HIGH AVERAGE RF POWER TESTS WITH 2 RF VACUUM WINDOWS AT PITZ

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Abstract

The Photo Injector Test facility at DESY, Zeuthen site (PITZ), was built with the aim to develop and characterize electron sources for future usage at FLASH and at the European XFEL.

Recently, the main focus at PITZ has been the study of gun reliability and photoinjector performance at high average power. The goal is to get stable and reliable operation with 6.4 MW peak power in the gun at 650 µs RF pulse length and 10 Hz repetition rate. To achieve this, a new RF feed system with two RF windows was installed at PITZ in 2014. During this test, the old gun 4.2 with a modified back-plane design for better cathode contact has been used. In this contribution the results of the RF conditioning of gun 4.2 with a detailed interlock analysis will be reported as well as results from recent electron beam characterization.

RF SYSTEM AND GUNS

The RF waveguide distribution system with two vacuum windows was installed at PITZ during summer 2014 and is shown in Fig. 1. This two RF windows solution was installed due to several breaks of Thales windows in the previous configuration (one RF vacuum window solution). The new solution has the particularity to have the 10 MW directional coupler invacuum. A short section with pressurized air was also installed between the SF6 gas and the vacuum section, to have an easy exchange between two different setups and to be as close as possible to the XFEL setup where there is no SF6. As additional safety it also acts as a buffer in case of a leak in the gas RF windows, preventing any SF6 to reach the vacuum system.

The gun 4.2 cavity was already used at PITZ and FLASH between 2008 and 2012. It was dismounted from FLASH due to problems with the old RF cathode spring design and a new RF spring design was implemented by re-machining the cavity backplane [1]. The new contact stripes were gold

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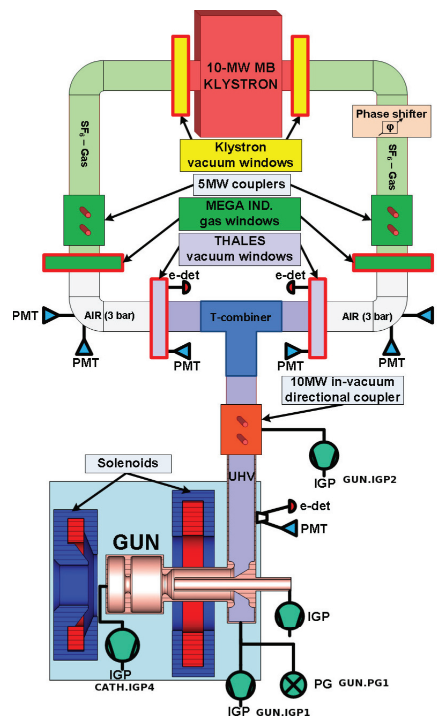

Figure 1: PITZ RF feed system in a two vacuum windows configuration (in operation since September 2014).

then rhodium coated and the cathodes used were electropolished to avoid damage to the contact spring stripes caused by bad contact with the cathode or by discharges. The gun 4.2 cavity was dry-ice cleaned to reduce dark current [2], and then mounted in the RF Feed system, as shown in Fig. 1. Conditioning of gun 4.2 started on 4.9.2014 and the gun was in operation at PITZ until the 1.11.2015.

CONDITIONING

The standard procedure applied for the conditioning of the RF guns is detailed in [3]. The control system used at

PITZ is based on DOOCS. Relevant properties are stored by the Data AQuistion system (DAQ). This data is then analysed to get statistics on conditioning and operation.

Conditioning of gun 4.2 started on September 2014 and continued until December. The main interlock (IL) systems are Photomultipliers (PMTs), electron detectors, reflection amplitude given by directional couplers and vaccuum pressure. The position of the IL sensors are shown in Fig. 1.

The power history of the conditioning of gun 4.2 is presented in Fig. 2. More than one month was spent to reach reliably full power with 100 µs RF pulse length.

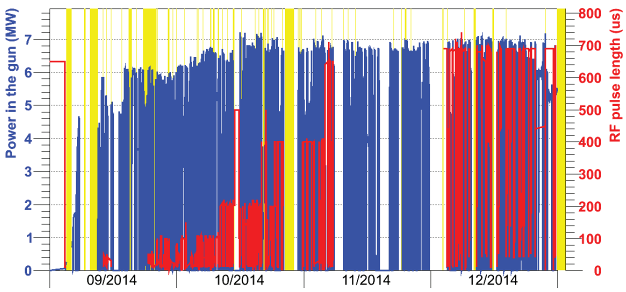

Figure 2: Power in the gun (blue line) and pulse length (red line) during the conditioning of gun 4.2. Yellow intervals show when information about the power in the gun is missing. No pulse length data was recorded for most of November 2014.

IL data from the DAQ was also analysed. 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 (ILs) and their rates for every week of gun 4.2 conditioning (as shown in Fig. 3), mainly ILs from PMTs looking at the vacuum windows were interupting the operation during the first five weeks. From the 6^{th} week of conditing on, mainly maximum reflection ILs, gun coupler PMT ILs and vacuum ILs interrupted the conditioning. From the 15^{th} week, the gun coupler PMT IL threshold was decreased to prevent vacuum ILs. The vacuum trips were successfully prevented, but the threshold was readjusted on the 18^{th} week (to an intermediate value) due to the large number of gun PMT coupler ILs.

OPERATION

The emittance of the electron beam produced by gun 4.2 has been measured using the slit scan technique [4], with a 11 ps to 12 ps (FWHM) Gaussian laser [5]. For each charge, the transverse laser spot diameter, the solenoid current and the RF gun phase have been optimized. The minimum emittance found with a gradient of 60 MV m^{-1} (corresponding to a power of ≃6.4 MW) and with 53 MV m^{-1} (≃5 MW) is shown in Fig. 4.

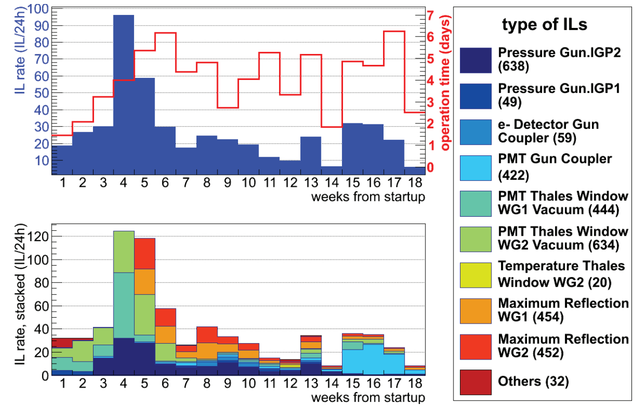

Figure 3: Rate of IL for every week of operation during the conditioning of gun 4.2. Top plot: Blue bars are the total number of ILs per 24 h of operation, when the power in the gun is more than 100 kW. No double counting when several ILs were triggered in the same event. The red line shows for every week the number of days 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.

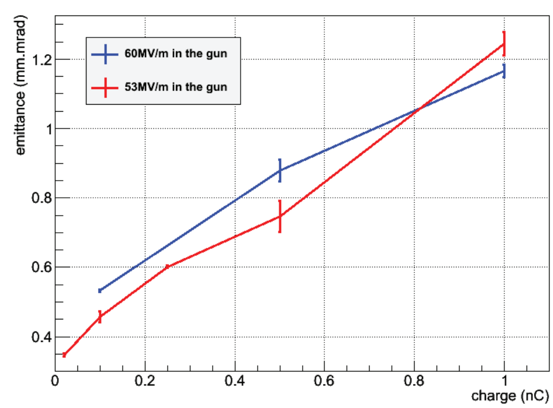

Figure 4: Minimum emittance measured as a function of the charge for two different gun gradients: 60 MV m^{-1} and 53 MV m^{-1}. Vertical error bars represent the statistical error over several measurements.

The measured emittance numbers for 53 MV m^{-1} are better than the specifications for the commissioning of the European XFEL. The projected emittance numbers at e.g. 0.5 nC are larger for 60 MV m^{-1} than for 53 MV m^{-1} due to the usage of a Gaussian temporal laser and that, according to simulations, the mismatch of the slices is much larger at 60 MV m^{-1} than at 53 MV m^{-1} even though the slice emittances is smaller at 60 MV m^{-1} than at 53 MV m^{-1}.

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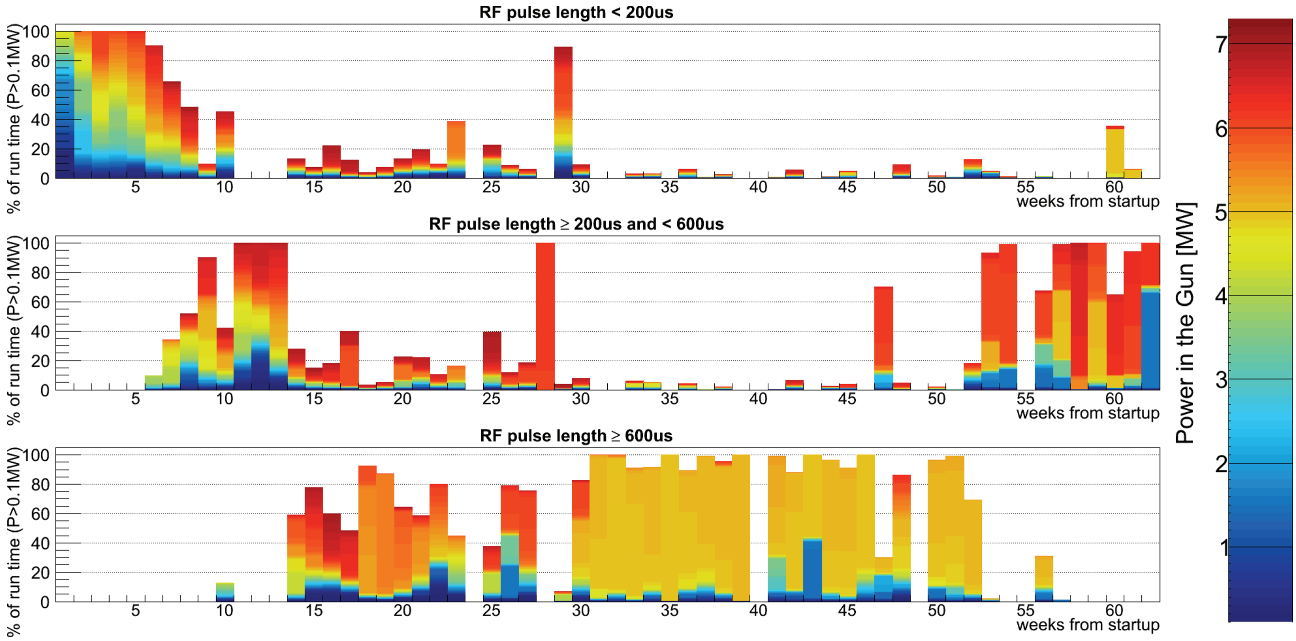

Figure 5: Weekly percentage of gun 4.2 operation time spent at different RF pulse lengths. The color code provides further information about the time spent at different power levels.

The fractional operation time for a given pulse length and power in the gun 4.2 is shown in Fig. 5. From the 14^{th} week of operation to the 29^{th}, the goal was to get stable operation at ≃6.4 MW and 650 µs RF pulse length. However, due to ILs (≃12 ILs per day), that was only possible for ≃ 50% of the time. From the 30^{th} week to the 52^{nd} week, the parameters were reduced to 5 MW and 650 µs RF pulse length (specification for the European XFEL commissioning). The gun was then much more stable (up to 96% of run time above 4.8 MW, ≃1.6 ILs per day). In the last 10 weeks of operation, to measure the emittance at ≃6.4 MW in the gun, a 250 µs RF pulse length was used and the operation resulted in being relatively stable (≃0.75 ILs per day). Even for these last two operation modes, the IL rate was above the admissible rate for FLASH or the European XFEL (1 IL per week of operation). However, recent developments of a fast gun recovery tool allow to recover after an IL in a few minutes instead of ≃1 h, which reduces ILs impact on the operation very significantly. The integration of this fast gun recovery tool in standard operation is ongoing.

CONCLUSION

Following the established conditioning procedure, gun 4.2 reached specification ($60\,\mathrm{MV\,m^{-1}}$, 650 µs RF pulse length and 10 Hz repetition rate) within 3-4 months of conditioning, the first month was mainly RF window conditioning, the last two for the gun. Then, despite 4 months of run at more than 6 MW and 650 µs RF pulse length, stable operation was not possible with these parameters, probably because of the ≃9 years long history of the gun 4.2 with heavy use at PITZ and FLASH and the subsequent re-machining of the cathode backplane. However operation at 5 MW with a 650 µs RF pulse length and at 6.4 MW with 250 µs RF pulse length was much more stable. In addition, a fast gun recovery tool will help to reduce the downtime down to an acceptable level for an FEL user facility. The measured emittances are within specifications for the commissioning of the European XFEL.

After the first months of conditioning of gun 4.2, there were no problems anymore with the RF windows, proving that the 2 windows solution works. Also the vacuum pressure was very low and no damage could be observed on the new cathode spring design, which demonstrates that the new gold-coated cathode spring with corresponding cathode plugs works as well.

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