STATISTICS ON HIGH AVERAGE POWER OPERATION AND RESULTS FROM THE ELECTRON BEAM CHARACTERIZATION 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 photo-cathode 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 µs RF pulse length and 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 is in operation since March 2016 and includes RF Gun 4.6 with an improved contact spring design. The RF input distribution consists of a coaxial coupler, a T-combiner and 2 RF windows from DESY production. In this contribution we will present statistics on the high average power operation and results from the characterization of the produced electron beam.

RF FEED SYSTEM AND GUN 4.6

The RF wave-guide distribution system used with Gun 4.6 is the two vacuum windows configuration as shown in Fig. 1. Such a two RF windows solution was re-installed in 2014 after several break-downs of RF windows in the previous configuration where only one RF vacuum window was used [1]. The current solution has the particularity to have the 10 MW directional coupler and the T-combiner in vacuum. Along with the gun installation, two re-coated and pre-conditioned DESY RF windows and a new T-combiner have been installed. The postion of the vacuum windows has been optimized to minimize the maximum field strength on the ceramic [2]. A short section with air under 3 bar pressure is realized between the SF_6 gas and the vacuum section, to allow for an easy exchange between different setups and to be as close as possible to the XFEL and FLASH setups which

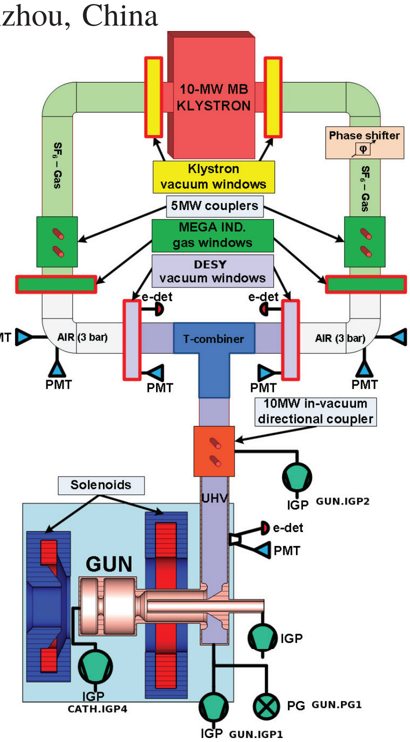

Figure 1: PITZ RF feed system in a two vacuum windows configuration.

use air-filled RF distribution systems. This section is also an additional safety, acting as a buffer in case of a leak in the windows, preventing any SF_6 to reach the vacuum system.

The Gun 4.6 is a new cavity and uses the new watchband-reloaded cathode spring design [3] 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 [3]. 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 [4].

OPERATION

The RF feed system of Gun 4.6 and its conditioning is described in [1]. The control system used is based on DOOCS [5]. Relevant properties are stored by the Data

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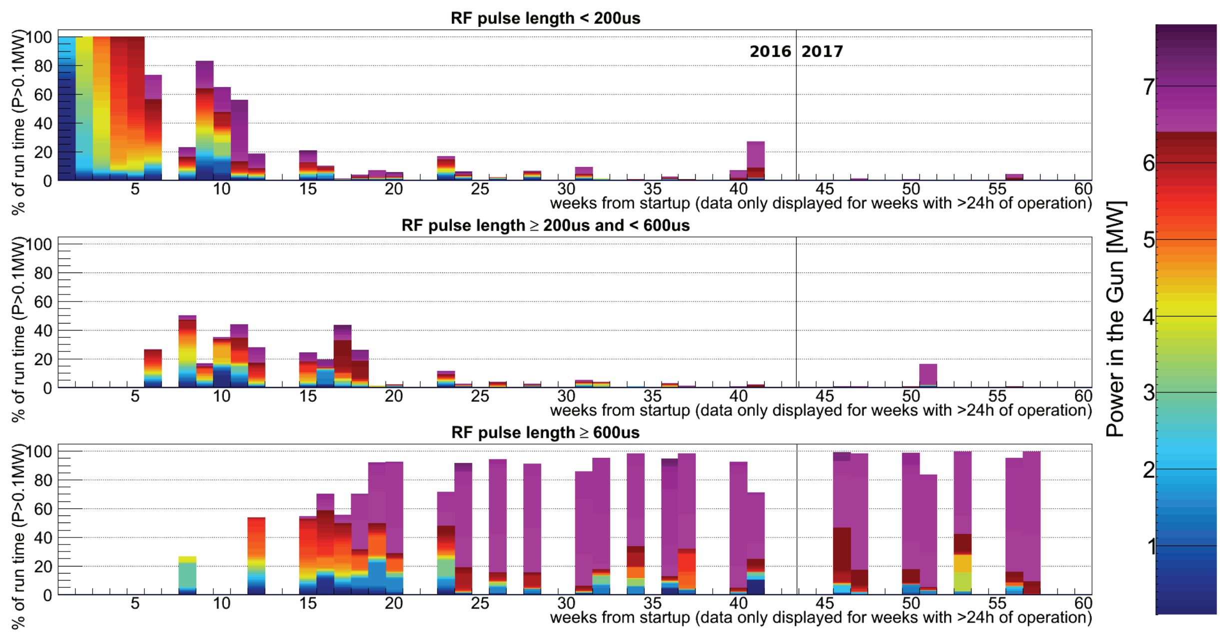

Figure 2: Weekly percentage of Gun 4.6 operation time spent at different RF pulse lengths. The color code provides further information about the time spent at different power levels. Weeks with less than 24 h operation time are not shown.

AQuistion 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 photo-multipliers (PMTs), electron detectors or reflected power (measured by directional couplers) exceed their respective thresholds. Vacuum pressures measured by Ion Getter Pumps (IGPs) and Pressure Gauges (PGs) are also monitored, but as they have slow signals (few Hz data rate), they only can interrupt operation between RF pulses.

Figure 2 shows the fractional operation time for a given pulse length and power in Gun 4.6 from the first day of conditioning (7.3.2016). The conditioning period was up to week 28, as previously reported [1]. After that, the uptime (fraction of operation time over 6 MW at over 600 µs RF pulse length) have been above 80% for most weeks. The weeks with lowest runtime are weeks with specific measurements which required lower power in gun. The goal is to reach an acceptable level for an FEL user facility (uptime ≥ 99%). That goal was almost reached in week 56 (with 98.9%) which was the first run time since conditioning where operation at nominal parameters was scheduled for the full week. We also observed comparable reliability for shorter periods when aiming at nominal parameters. That demonstrates that the design of Gun 4.6 allow to reach XFEL nominal parameters with a good reliability.

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.

The type of interlocks and their rates for every week of Gun 4.6 operation is shown in Fig. 3. Discussion for the conditioning period (up to week 28) has been previously reported [1]. Light has been observed for a few days near the vacuum window on week 31. The problem (probably caused by a mico-protusion acting as a field emitter) looked similar to the one in week 23 as inspection did not reveal the reason and the problem was quickly conditioned away. The interlock rate during operation has a small decreasing trend (from ~6 IL/24h down to ~3 IL/24h from week 32 to week 57).

After the troubles in week 23, the PMTs in the air side of the second wave-guide (WG2) were disabled from week 24 to week 50. They were subsequently re-enabled and did not impact operation anymore.

Starting from the beginning of 2017 (in week 45) a new interlock feature, called interlock counter, has been implemented. With the interlock counter feature active, the next RF pulses after an interlock from a fast sensor are enabled unless a second interlock happens within 1 s. The interlock counter prevents the interruption of operation when the 100 ms between RF pulses are enough for the gun to recover from a breakdown. In Fig 2, the interlocks which only stop the operation for a part of a RF pulse are included as normal IL. An interface with the control system and DAQ is under development to allow for that distinction. Nevertheless, it was found that during week 58, half of the interlocks did not interrupt operation thanks to the interlock counter.

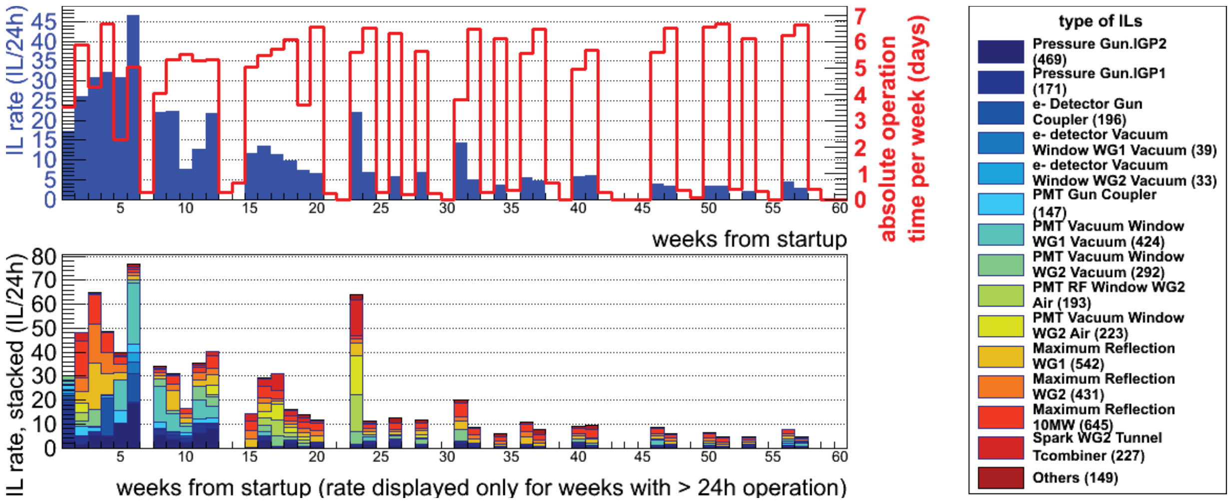

Figure 3: Rate of ILs for every week of operation of Gun 4.6. Top plot: Blue bars are the total number of ILs per 24 h of operation for weeks with more than 24 h operation, when the power in the gun is more than 100 kW. No double counting when several ILs were triggered in the same event. The red line 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). Only weeks with more than 24 h operation time are shown. The total number of ILs over the full period is shown for each IL sensor in the legend. For the first 6 weeks, maximum reflection ILs might be missing.

It has been possible to reach ~ 99% uptime despite the significant number of trips (~3 IL/24h) thanks to a fast ramping technique [6] which modulates the RF frequency to follow the cavity resonance during the ramp-up and also to the reduced number of interruptions prevented by the interlock counter.

ELECTRON BEAM MEASUREMENTS

The projected transverse emittance of the electron beam produced by Gun 4.6 has been measured using the slit scan technique [7]. The photo-cathode laser used was uniform transversely and Gaussian longitudinally with a 11 ps to 12 ps Full Width Half Maximum (FWHM) duration. 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. 10 consecutive measurements have been done to get statistics for the settings with the smallest emittance value. The electron bunch length has also been measured [8] using a Transverse Deflecting Structure (TDS). Table 1 summarizes the result for 100 pC and 500 pC extracted charge.

Table 1: Optimized emittance and FWHM length measured for different charge Q. The solenoid current I_{main} and the laser spot diameter at the cathode $\oslash_{laser}$ have been optimized for the best emittance.

Q (pC)	$\oslash_{laser}$ (mm)	I_{main} (A)	ϵ_{xy} (mm.mrad)	FWHM bunch length (ps)
100	0.8	386	0.37 ± 0.01	11.9 ± 0.3
500	1.2	392	0.80 ± 0.04	17.1 ± 0.4

The dark current has been monitored and stayed close to 150 µA with 6.5 MW in the gun.

CONCLUSION

After ~ 4 months of conditioning, Gun 4.6 reached XFEL specification (6.5 MW@650 µs RF pulse length and 10 Hz repetition rate). Uptime up to 98.9% and emittances compatible to FEL have been observed. The gun is planned to be shipped to the European XFEL later this year.

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