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DEVELOPMENTS AND FIRST RESULTS FROM AN RF TEST STAND FOR HIGH BRIGHTNESS C-BAND PHOTOGUNS AT PSI

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Abstract

An international collaboration between PSI and INFN-LNF has been undertaken with the aim of developing the next generation of high brightness electron sources. Through this collaboration, two unique high gradient RF photoguns that operate in the C-band frequency regime have been designed and realized. Concurrent to this, a new high power test stand at the Paul Scherrer Institut has been commissioned to test these novel devices. Here we report on the new test stand and the first results from the high-power testing of these devices.

INTRODUCTION

Developing the next generation of RF photoguns for FELs and other high brightness electron machines is key to continuing to push the limits of brightness in new facilities. In order to increase the brightness of the electron beam generated, it is important to push the cathode accelerating gradients well-beyond the current state-of-the-art of 100-120 MV/m. As part of the IFAST programme, which aims to develop the next generation of accelerator technologies, a project between PSI and INFN has been undertaken with two industry partners to develop the next generation of electron sources through the use of high gradient C-band technology. To test these new electron sources, a high power RF test stand has been developed at the Paul Scherrer Institut. In this paper, we report on the commissioning of this new test stand and the first high power results.

DEVELOPMENT OF HIGH BRIGHTNESS C-BAND RF PHOTOGUNS

The motivation for this work was the development of RF photoguns that could withstand higher electric field gradients on the cathode. The two photoguns have been extensively reported on in [1, 2]. However, we briefly detail them here. The first photogun is a standing-wave RF photogun with a more conventional RF design with 2.5-cell but designed in the C-band frequency regime compared to more typical S-band. The cells are manufactured using high-precision turning and then clamped together rather than the more standard brazing. A new mode converter has been realised to feed the gun and to reduce the dipole and quadrupole field components, which can result from single and dual feed input couplers. In contrast to standing-wave technology, the second gun, which has been realised, is a travelling-wave RF photogun. This device is a 11.5-cell RF photogun fed

Figure 1: High power klystron-modulator (Top) and installed SW RF Photogun in test stand (Bottom).

through coaxial input and output couplers. The design is completely new and features a load-lock compatibiliy to allow the use of non-metallic cathodes. Each of these guns aims for cathode gradient beyond the S-band state-of-the-art, which are able to reach gradients up to 120 MV/m [3].

DESIGN AND COMMISSIONING OF THE C-BAND TEST STAND

To test these two RF photoguns, a new C-band high power test stand has been designed and commissioned. Below is a description of the new test stand.

RF Source

Prior to the development of the new RF photogun test stand, a klystron test stand remained in place after moving

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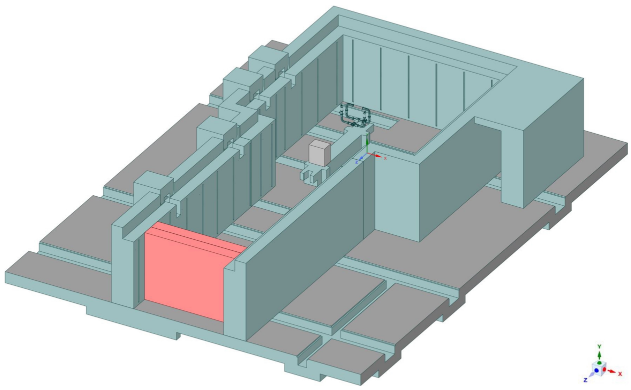

Figure 2: CAD model of the new bunker developed for the test-stand with the gun and the dump mounted on the girder. Electron beam follows the z direction.

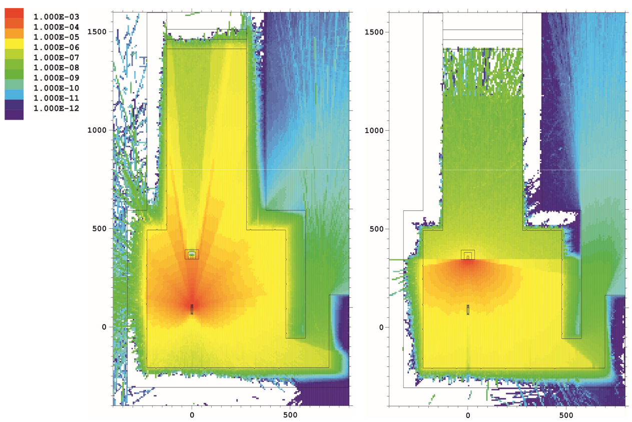

Figure 3: Dose rate from photons (pSv per 1 electron) on the horizontal (z, x) plane (view from the bottom of the bunker), for the losses on the gun (left) and on the dump (right).

the SwissFEL injector (test facility) to PSI's East Campus (Fig. 1). This klystron test stand is used to prepare klystrons for high power operation in SwissFEL. Furthermore, the test stand also allows the testing of concepts for SwissFEL, such as changes to the low-level RF system. The klystron test stand features a 50 MW C-band Canon klystron with a Scandinova modulator. The photogun test stand will use this RF source to drive the high power testing of the RF photoguns. To do this it requires a new waveguide network and to address the issue of operating a higher frequency standing-wave RF photogun without a high power circulator.

Bunker Upgrade and Radiation Simulations

Building off the back of this klystron test stand, the new RF photogun test facility recommissioned the remnants of the SwissFEL injector test facility bunker through new radiation shielding walls and new Personnel Safety System (PSYS). The new bunker layout is illustrated in Fig. 2 where the new shielding wall is illustrated in red. A girder used to test the original S-band photogun for SwissFEL, which remained in place after the facility was moved, was used to support the new RF photogun. This is important as later it

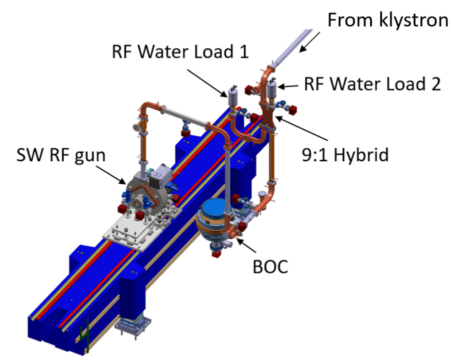

Figure 4: Waveguide layout for high power test stand.

would allow a like-for-like switch, in the case the new gun was installed in SwissFEL.

Before switching on the test stand, it was important to understand the radiation generated within the bunker. The primary source of radiation in the test stand area is the dark current produced in the gun. This dark current can be lost either in the gun itself or on the electron beam dump which is forseen to be installed 2.3 m downstream from the gun. Fluxes of the secondary particles resulting from the losses of electrons were simulated using MCNP [4]. The CAD model of the bunker shown in Fig. 2 was converted into the MCNP model using the SuperMC program developed by the FDS team [5]. For an efficient calculation of the photon and neutron flux attenuation by the thick shielding, variance reduction parameters were calculated using the ADVANTG software [6]. Obtained estimates of the prompt dose rate around the test stand (see Fig. 3) were compared with the operational limits, and ultimately used to provide an operational safety concept published at [7].

Waveguide Network and Circulator-Free Operation

The new waveguide network, illustrated in Fig. 4, sees the output waveguide from the klystron approaching from the top right. For any test stand that wants to operate with a high power standing-wave cavity it is important to prevent large power reflections toward the power source, in this case a klystron. It was the original idea of the group to install an in-vacuum circulator. Unfortunately, this was unable to be realised due to issues during fabrication and therefore another concept was devised. Rather than using a circulator, it was decided that one could attenuate the line using a 9:1 hybrid. This would mean that, although only 10 % of the RF power would be fed towards the RF gun, the hybrid would also allow only 10 % of the reflected power to propagate back towards the klystron. As the power fed towards the gun would now be limited to 5 MW, excluding waveguide attenuation, we decided to add a BOC RF pulse compressor to increase the peak power in exchange for pulse length. This meant that, for a reduction in the pulse length from 2.5 µs to 300 ns, the peak power could be increased by a factor of 4. Consequently, this would give enough peak power to test

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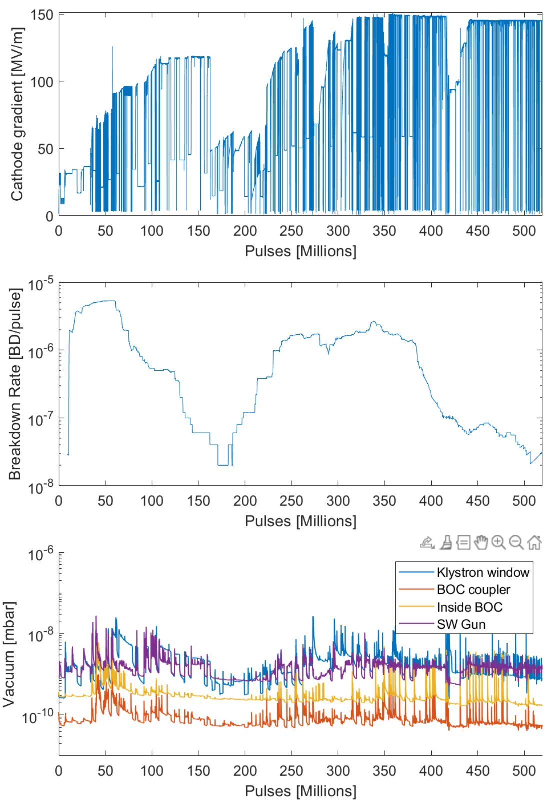

Figure 5: High power testing of the SW gun.

the standing-wave RF photogun up to its design gradient of 160 MV/m while keeping the mean and peak reflected power to the klystron below 0.5 and 1 MW, respectively. The two other ports of the 9:1 splitter each have their own RF water load to absorb the residual power.

FIRST HIGH POWER OPERATION

Conditioning of the SW RF Photogun began in December 2023 when the first high power RF was fed into the gun. The history of the high power operation is illustrated in Fig. 5. The initial conditioning began with a 50 ns RF pulse to test the waveguide network, much of which had never seen high power or had been exposed to air for large periods of time. Outgassing primarily limited the system with a maximum vacuum level of approximately $3{\times}10^{-8}$ mbar throughout the system. During this time, the cooling system for the BOC was still under preparation limiting the maximum power which could be sent to the gun to 4.5 MW. With the finalisation of the BOC cooling, operation moved to using the BOC with a 1.5 µs klystron pulse and 300 ns RF compressed pulse. The power was increased gradually with the aim of keeping the vacuum level to below 3×10^{-8} mbar. Peaks in the reflected power towards RF water load 2 and the klystron were considered RF breakdown events and the system was interlocked for a few seconds before the system reacted. If the vacuum level was below the threshold, the power resumed with a 10 % reduction where it was ramped back towards the power at which the system experienced the interlock. If the vacuum was above the threshold the system would set the power to zero and ramp back to the previously achieved power over several minutes. In the absence of vacuum activity and RF breakdowns, the system would continue to ramp at a rate of approximately 500 kW per hour. The conditioning first ramped to an output power of 27.5 MW from the klystron, which equated to approximately 9-10 MW of input power into the gun. The choice of this limit was the knowledge that the RF water load 1 was previous operated to 25 MW when connected as part of the klystron test stand. To increase the input power to the gun without exceeding this peak of 25 MW input power the klystron RF pulse length was increased. This ultimately led to a gradient of 120 MV/m on the cathode. After reaching this limit at 170 million RF pulses, it was decided to push the klystron power to 45 MW. To do this, the load was conditioned to ensure that it was able to take the input power. The pulse length was reduced back to 200 ns and the power increased from 27.5 MW. This resulted in a reduced input power into the RF gun while the RF pulse was too short for pulse compression. Following this, the pulse length was doubled to 400 ns and again to 800 ns before an increase to 1.5 µs allowed for the pulse compressor to be used again and conditioning of the gun resumed.

Once reaching 47 MW from the klystron, the pulse length was increased to 2 µs and the power reduced by 25 %. A continuation in the conditioning saw an increase in the power towards the 50 MW. At 46 MW or 143 MV/m on the cathode, and at around 350 million RF pulses, the klystron saw a large outgassing of the its window. During this time the power was reduced to allow the vacuum to condition, and the power was slowly increased over time. To improve reduce the reflected power towards the klystron, the phase flip was slowed from 50 ns to 200 ns. This saw a 20 % reduction in the peak reflected power towards the klystron. With this modification to the flip, the power continued to be increased resulting in a cathode gradient of 147 MV/m. At this point, the system was ran with a constant RF input parameters in order to gather some information on the stability at which the system could run at 147 MV/m.

CONCLUSIONS AND FUTURE PLANS

A new high power C-band test stand has been commissioned at the Paul Scherrer Institut to test the high gradient photoguns under development as part of the IFAST programme. Radiation models have demonstrated the new wall and the original chicane are sufficient to keep the radiation outside within safe levels. With the successful recommissioning of the bunker, the first high power operation was on a standing-wave RF photogun that has high performance with a gradient of at least 147 MV/m on the cathode.

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