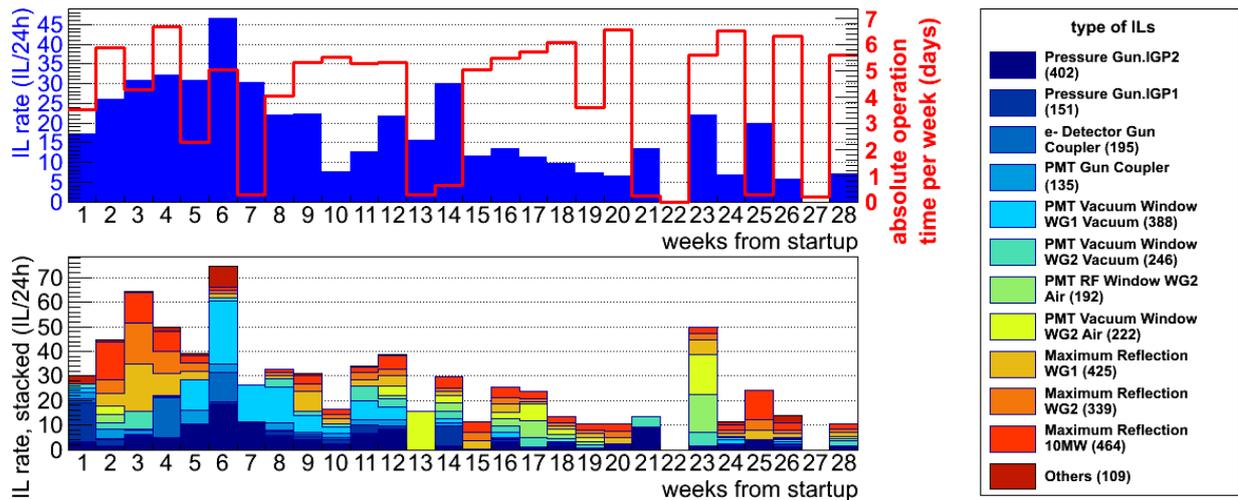


Figure 3: Rate of ILs for every week of operation of gun 4.6. Top plot: Blue bars are the total number of ILs per 24 h of operation, when the power in the gun is more than 100 kW. No double counting when several ILs were triggered in the same event. The red line shows for every week the number of days of operation. Bottom plot: Number of ILs per 24 h for each of the main ILs. If several ILs happen at the same time, they are all counted individually (double counting). The total number of ILs over the full conditioning period is shown for each IL sensor in the legend. For the first 6 weeks, maximum reflection ILs may be missing.

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