

## CONDITIONING AND HIGH POWER TEST OF THE RF GUNS AT PITZ

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### Abstract

This paper describes the recent results on conditioning and dark current measurements of the photocathode rf guns at the photoinjector test facility at DESY Zeuthen (PITZ). For successful operation of high gain SASE FELs, a high phase space density of the electron beam is required. A high gradient in the gun has to be applied to produce high quality space charge dominated beams. In addition, long rf pulses and a high repetition rate should be achieved to provide high average power of the FEL radiation. The first PITZ rf gun has been successfully tested at a mean power up to 27 kW (900  $\mu$ s, 10 Hz and 3 MW) and has been installed in the VUV-FEL at DESY Hamburg. Another rf gun has been installed at PITZ in January 2004 and is being conditioned for high power tests. The dark current behavior for various cathodes and a multipacting condition are presented.

### INTRODUCTION

The photoinjector test facility at DESY Zeuthen (PITZ) has been built to achieve high quality electron beams and to study their characteristics for future applications at free electron lasers. The setup is shown in Fig. 1. The first PITZ rf photocathode gun named prototype #2 was commissioned in 2003 to fulfill the VUV-FEL requirements with 900  $\mu$ s long rf pulses at 10 Hz repetition rate and an rf gradient at the cathode of 40 MV/m [1]. That corresponds to a maximum average power of 27 kW in the gun cavity with 0.9 % duty cycle. The gun has been installed in the VUV-FEL at the TESLA Test Facility (TTF) at DESY Hamburg in January 2004 [2].

The second phase of PITZ has started for development toward the XFEL which is in the planning phase as an European project. For this project, the beam parameters requested at the gun are 650  $\mu$ s beam pulses at 10 Hz repetition rate and 0.9 mm mrad transverse emittance at 1.0 nC beam charge [3]. That means the gun should be operated with  $\sim$ 700  $\mu$ s rf pulse at 10 Hz repetition rate and a gradient at the cathode of 60 MV/m. This corresponds to an average rf power in the gun of about 46 kW.

A second rf gun dating from an earlier production with the same geometry (called prototype #1) has been installed in January 2004 and it is being commissioned to further progress toward the XFEL requirements. At present, the rf

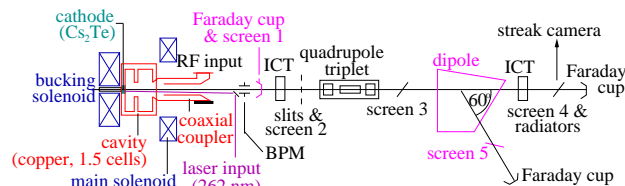


Figure 1: Schematic view of the gun and diagnostic sections.

gradient of 60 MV/m cannot be reached because the available klystron peak power is limited to 5 MW. An upgrade of the klystron to 10 MW peak power is foreseen at the end of 2004. Our current approach is to increase the rf pulse length with the maximum rf gradient to put the same average rf power into the gun as required for the XFEL operation. This gun cavity prototype #1 is not ideal to study the electron beam properties because its copper was from an old production which showed small blowholes and resulted in serious vacuum problems when it was operated first. The major vacuum problems were solved using modern vacuum aids. With this cavity also the cleaning procedure for high gradient ultrahigh vacuum copper cavity had been developed. Since the inner surface quality of this gun cavity is much worse than that of gun cavity prototype #2, a large amount of dark current is generated in this cavity. Despite the limited vacuum and dark current conditions of this cavity, it is suited to study the high average power behavior of the gun, the rf system and the water cooling system. During the conditioning work, dark current behavior of the present gun was investigated with several cathodes.

### STATUS OF THE CONDITIONING

Conditioning of the gun cavity is ongoing to reach the requirements for the XFEL. Since the inner surface of the cavity is not very clean, the conditioning is not straightforward but time consuming. To compensate the limited peak power of the present klystron, long rf pulses have been used. One example (1100  $\mu$ s) of a long rf pulse is shown in Fig. 2. In parallel with increasing the average rf power in the gun cavity, the main solenoid current was swept over the whole range (0  $\sim$  400 A) to perform the conditioning for the entire operating condition of the gun. In June 2004, an average power of 30 kW has been reached.

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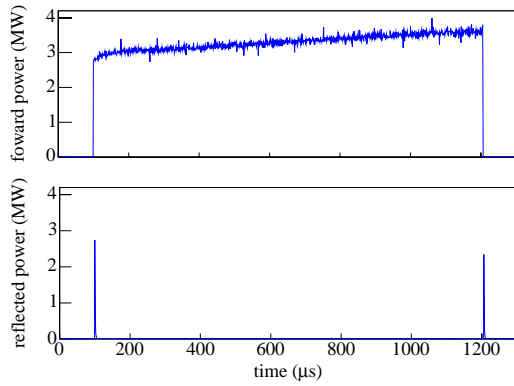


Figure 2: Forward (upper plot) and reflected (lower plot) rf pulse at the gun cavity.

## DARK CURRENT

Main dark current sources of the rf gun cavity are the photocathode area, and the gun backplane close to the cathode, and the two irises. The field-emitted electrons from the two irises cannot flow out of the gun cavity, but the dark current emitted from the area around the cathode can reach the beamline downstreams. Fig. 3 shows a dark current image with and without the electron beam at screen 1 which is located 78 cm downstream of the cathode. At the left picture, the thin inner ring comes from the circumference of the  $\text{Cs}_2\text{Te}$  film on the cathode, and the thick outer ring comes from the cathode plug edge and the inner hole of the copper backplane of the cavity. At the right picture, the electron beam (a white spot in the center) is shown with the dark current. Although the field emission from areas away from the cathode region cannot directly go down the beamline, it plays a role in the total amount of dark current measured downstreams: much higher dark currents have been measured in comparison with the previous gun cavity even with the same cathodes.

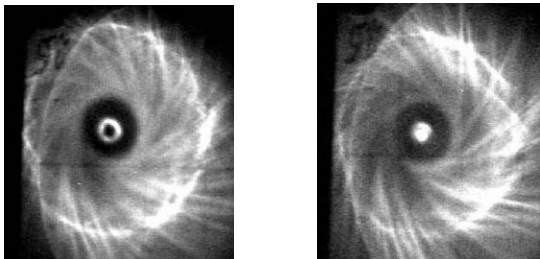


Figure 3: Dark current image (left) and dark current together with the beam (right) at screen 1.

The amount of dark current has been measured with a Faraday cup at the same position as screen 1. One Mo cathode (#47) and three  $\text{Cs}_2\text{Te}$  cathodes (#60, #61 and #500) have been used to study the dark current behavior. Cathode #60 has been used for more than one year and cathodes #61 and #500 have been used only several weeks. The mea-

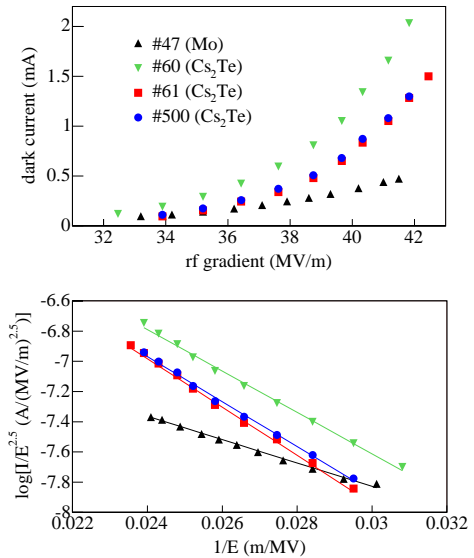


Figure 4: Dark current measurements (upper plot) and their fits to estimate the field enhancement factors and the effective areas (lower plot).

sured dark current is about six times higher than the amount produced with the previous gun [5] (Fig. 4). The  $\text{Cs}_2\text{Te}$  film thickness ( $t$ ) and diameter ( $\phi$ ) on the cathodes and the field enhancement factor ( $\beta$ ) and the effective emitting area ( $A_e$ ) of the cathodes are summarized in Table 1. The field enhancement factors for the different cathodes are slightly smaller than for the case of the previous cavity. The effective emitting areas for the field emission are three order of magnitude higher than for the case of previous cavity [5]. The cathodes (Fig. 5) and the diagnostics in the beamline were damaged by the dark current.



Figure 5: Damaged  $\text{Cs}_2\text{Te}$  film on the cathode #60. Photographs were taken on March (left) and May (right) 2004.

Table 1: Dark current properties of the cathodes.

	$t$ (nm)	$\phi$ (mm)	$\beta$	$A_e$ (m <sup>2</sup> )
#47	-	-	77.5	$4.2 \times 10^{-10}$
#60	30	10	137.2	$2.5 \times 10^{-12}$
#61	30	5	159.9	$2.0 \times 10^{-13}$
#500	60	5	149.2	$5.0 \times 10^{-13}$

## MULTIPACTING

Figure 6 shows a typical dark current signal together with the rf forward power in the gun cavity prototype #1. Two multipacting peaks occur at the beginning and the end of the rf pulse. The main part of the dark current increases slowly and decreases quickly because the rf power in the cavity has a finite rising and decay time and also the amount of the field emission has a relation of  $I_{emission} \sim E^2 \cdot \exp(-1/E)$  [6].

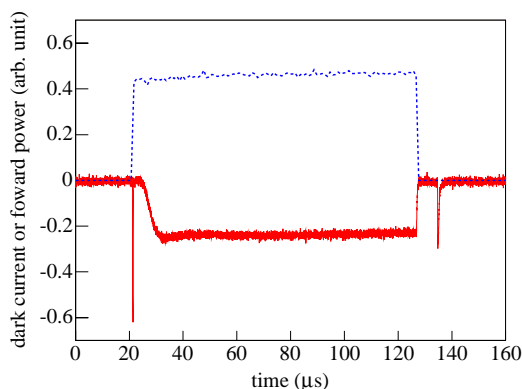


Figure 6: RF forward power in the gun (dotted blue line) and dark current signal (full red line).

The first multipacting peak appears just after starting the rf forward pulse and the second peak has some delay after the end of the rf pulse. That means the multipacting occurs when the cavity has a very low rf gradient. If we assume that the multipacting occurs at the same gradient in the cavity, we can use the following relation for the second peak:

$$E_{multipacting} = E_{gradient} \cdot \exp(-t_{delay}/\tau), \quad (1)$$

where  $E_{multipacting}$  is the rf gradient when the multipacting occurs,  $E_{gradient}$  is the gradient on the flat region of the rf pulse,  $t_{delay}$  is the delay between the end of the rf forward power and the beginning of the second multipacting peak, and  $\tau$  is the rising and/or decay time of the rf field in the cavity. For the first multipacting peak, it is hard to define accurately the time difference between the starting of the rf pulse and the peak.

$t_{delay}$  has been measured as a function of  $E_{gradient}$ . The result is shown in Fig 7 as black dots with measurement errors. With the plot of  $E_{gradient}$  and  $t_{delay}$ , we can make a fit with the following relation:

$$t_{delay} = \tau \ln(E_{gradient}) - \tau \ln(E_{multipacting}). \quad (2)$$

The red line in Fig 7 shows the fit using Eq. 2. The fitted  $E_{multipacting}$  is 3.04 MV/m and  $\tau$  is 3.07  $\mu$ s. This decay time can be compared with the value of 2.8  $\mu$ s obtained from the field simulation for the gun cavity prototype #2.

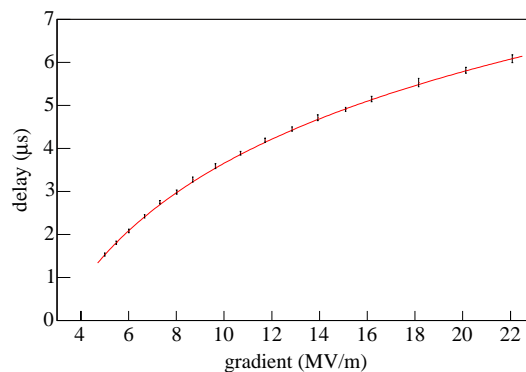


Figure 7: Delay of the multipacting peak with error bars (black points) together with a fit using Eq. 2 (red line).

## DISCUSSION

After successfully finishing the characterization of the first rf gun for the VUV-FEL at TTF, another gun has been installed at PITZ and is being conditioned for the developments toward the XFEL. In June 2004, an average power of 30 kW has been achieved. The dark current was measured and the behavior was compared with the first gun. The amount of dark current of the present gun is very high for known reasons. The corresponding field enhancement factors are slightly smaller but the effective field emitting areas are much larger than for the first gun cavity case when we use the same cathodes. Such a large amount of dark current damaged several devices in the vacuum system. Obviously, more effort to limit the dark current is necessary. From the measurement of the delay between the end of the rf forward power and a multipacting peak, a multipacting condition was found to be 3.04 MV/m at the cathode. The rf decay time of the cavity was estimated to be 3.07  $\mu$ s.

A new cavity and a new klystron with 10 MW peak rf power are under preparation toward fulfilling the requirements for the XFEL.

## REFERENCES

- [1] M. Krasilnikov *et al.*, "Characterization of the electron source at the photo injector test facility at DESY Zeuthen," Proc. FEL 2003, Tsukuba, September 2003.
- [2] S. Schreiber and K. Flöttmann, "Commissioning of the VUV-FEL injector at TTF," the present proceedings, MOPKF022.
- [3] <http://xfel.desy.de>.
- [4] M. Krasilnikov *et al.*, "Optimizing the PITZ electron source for the VUV-FEL," the present proceedings, MOPKF027.
- [5] J. H. Han *et al.*, "Dark current measurements at the PITZ rf gun," Proc. DIPAC 2003, Mainz, May 2003.
- [6] J. W. Wang and G. A. Loew, "Field emission and rf breakdown in high-gradient room-temperature linac structures," SLAC-PUB-7684, 1997.