

CONDITIONING OF A NEW GUN AT PITZ EQUIPPED WITH AN UPGRADED RF MEASUREMENT SYSTEM

M. Otevřel¹, G. Asova², J. W. Bähr, M. Hänel, Y. Ivanisenko, M. Khojoyan³, M. Krasilnikov, M. Mahgoub, D. A. Malyutin, A. Oppelt, S. Rimjaem, J. Saisut⁴, F. Stephan, M. R. Tanha⁵, G. Vashchenko, X. Wang⁶, DESY 15738 Zeuthen, Germany

A. Brinkmann, K. Flöttmann, D. Reschke, DESY, 22603 Hamburg, Germany

Abstract

A new photocathode electron gun is about to be characterized at PITZ. It is an L-band normal conducting 1.6 copper cell cavity with improved cooling system. It has the same design as the previously installed gun, characterized at PITZ during the run period 2008/9[1]. Due to the particle-free surface cleaning method utilizing dry ice, a significant reduction of the dark current was achieved in case of the previously tested cavity. This effect is also expected for the new gun. To improve the accuracy of the RF power measurement and control, a new in-vacuum directional coupler was installed between the T-combiner combining the two 5 MW arms of the RF source and the input coaxial coupler. The new in-vacuum coupler will provide much more accurate information about the RF power in the gun and will allow applying appropriate control feedback. Consequently improved stability of the gun operation is expected. Conditioning results of this new gun cavity will be presented as well as results of measurements of gradient and gun phase using this new coupler.

INTRODUCTION

The main goal of the Photoinjector Test Facility in Zeuthen (PITZ) is to develop and test the RF accelerating cavity (RF gun) for the high brightness Free Electron Lasers (FEL) in particular for FLASH and the European X-FEL project. The main demand for such an RF-gun is that it should provide an electron bunch of a very small transverse emittance (namely 0.9mm·mrad for a 1nC bunch), since this quantity can no further be improved by the consequent parts of the beamline. The new gun 4.1 is a representative of the 4th generation of RF cavities of PITZ, which is expected to reach this goal. The other twin exemplar of 4th design generation – the gun 4.2 – has been installed in May 2008 and operated at PITZ in 2008-2009. Now this gun is installed at FLASH for FEL operation. This gun has demonstrated to provide 1nC electron bunches of projected transverse emittance as low as 0.9mm·mrad [2,3]. The installation of the new gun into

the PITZ beamline came together with a significant upgrade of the PITZ facility. There were new components installed into the beamline, namely the tomography module for the transverse phase space reconstruction and a new CDS booster – a replacement of the old TESLA booster. There were also upgrades in the RF system. The current setup for the RF gun feed is shown in Fig.1. It consists of the 10MW multi-beam klystron with two ~25m long output arms which are filled with SF₆. Since only 5MW vacuum windows are available at PITZ, the both arms have to be combined under vacuum conditions. The combination of these arms is provided by an in-vacuum T-combiner. The most important upgrade was the

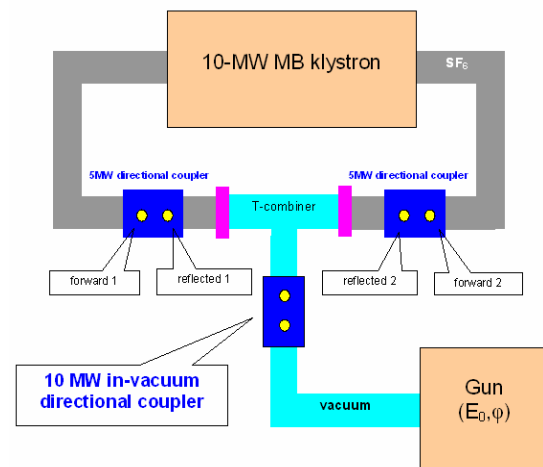


Figure 1: RF setup of the PITZ facility after the upgrade.

implementation of a new 10MW in-vacuum directional coupler, which provide the ability to measure the power and phase at the input of the gun directly without the need of processing the data obtained from two 5MW couplers at respective 5MW RF waveguides before they are combined. The 10MW in-vacuum directional coupler also makes applying the feedback loop possible, which was not the case before.

GUN 4.1: DESIGN AND CLEANING

The gun 4.1 is one of the two prototypes of the 4th generation of L-band normal conducting 1.6 copper cell cavities developed and tested at PITZ. The main upgrade in comparison with the previous generation is in the

¹ marek.otevrel@desy.de

² On leave from INRNE, Sofia, Bulgaria

³ On leave from YerPhI, Yerevan, Armenia

⁴ On leave from Chiang Mai University, Chiang Mai, Thailand

⁵ On leave from Kabul University, Kabul, Afghanistan

⁶ On leave from University of Science and Technology of China, Hefei, China

advanced multi-channel cooling system, which provides much better and homogenous cooling in particular of both end-plates and the iris of the gun. Both 4th generation cavities have as much as 14 independent cooling channels. Such a design provides better control of water flow-rates through these channels. Since the average power in the gun is as high as ~50kW, the cooling capacity and stability of the cooling system is a critical issue. Another issue was using the Dry Ice Cleaning method for cleaning both 4th generation cavities. By implementation of this cleaning method, significant reduction of the dark current has been achieved in both guns 4.2 and 4.1 [1].

CONDITIONING

Setup and Conditions

The gun 4.1 has been installed at PITZ at the end of 2009. The goal for the conditioning was to achieve stable run at 6-7MW peak power, 700 μ s RF pulse length with 10Hz repetition rate. Those parameters result in average power as high as ~50kW. The Thales 10MBK multi-beam klystron of 10MW peak power has been used to generate the RF pulse. Besides the above mentioned RF feed system (Fig.1) the RF gun is equipped with the main and bucking solenoid for the space charge compensation. Initially, the Molybdenum cathodes have been used for the conditioning. Other supporting and health monitoring systems were following:

- Vacuum maintaining system equipped with Titanium Sublimation Pumps (TSPs) and Ion Getter Pumps (IGPs)
- Fast interlock system capable to switch off the next pulse in case of unacceptable conditions
- Photomultipliers and Photodiodes for light detection and Electron detectors for intermediate particle collection.

The diagnostic systems serve for controlling and/or monitoring of the run conditions. Vacuum is watched via IGP currents and also via vacuum gauges. There is a water cooling system to keep the gun in resonance temperature with precision of 0.05K [4]. The amount of dark current is measured with a Faraday Cup. The momentum of high-energy edge of the dark current is measured using a dipole magnet. There are also small dipole magnets (steerers) for fine modification of the electron trajectories, screen stations and Beam Position Monitors for position monitoring and Integrating Current Transformers for non-destructive charge estimate. The setup is sketched on the Fig 2.

Progress and Difficulties

It was foreseen in the time schedule for the conditioning of the gun to take approximately 4 months, which was about the period spent for conditioning of the previous gun [1].

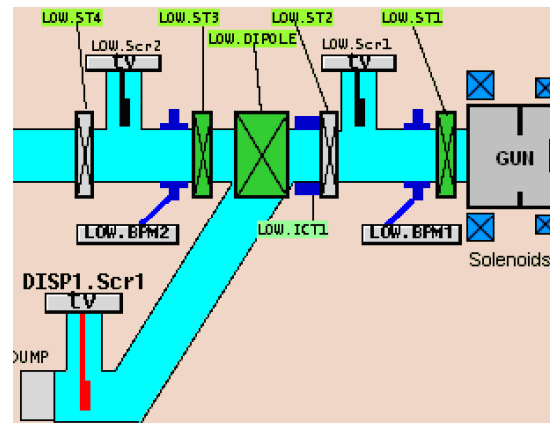


Figure 2: Setup of the PITZ low section. (The beam goes from right to left).

Nevertheless, the conditioning process has been finished at the end of July 2010 – 6 months after the conditioning started. (February 2010). Among others there were two main reasons for such a delay. First, the gun has been conditioned in parallel with installation work for other components in the tunnel. Consequently - and unfortunately - the conditioning could be done only during afternoon and night periods, since the morning period was used for the mechanical work. Only during the weekends there was a continuous run. Second, besides of the new gun, there were also a few new in-vacuum RF components installed in the section that also needed to be conditioned. In particular it was a new T-combiner – a T-shaped waveguide piece which combines the power from two 5MW RF waveguides – and a new 10MW in-vacuum directional coupler.

In the first part of the conditioning period we observed mainly light signals in the gun section, but as the conditioning process continued, the vacuum events in the T-combiner and the 10MW in-vac. coupler became to be the limiting factors of the conditioning progress. From the analysis of the data obtained during the conditioning process one could conclude, that the problem was indeed most probably not in the gun itself, but in the new in-vacuum RF components. The suspicion was also emphasized by the fact, that the 10MW in-vacuum coupler could not be baked beforehand due to mechanical reasons.

Changes in the Procedure

Several experiments were done to improve and/or understand the situation of that time, including detailed inspection of all the readouts of the temperature sensors at the in-vacuum RF components, inspection of higher-harmonics levels of the RF field or placing small permanent magnets on different places of the in-vacuum RF waveguide's surface to provoke or affect multipacting, but none of them brought any significant progress. Therefore a certain modification of the conditioning process has been suggested. The standard way how to condition the gun is to try to achieve

maximum peak and average power in the gun cavity by increasing the feed power level while fixing all other parameters like RF pulse duration and repetition rate. The idea of the proposed modification lay in increasing rather the RF pulse length instead of the (peak) power level. At the beginning of the procedure the feed power was increasing to its maximum for extremely short RF pulse (only 1 μs – nominal 100-700 μs). This was possible very fast. After that the gun was conditioned by a slow increase of the RF pulse length. By this method only average power was increased, but not the peak power (since it was at its maximum level). Consequently the peak power was larger, but the average in-gun power was significantly lower in comparison to the conventional method. This approach also led to the situation, in which we had constant and fairly bad vacuum in the gun and in-vacuum RF component for a few weeks - effectively without any high peaks in pressure and therefore with acceptable frequency of interlocks. This finally accelerated the out-gassing process and resulted in significant progress in consequent conditioning period.

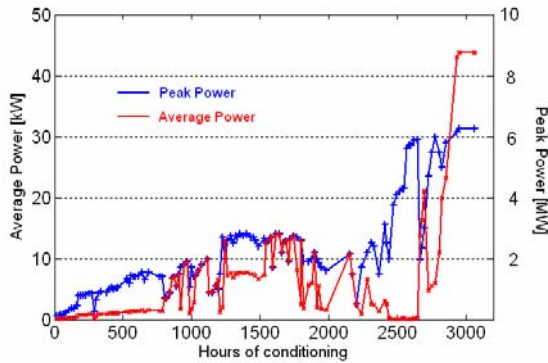


Figure 3: Conditioning history: the Peak Power (blue line) and the Average Power (red line) during the conditioning process.

Current Status

After two weeks conditioning using the new method described above we switched again to the longer RF pulses and finally could reach full power within a few days. After that we started to sweep the solenoid magnets and quite soon got fairly stable operation even for this condition. The history of conditioning is shown on Fig.3. Here only those hours were accounted, when there has been conditioning.

Dark Current Measurements

The dark current has been measured using the Faraday Cup $\sim 0.8\text{m}$ distance downstream the cathode. After doing the solenoid scan, the maximum value was taken as the measurement result for the given power level and the RF pulse length. The results are shown on Fig.4. According to the current measurement results, the gun 4.1 produces dark current level comparable to that measured with the previous gun 4.2 [1].

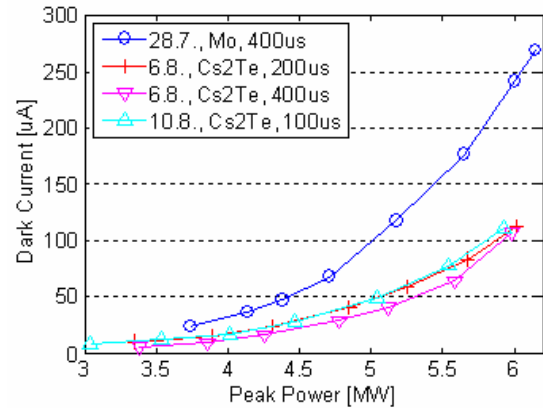


Figure 4: Maximum Dark Current dependence on the Peak Power in gun. The comment line in the legend contains date of measurement, cathode type and RF pulse length respectively.

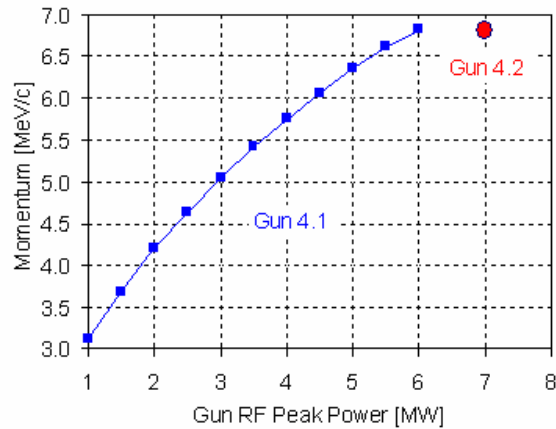


Figure 5: The maximum mean momentum of the accelerated electron bunch as a function of the RF power transported to gun given by the 10MW in-vacuum directional coupler.

The somewhat higher levels for the molybdenum cathode could be caused by the fact that this cathode is already fairly old and full of scratches from frequent inserting and removal. It also should be mentioned, that the peak power levels of recent measurements were taken with the new 10MW in-vacuum directional coupler which has not yet been properly calibrated. Indeed there are some suspicious circumstances around the measurements from the directional couplers, since we measure a significant difference between in-gun power for the previous gun ($\sim 7\text{MW}$ - gun 4.2) and the current gun ($\sim 6\text{MW}$) at maximum RF power obtained from the same klystron. More, we measure approximately the same maximum mean momentum around 6.8MeV/c of the electron bunch for both guns at maximum klystron power level (Fig.5). The probable reason is a possible discrepancy in the RF power meter calibration. Consequently it might be that the dark current level is even slightly lower than that of the previous gun 4.2. This matter is still to be investigated.

By all means however is the dark current a factor of 10 lower than that of 2nd and 3rd generation gun prototypes which received a particle-free cleaning with high pressure water rinsing instead of the currently used dry-ice-cleaning technique.

RF PHASE STABILITY MEASUREMENTS USING THE 10MW IN-VACUUM DIRECTIONAL COUPLER

FEL design claims stringent specifications upon the electron bunch source stability. In particular, the instability of the RF phase negatively affects the FEL performance. The charge dependence on both the laser energy and the RF phase could be used for investigation of instability of these quantities. Since the dependences of the bunch charge on the RF phase and laser energy are nonlinear and, more importantly, the dominance of these quantities on the space charge varies over the operating-point-space there is a possibility to decouple the effects from each other. The measurements and the analysis method have been proposed in [5].

Experimental Results

The measurements were done only for reduced peak power in the gun (~ 1.09 MW) [5] since the gun was at the beginning of the conditioning stage at that time. The charge was measured with the Faraday cup closest to the cathode. Main solenoid was running at 210A to focus the beam on the Faraday cup. The set of four operating-points were at (set-point) phases -80, -60, -40 and -20 degrees.

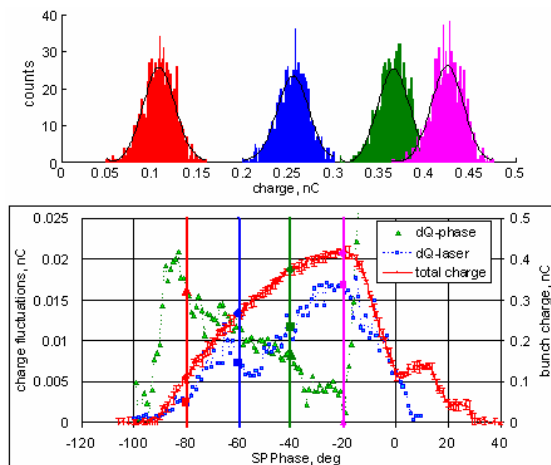


Figure 6: RF phase and laser energy jitters decoupled as result of the analysis of the electron bunch space charge jitter. Measurements done at ~ 1.09 MW peak power in gun, laser transmission fixed at 10%.

The laser transmission was fixed on 10% for all these points. The measured distributions at the operating-points are shown in the upper part of the Fig.6 (the coloured histograms) together with their “winning” fits (the black curves). By applying of the procedure described in [5] following results were obtained: 1.77deg for the RF phase and RMS jitter and 12.5% RMS relative jitter for the laser

energy. No feedback has been applied for these measurements. The high laser energy jitter is caused mainly because of instability of the pump diode of the laser oscillator due to its aging. Another reason may be that the laser was operated at short Gaussian pulses with ~ 2 ps FWHM, which is far from the normal operating mode – the flat-top pulse shape 20 ps long. The laser energy jitter RMS value obtained by the charge measurements is in good correspondence with the one measured using PMT.

CONCLUSION

The gun 4.1 was successfully conditioned at PITZ. The peak power achieved is 43.75 kW (6.25 MW peak power, 700 μ s RF pulse length, 10 Hz repetition rate). However there might be uncertainty of this value due to possible discrepancy on RF power meters calibration. According to the beam momentum based calibration results, the real power delivered into gun should be higher than that given by the coupler, since the same beam momentum of ~ 6.8 MeV/c was measured for the previous gun 4.2, but according to the power measurements at that time we had peak power in the gun as high as ~ 7 MW.

The gun shows fairly low level of dark current ~ 100 μ A like its predecessor – the gun 4.2 – did during the last run period. So far both guns were dry-ice cleaned. This confirms the advantage of this technology.

A new method has been applied to investigate the RF phase and cathode laser energy jitters from the measured jitter of the electron bunch charge. Preliminary tests gave RMS jitter of 1.77 deg for the RF phase and 12.5% for the laser pulse energy, which are rather high. However, the measurements were not performed at standard conditions for neither the laser nor the RF system and are expected to be better for the standard operation.

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