DARK CURRENT INVESTIGATION OF FLASH AND PITZ RF GUNS*

L. Monaco#, P. Michelato, C. Pagani, P. Pierini, D. Sertore
INFN Milano – LASA, I-20090 Segrate (MI), Italy
J. H. Han, S. Schreiber, DESY Hamburg, Germany
M. Krasilnikov, F. Stephan, DESY Zeuthen, Germany

Abstract

The dark current is one of the limiting factors in the RF guns operation at high accelerating gradients. The continuous request of higher brilliance sources and further emittance minimization, leads to apply higher gradients in the RF gun cavity, with the undesired consequence of a significant increase in dark current production. In this context we set up a collaborative effort to identify the dark current sources in the gun, in order to discriminate between the gun and cathode contribution. A critical analysis and organization of dark current measurements, taken during the operation of TTF and PITZ guns, with several cathodes operated at different accelerating fields and solenoids focusing, is presented. Potential areas of improvement are also discussed, together with a possible associated program.

INTRODUCTION

Dark current emission is one of the limiting factors in the operation of RF gun-based linear accelerators, due to possible activation and damage of accelerator components and the possibility of inducing quenches in superconducting cavities. Since 1998 the operating accelerating field of L-band guns has been raised from 35 MV/m to about 42 MV/m. Since the actual plans foresee to further push it up to 60 MV/m, the physical mechanisms originating dark current emission in cathodes need to be understood clearly.

In this paper we present a summary of the dark current measurements performed since 2002 on different cathodes (both uncoated Mo plugs and Cs_2Te) in the PITZ and FLASH guns. After a brief discussion on the dark current measurements we present a possible interpretation of its physical origins.

HISTORY OF DARK CURRENT MEASUREMENTS IN RF GUNS

In order to understand the origin of dark current emission and to find solutions to mitigate its effects, we have collected the preparation and measurement data available in the DESY and LASA logbooks since 1998. Cathodes prepared at LASA [1] are shipped to the DESY (Zeuthen and Hamburg) RF guns in UHV condition to preserve their photoemissive properties. Table 1 summarizes the cathodes used in the different RF guns (including uncoated Mo plugs) at the various laboratories of the collaboration. All the data are also available on line [2]. The gun naming identifies the different RF structures: "G" guns have been tested and developed at FNAL while "PITZ" guns at DESY Zeuthen.

Table 1: Summary of the cathodes used either at DESY Hamburg or Zeuthen since 1998 with some of the relevant parameters for dark current data measurements

Where	Machine	RF gun	Cath. Used	Date	Faraday cup
DESY-Hamburg	TTF	G3	13$^{\diamond}$	Nov-98/ Mar-02	FC(*)
			1§		
			4$^{\otimes}$		
		G4	1$^{\diamond}$	Jun-02/ Nov-02	FC(*)
			1§		
			1$^{\otimes}$		
	FLASH	PITZ-G2	6$^{\diamond}$	Mar-04/ in use	2GUN(**) 3GUN(***)
			1$^{\otimes}$		
DESY-Zeuthen	PITZ	PITZ-G2	8$^{\diamond}$	Mar-02/ Oct-03	DC(**)
			6$^{\otimes}$		
	PITZ1.5 PITZ1.6	PITZ-G1	8$^{\diamond}$	Mar-04/ Sep-05	DC(**)
			3$^{\otimes}$		
	PITZ1.6	PITZ-G3	1$^{\diamond}$	Mar-06/ in use	DDC(**) DC(***)
			3$^{\otimes}$		

(*) positioned at 0.62 m from the cathode surface
(**) positioned at 0.78 m from the cathode surface
(***) positioned at 1.27 m from the cathode surface
$^{\diamond}$ Cs_2Te, § KCsTe, $^{\otimes}$ Mo

Dark Current Measurements

The dark current measurements presented here have been selected at the standard operation conditions of FLASH (40÷42 MV/m at the cathode, main and bucking solenoid currents 277A, and 20A, respectively) and, to be comparable, at the same conditions for PITZ. Moreover, even if two Faraday Cups (FCs) are available in FLASH and PITZ, we report here only data collected at the FC location placed at 0.78 m from the cathode front surface.

PITZ

The dark current measurements data at PITZ span over many years, using three different guns and several cathodes as shown in Fig. 1. A first trend to notice is the decrease of dark current during each gun operation. This effect is more pronounced for PITZ-G1 and PITZ-G3 and can be explained as an effect of the gun cavity conditioning [3]. For PITZ-G2, we do not have the initial data but, except for cathode #57.2, we might notice that a constant level of dark current is reached after about one and a half year of operation. Comparing the end of the PITZ-G2 run with the beginning of PITZ-G1, we observe a sharp increase of the dark current, for the same cathodes (#60.1, #61.1 and #500.1), due to the need for conditioning of the new gun. This effect was clearly seen

*Work supported by the European Community, contract number RII3-CT-2004-506008
#laura.monaco@mi.infn.it

also during TTF operation when G3 was substituted by G4 [3]. The subsequent increase of dark current of cathode #60.1 and #61.1 was due to damaging of front surface during the conditioning of the new gun [4]. A different trend has been observed in changing from PITZ-G1 to PITZ-G3, where no clear increase of the dark current is visible. This smoother behavior might be explained by the fact that PITZ-G3 has been baked before operation. The uncoated Mo plugs, highlighted by the magenta color in the plot, showed dark current emission levels comparable to the Cs_2Te cathodes, suggesting a dominant influence of the plug substrate or the gun conditions on the dark current emission mechanism.

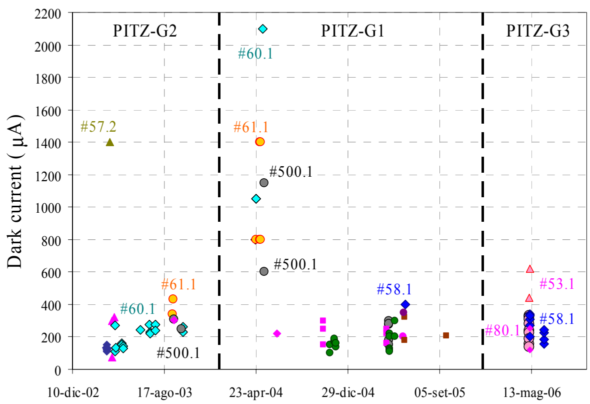

Figure 1: Dark current measurements at PITZ starting in ‘02 till today. Three different guns are considered. Data from Cs_2Te and Mo cathode are reported.

The last comment is for cathode #53.1, which showed higher emission levels in the PITZ-G3 gun. This cathode was scratched at its border during handling (Fig. 4-left), causing uncontrolled local field enhancements.

FLASH

Fig. 2 shows the dark current measured at FLASH in the last two years, using the PITZ-G2 gun. In this case only Cs_2Te cathodes have been measured. We observe that the dark current is quite low already from the beginning of operation (cathode #42.2). This is consistent with the fact that the gun has been conditioned at PITZ before its use at FLASH.

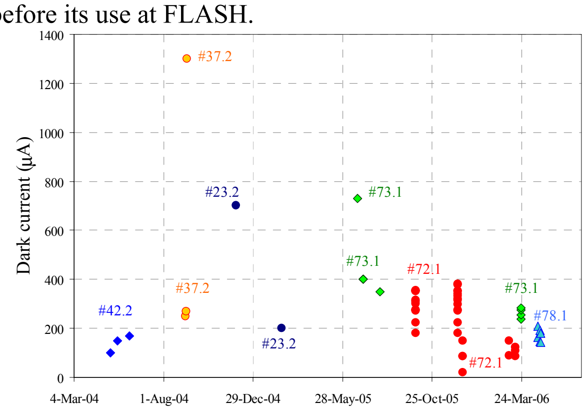

Figure 2: Dark current measurements at FLASH with PITZ-G2 gun, from 2004. Only Cs_2Te cathodes have been used.

The very sharp increase observed for cathode #37.2 (a factor of 5 in 2 days) was due to a mechanical accident during the cathode handling, that produced dust and contaminated the plug surface. After this event, cathode #23.2 was inserted in the gun and the dark current started decreasing again, even if from higher levels. After about one year of continuous operation, nearly the initial values have been restored.

The last consideration is relative to cathode #78.1. The plug was electro and then optical polished. The electropolishing (EP) was performed to decrease the plug border roughness. The first measurements do not show a significant effect on the dark current emission levels. Possibly the optical polishing procedure performed after the EP might have increased again the plug border roughness. A new Mo plug has been firstly optically polished and will then be EP before the coating deposition to preserve the border condition and assess possible benefits in reducing the dark current emission.

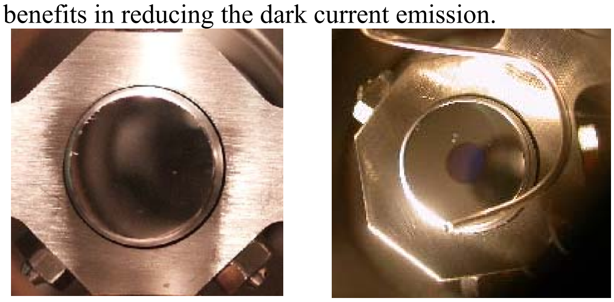

Figure 3: Left: Cathode #53.1 with scratches on the border. Right: A picture of cathode #37.2 taken after the accident: near the coating a bright particle is visible.

DARK CURRENT IMAGES

Images taken at different locations along the injector, varying solenoid or accelerating fields, are an important tool to study and understand the dark current origin.

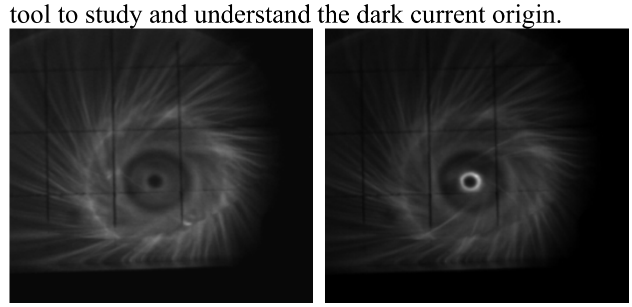

Figure 4: Dark current images from a Mo cathode (#56.2) on the left, and a Cs_2Te cathode (#54.2) on the right. Clear flares are visible as well as three circular regions of different intensities on both cathodes.

During machine operation the dark current image is typically a spot with dimensions similar to the laser generated beam. However, the patterns shown in Fig. 5 have been obtained by varying the solenoid settings in order to highlight some structures providing insights about the physical regions which could originate high dark current emission levels. The sources of the images shown in Fig. 4 are an uncoated Mo plug (left) and a Cs_2Te photocathode (right).

In both images we observe flares spiraling from the center outwards due to the large energy spread of the emitted electrons traveling in the solenoidal magnetic fields. The flares seem to originate from the outer and middle rings. The outer flares have been attributed, in the past, to dark current coming from the region between the plug and the gun body [3], where the RF contact spring is located. In this region increased field enhancements due to local curvatures of the geometry or damaged surfaces could lead to increased electron emission.

The "Scratch" Test

In order to simplify the identification of dark current sources we have damaged the front surface of an optical polished cathode with an intense ns laser beam in few controlled positions (cathode #80.1). Fig. 5 (left) shows the spot pattern we produced. We chose an asymmetric distribution of the spots to be able, later, to identify the single dark current sources.

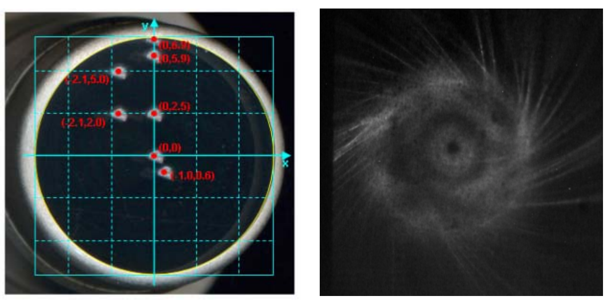

Figure 5: On the left, the plug with regular spot pattern on the surface. On the right, a dark current image showing no hot spots. The dark current value is within usual limits.

This cathode was then tested at PITZ during the spring '06 and a typical image is shown in Fig. 6 (right). The experiment showed a dark current pattern similar to that of regular cathodes. None of the damage locations on the front surface originated emission spots, even changing focusing and accelerating gradient parameters. This could indicate that any field enhancement induced by the laser damage is substantially lower than the typical values at the gun/plug boundary.

DARK CURRENT MODELING

We also developed a simple computational model to reproduce the dark current patterns at the screen, with the aim to possibly identify dark current sources. Fig. 6 shows two cases, using the ASTRA code [5]. The left case correspond to particles generated only on the plug border, at 25 azymuthal angles, in order to mimic the spring convolutions (~80 in the present design). This simulation reproduces the main features of the images in Fig. 5, indicating once more that the plug border region, where the RF spring is located, could be responsible of the dark current emission. The outer rings are reproduced, as well as the central ring and the flares, faint but visible in the outer part of the figure. Increasing the number of azymuthal positions results in a more defined outer ring image.

The emission process, in the simulations, does not take into account the Fowler-Nordheim dependence of the emitted current with the accelerating field on the cathode. This effect changes the relative intensity of the main features of the image, but not the overall structure.

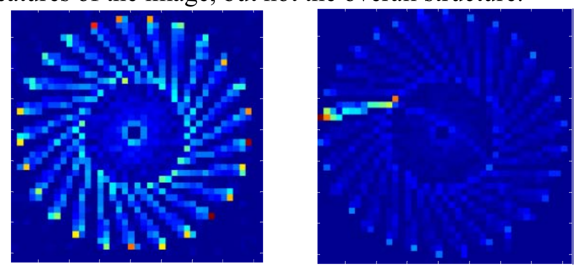

Figure 6: Simulation of the dark current pattern. Left, particles generated on the plug border at 25 angles. Right, one "hot spot" on the plug border has been enhanced.

The right plot in Fig.6 corresponds to the previous case, in which a single spot population was artificially enhanced, to create a "hot spot" of electron emission. At this position, two bright spots are visible and a light blue flare crosses the whole image. Since many particles have been used for the hot spot generation, the underlining structure is fainter then before.

CONCLUSIONS

The dark current data measured on several cathodes, and with different guns, at FLASH and at PITZ have been collected and critically analyzed. They show that the total dark current decreases both as the gun cavity conditioning proceeds and as a "local" conditioning of the cathode takes place. On the opposite side, improper handlings, generation of dust particles or mechanical damages at the front surface of the cathode lead to an increase of the dark current. Moreover, our analysis shows that there is not a significant difference in dark current emission between uncoated Mo and coated cathodes. The main features of the dark current images experimentally measured at the beam screen locations have also been reproduced by particle tracking simulations in the RF gun. The simulations seem to confirm the hypothesis that the particles originate from the region between the plug and the gun body [3], where the RF spring is located. In this region field enhancements due to local curvature of the geometry and to damaged surfaces, or particles created by the friction between the cathode and the spring, could lead to strong field emission. Further tests are planned to confirm or invalidate this hypothesis.

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