

STATUS OF THE L-BAND GUN DEVELOPMENT AT PITZ

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Abstract

Gun5, the new generation of high-gradient normal conducting 1.3 GHz RF guns for linac-driven free-electron lasers like FLASH and European XFEL is under development at the Photo Injector Test facility at DESY in Zeuthen (PITZ). Its improved cell geometry and cooling concept allow for RF pulse durations of up to 1 ms at 10 Hz repetition rate, at gradients of ~60 MV/m at the cathode. Gun5 is also equipped with an RF probe for measurements of the RF field inside the gun.

The first gun of this type, Gun5.1, is in operation at PITZ since April 2022. Gun5.2 will be commissioned at the FALCO conditioning facility at DESY in Hamburg, starting in June 2024. This gun is equipped with a balanced (symmetric) RF waveguide feed to the coaxial power coupler to prevent a coupler kick and thus improve the beam quality delivered by the electron source.

Further guns are currently in the manufacturing process. In parallel, studies towards a more reliable cathode spring design are ongoing, in order to overcome observed issues during the high duty cycle operation of Gun5.1. This article will give an overview on all those developments.

INTRODUCTION

For 25 years, the development of electron sources for linac-driven Free Electron Lasers (FELs) like FLASH and European XFEL takes place at the Photo Injector Test Facility at DESY in Zeuthen. Over the years, the facility developed into a place for accelerator R&D, but the original purpose of optimizing electron guns is still one pillar of the PITZ research program.

The PITZ gun is an L-band (1.3 GHz) normal conducting 1 ½ cell standing wave copper cavity operated in π -mode. In total, 10 different electron sources (guns) have passed through the PITZ facility over the years. During this time, 5 optimized gun setups have been delivered to FLASH, and 3 to European XFEL.

With time, the operations specifications for the electron gun have changed towards more demanding parameters, in terms of gradient and pulse length, as well as in terms of stability and reliability. The currently envisaged operation parameters are an RF pulse length of up to 1 ms at a repetition rate of 10 Hz, and an operation gradient of 60 MV/m, corresponding to an RF power input of up to 6.5 MW into the gun cavity. At these parameters, the RF gun has to fulfill the user requirements in terms of stability and reliability.

Gun5 is the latest generation of electron guns for high duty cycle operation with improved stability and reliability [1]. Compared to the previous Gun4 type, it has an optimized cell geometry with elliptical irises for higher RF efficiency and reduced surface field strength which shall allow for more stable and reliable operation. It furthermore has an optimized water cooling which allows cooling of up to ~65 kW average power. Thus, it permits higher duty cycle operation. Improved rigidity of the cavity will reduce the deformation over the up to 1 ms long RF pulse (pulse heating). Another new feature is the existence of in-cavity RF probe(s) which allow a direct control of the RF field in the cavity and thus facilitate LLRF regulation. It furthermore allows the use of a new, symmetric RF distribution system by means of a symmetric power coupler which has the additional advantage of reducing the power load on the needed RF windows by 50% by the use of two input arms. Several cavities of Gun5 type are being produced and will replace the currently used Gun4 type cavities at FLASH and European XFEL.

GUN5.1

Gun5.1 is the prototype gun and is in operation at PITZ since April 2022. It still uses the old RF distribution system from the Gun4 type described in [2]. As reported in [2], the operation of Gun5.1 at PITZ was limited by short interruptions within the first part of an RF pulse, so-called minibreakdowns, occurring at higher average power settings. In 2023, the gun conditioning focused on the study of this phenomenon which was found to be related to a cathode spring problem that finally manifested in August 2023. The cathode spring was therefore exchanged but the operation stability did not improve significantly. Since the gun will be exchanged in the near future, it was decided to finish the planned physics program despite the instabilities, and to use Gun5.1 afterwards as testbed for a new cathode spring development, which is described below.

GUN5.2

The design of Gun5.2 (and all subsequent guns) is slightly different from the prototype, Gun5.1. It has a reinforced cathode backplane, two pickups, and minimally corrected inner dimensions in order to better match the resonance frequency after production. The tuning parameters are reported in Table 1 and compared to the values from Gun5.1. The effect of correcting the inner cavity dimensions on the frequency after production is clearly visible.

The goal of the tuning is always a resonance frequency (π -mode) of about 1.300300 GHz at room temperature in air, leading to an RF resonance of 1.3 GHz at an operation temperature of about 52°C in vacuum.

Table 1: π -mode frequencies of Gun5.1 and Gun5.2 after cavity production and after the frequency tuning.

Frequency (GHz)	Gun5.1	Gun5.2
after production	1.299944	1.300777
after tuning	1.300464	1.300275

Figure 1 shows the field distribution in the cavity after the tuning, obtained in the final bead pull measurement. For beam dynamics reasons, the field balance should be between 1.05 and 1.1, i.e. the field at the cathode plane should be 5-10% higher than the maximum field in the full cell.

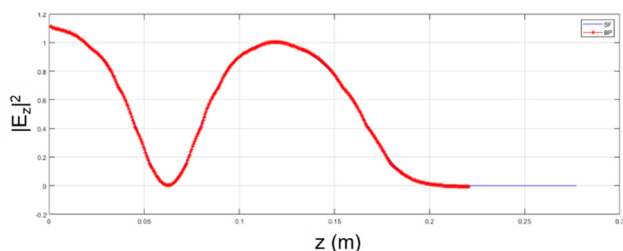


Figure 1: Result of the bead-pull measurements for the π -mode after the last tuning step. Data is shown in red (BP), Superfish simulations as a blue line (SF). The resulting field balance is 1.054.

After tuning and dry-ice cleaning, the gun was set up on its special frame together with the RF vacuum components (power coupler and RF windows), and the gun solenoids. The RF setup of Gun5.2 also differs from the one of Gun5.1: it was mounted with a symmetric power coupler which combines the functions of power combiner and gun input coupler, thus allowing for a considerably more symmetric field distributions in the gun RF input. With this setup, the formerly observed coupler kick [3] shall be reduced considerably.

In June 2024, the gun was installed at the new conditioning test stand in Hamburg, FALCO (Facility for L-band Conditioning), see Fig. 2. After receiving the operation permission, gun conditioning started on 18.7.2024. The conditioning progress is shown in Fig. 3. Gun5.2 will be moved to PITZ for beam measurements as soon as the next gun, Gun5.3, is ready for conditioning.

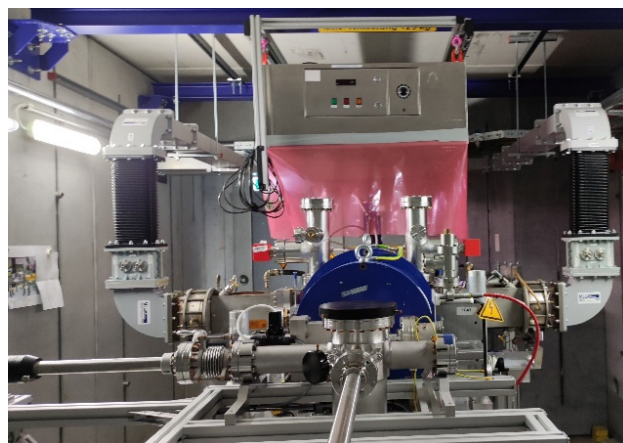


Figure 2: Gun5.2 at FALCO.

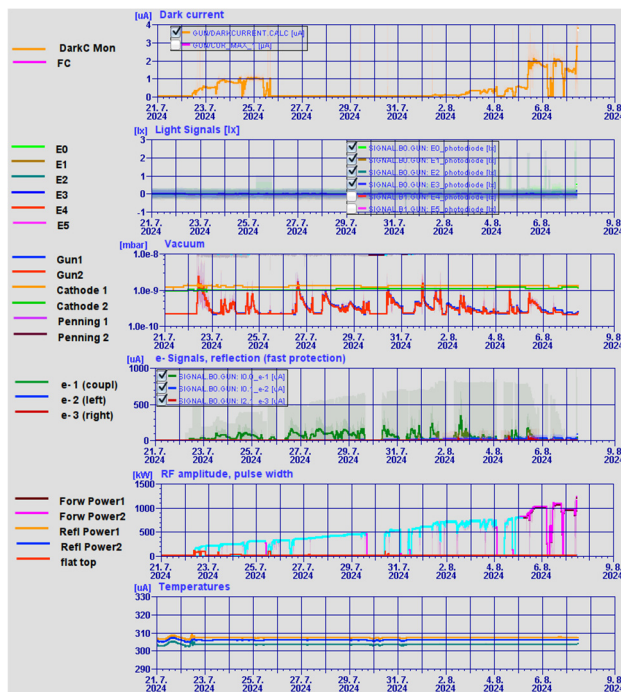


Figure 3: Conditioning progress at 10 μ s RF pulse length during the first 2 weeks of operation at FALCO.

GUN5.3 AND FURTHER CAVITIES

Gun5.3 is currently in the final manufacturing phase. Due to several issues in the challenging multi-step production procedure, the gun is behind schedule. After tuning and dry-ice cleaning, it will be set up in a similar manner like Gun5.2 (i.e. also with symmetric coupler), and will be taken into operation at FALCO later this year. Dependent on the operation behavior of Gun5.2 and Gun5.3, it will be decided which of the two guns will be installed at European XFEL in the summer shutdown 2025. The second gun will serve as spare gun.

The production of three further guns (Gun5.4, Gun5.5, and Gun5.6) is in progress at the workshops in Hamburg and Zeuthen. They are envisaged to be exact copies of Gun5.2 / Gun5.3 and will also be conditioned at FALCO for later installation at PITZ, FLASH, and European XFEL.

RECENT DEVELOPMENTS

As already observed in the past, at long RF pulses, the large power entering the cathode spring area can lead to sparks and subsequent surface damages in that sensitive region. For this reason, the spring design was improved already twice over the last years.

At Gun5.1, for high-power operation at 1 ms RF pulse length, the latest design seems nevertheless not sufficient: after the number of vacuum interlocks in the cathode region increased over a longer period, a cathode spring problem manifested in August 2023 which prevented further gun operation. The gun was opened from the cathode side and inspected. Damages in the area of the cathode spring and the spring itself were observed, see Fig. 4. The region was polished in-situ as good as it was possible, and a new cathode spring was inserted. Gun5.1 went again into operation - with only minor improvements of the operation performance.



Figure 4: Observed damages at the cathode spring region: in-situ observation (left) and marks at the dismounted spring (right).

The observed damages were analyzed and supporting simulations were conducted, see Fig. 5. The issue was found to be related to the number of contact points of the spring to the copper material on the one side, and to the cathode body on the other side. Due to manufacturing tolerances, the spring is not an ideal, closed ring with a homogenous distribution of contact points - especially in the vicinity of the gap where the CuBe spring starts / ends.

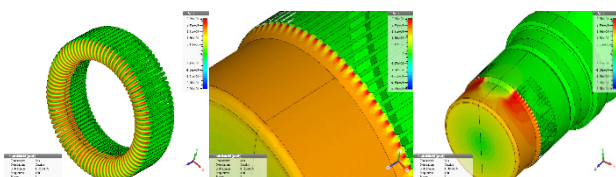


Figure 5: Simulations of the contact points at a perfect ring-like spring (left), at the cathode (center), and when using a spring with 11 missing contact points (right). The local field spikes are visible at the cathode and at the spring in all cases. In the case of missing contact points, the area without contact sees a reduced field, while the field at the neighboring contact points is strongly increased (here: ~35%). The additional charged particles, generated by glow emission, and the higher field amplitudes favor sparks between cathode spring and the cathode which destroy the corresponding, originally smooth surfaces.

The path length for the surface current until the contact points was considered another problem. Any disturbance of the current flow due to changes in the number and quality of the contact points leads to increased surface currents in the neighboring contact points, resulting in heating and subsequent glow emission at the regions where the current is increased, as shown in simulations (Fig. 5).

Different approaches for solving the problem are currently investigated by groups in Zeuthen and Hamburg. The major points of improvement are the path length of the surface currents, the number of contact points (i.e. the windings of the spring), and the quality of the electrical contact to allow for a good current flow. One of the new ideas is compatible with the current design of the cathode region. It uses a commercially available, canted helical spring and was verified in DC-pulse tests in the lab. DC currents up to 1.7 kA were applied at 10 Hz with a constant pulse length of 800 μ s, to be comparable to the RF parameters used in the gun. The contact resistance was measured and was found to be similar for the current (watchband) and the new spring design. No signs of overheating and / or burning at the contact points were observed. For this reason, the new spring design was recently installed into Gun5.1, and tests in the normal RF environment are currently ongoing.

CONCLUSION

This article summarizes the recent RF gun developments at DESY. In total, 6 cavities of the new Gun5 type will exist within the next years and will replace the older Gun4 type cavities used at FLASH and European XFEL. In order to solve the observed problems in the cathode spring region which are induced by the high average power load, R&D activities supported by simulations are ongoing. One of the improved cathode spring designs is currently in the test phase at PITZ and might be implemented to the other Gun5 cavities after proving its performance in Gun5.1.

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