COMPARISON OF 2 CATHODE GEOMETRIES FOR HIGH CURRENT (2 KA) DIODES

M. Caron, F. Bombardier, E. Merle, Ch. Noël, O. Pierret, R. Rosol, C. Vermare

CEA/DIF Polygone d'Experimentation de Moronvilliers – 51 Pontfaverger-Moronvilliers, France

N. Pichoff, DPTA/SP2A, A. Piquemal, DPTA/SPPE, CEA/DIF 91 Bruyères-le-Chatel, France

D.C. Moir, LANL-DX6 – NM Los Alamos – USA

Abstract

AIRIX (FRANCE) and DARHT axis-1 (USA) facilities are two high current accelerators especially designed for X-ray flash radiography. The produced electron beam (2 kA, 60 ns, 3.5 to 3.8 MeV at the diode output) is extracted from a velvet cold cathode. Specific calculations have demonstrated the influence of the cathode geometry on the emitted beam profiles [1]. In order to check this assumption two different experiments (DARHT march 2003 – AIRIX march 2004) have been performed. The beam characteristics with two different geometries have been compared both theoretically and experimentally. The beam simulations have been done with 3 codes: a home-made one (M2V) and 2 commercial ones (PBGUNS and MAGIC). The extracted beam current and transverse profiles, for the first experiment, have been measured and compared to simulations results. In the second one, we have mainly compared the primary current intensity that can be drawn with the two different K-designs for a given energy.

INTRODUCTION

Since the first reports on the X-ray sources like DARHT Axis 1 or AIRIX [1] [2] [3], some efforts have been devoted to improving the overall electron beam quality in order to reduce for instance the beam focal spot. One of the most relevant parameters to assess the ability for a beam to be more focused is the so-called emittance ε. ε can be seen as an intrinsic beam characteristic that can only increase all along the acceleration line. At first glance, the smaller ε onto the X-ray converter, the smaller the spot size is. Therefore, the main challenges we have to face are on the one hand to reduce the emittance as much as possible at the e-beam production stage and on the other hand to limit its growth during regular transport. This paper rather deals with the first point since reducing ε remains a key issue in the successful development of new cathode designs. We present in the first section the two different cathode geometries taken into consideration in this report as well as the numerical simulations exhibiting the expected gain in terms of beam quality. Then section 2 is dedicated to the description of the two experiments performed so far at DARHT Axis 1 and AIRIX facilities. A comparison between theoretical predictions and experimental results is done in section 3.

THEORETICAL BACKGROUND

The driving forces responsible for the major cathode developments have been quite extensively described elsewhere [1] [4] and have lead to an evolution from our regular standard K-geometry to a modified one: the so-called Pierce geometry. The main differences between them become clear from figure 1.

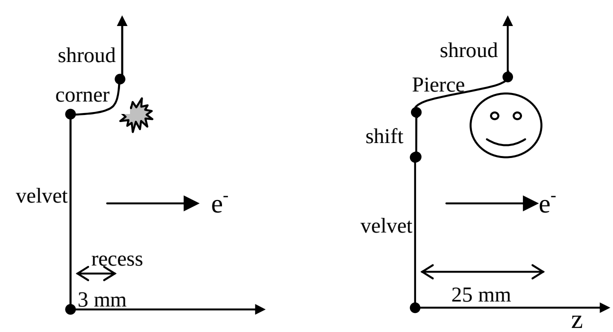

Figure 1: Cathode geometries: a: Standard; b: Pierce.

These geometrical modifications have been implemented into numerical simulation tools independently developed. The entire diode theoretical description has not only been performed by means of a home made code called M2V [5], but also with two commercial codes PBGUNS [6] and MAGIC [7] which are based on very different models. In any cases, the beam is always extracted from the cathode under space-charge limited flow. Electrons are focused out of the diode by means of a solenoid whereas another coil brings the residual magnetic field on top of the cathode down to zero. Up to now, it has been shown that the beam distribution into the (x,x') phase space simulated nearest to the anode level with M2V, PBGUNS or even MAGIC look very similar provided that stationary conditions are considered (front edges excluded) [8] [9].

According to the theoretical calculations, the main improvement expected from the use of the newest type of cathode is to get an emittance reduction of about 10 to 30 % for the same values of primary currents and energies.

EXPERIMENT

The experimental part of this work was first performed at DARHT Axis 1 on March 2003 and then at AIRIX facility on March 2004. Actually, current characterisations dealing with accelerated beams are still running on both sides but they are out of the scope of this paper. Here, we thus take a step back and concentrate on the beam analysis near the entrance of the accelerator line. Basically, such characterisation stage aims to check the validity of the theoretical predictions. In other words, for the same experimental conditions we want to compare the performances in terms of beam quality between the two cathode geometries.

DARHT Experiment

For a complete beam characterisation at the diode output the following set of data is required: the primary beam current intensity (I), the primary beam energy (E), the mean angular beam dispersion (R’), the RMS beam size (R) as well as the beam emittance (ε). The first two parameters are given in a routine way by the regular electrical captors present into the beam lines. For the last three ones, a classical beam diagnostic based on the detection of the electron induced Cerenkov radiation has been used for the present purpose. As a first step prior to a more refined analysis, we present in figure 2 and 3 the beam patterns and the related transverse profiles measured for the both types of cathodes at the same location (z=1.67 m away from K).

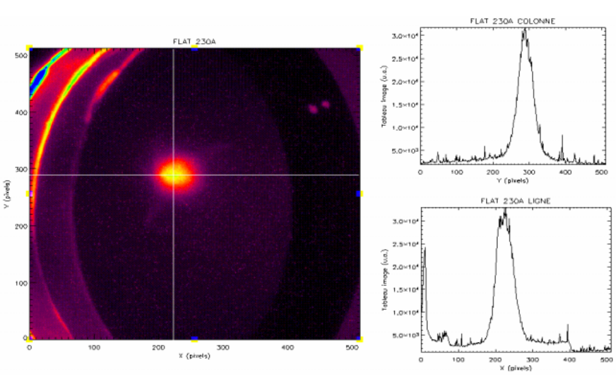

Figure 2: Beam pattern from Cerenkov light recorded for the standard cathode (I=1.84 kA, $I_{focusing\ magnet}$ = 230A)

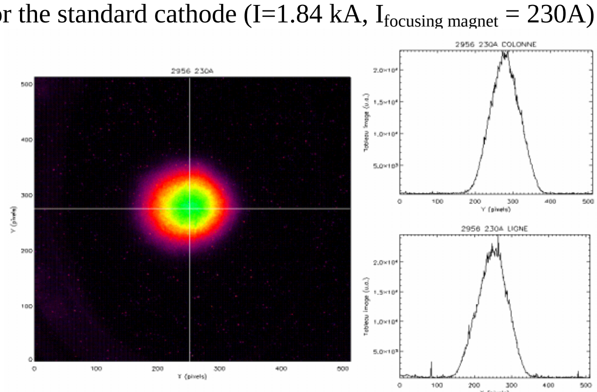

Figure 3: Beam pattern from Cerenkov light recorded for the Pierce cathode (I=1.77 kA, $I_{focusing\ magnet}$ = 230A)

First remark looking at figure 3 is that the entire set of emitted electrons falls down into a sharp contour. This remark is no longer valid for figure 2 where long wings are visible. Moreover, an additional peak to the main one rises up near the edge. A possible interpretation of such interesting findings assumes that the emitted light from the outer part is due to the superimposition of an Optical Transition Radiation to the main Cerenkov signal. The OTR contribution would be induced by electrons coming from the foot of the main distribution interacting with the metallic radiator holder. However both cathodes exhibit a clear difference with respect to their beam profiles and the main conclusion drawn is that the Pierce geometry offers the opportunity to get rid off the disturbing background signal observed while using the standard cathode. This outcome appears like the first qualitative improving point brought by the modified K-design regarding to the beam quality.

AIRIX Experiment

As already mentioned in the previous section, the same parameters E, I, R, R’ and ε are required to achieve a complete beam properties investigation. From a primary beam energy spread measurement performed with a time resolved magnetic spectrometer [10] the mean beam energy value can be known while the corresponding primary current intensity is given by the magnetic loops of a Beam Positioning Monitor located in front of the spectrometer entrance. When varying the diode voltage, different (E, I) values are measured and plot together to form a kind of Voltage-Current Diode Characteristic.

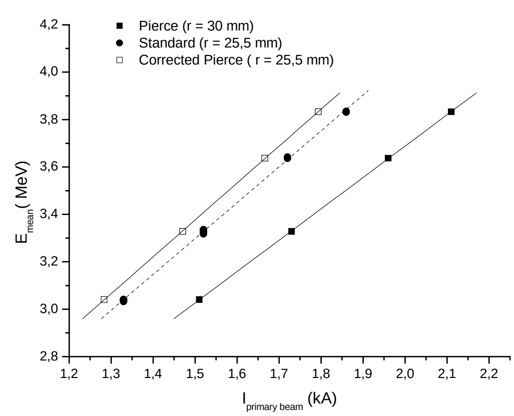

Figure 4: Energy current diode characteristics.

The full symbols correspond to the measured values. As the velvet radii are different we have tried to estimate the emitted current for a Pierce cathode with the same emitting surface (open squares). This correction has been done assuming that the emitted current intensity follows a velvet radius square law. It turns out that a small shift is observed meaning that for a given diode voltage the Pierce cathode would emit slightly less electrons.

The beam patterns from electron induced Cerenkov light have been recorded for different current intensity settings on an upstream focusing magnet and for both cathodes. The radiator is a 5 µm thick aluminium coated mylar foil, tilted with respect to the accelerator axis to the right angle in order to make light easily measurable by an intensified and a two dimensional gated camera (512 x 512 pixels^2, 8 bits, 5 ns minimum exposure time).

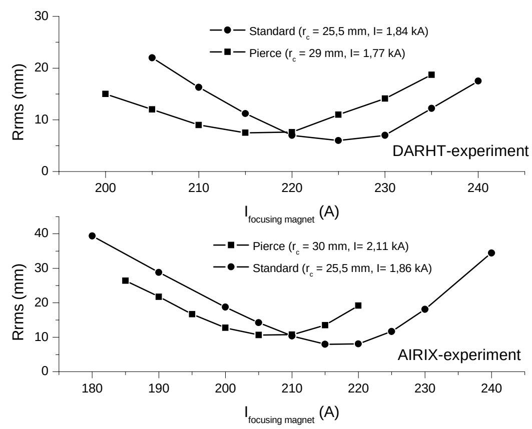

Figure 5: R_{rms} evolution as a function of the focusing magnet current intensity for both experiments (z = 2.095 m for AIRIX, z = 1.890 m for DARHT).

For the standard cathode, the RMS beam radius varies as a function of the extraction current intensity with a stronger slope than for the Pierce one near the beam-waist. This behavior might be an advantage in terms of beam stability since the beam transport from the diode to the accelerator line would be less sensitive to slight current drift into the extraction solenoid.

RESULTS AND DISCUSSION

Part of the experimental results measured either at DARHT or at AIRIX can be used now to verify and to validate the diode modelling by the different numerical simulation tools.

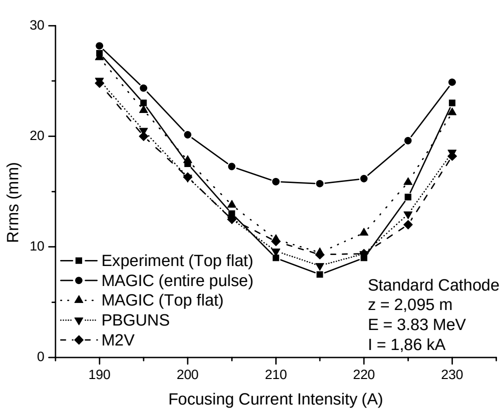

Figure 6: Envelope radius as a function of the focusing magnet current intensity.

As an example, we present above one comparison between experimental data and theoretical calculations for the standard cathode. As long as the front edges of the pulse are not taken into account in the numerical simulations the whole calculated datasets fit quite properly the measured ones. In order to make a more stringent validation of the numerical simulations we need now to measure some more refined experimental parameters like ε for instance, ideally in a more accurate way than the usual three-gradient method.

CONCLUSION AND OUTLOOK

The first results dealing with the e-beam characterisation at the diode output have shown measurable differences between the two cathodes geometries under investigation. The Pierce geometry has shown promising behaviours with respect to the beam quality like some better defined beam profiles and a smoother beam-waist at the entrance of the accelerator. This makes it very worthwhile to further investigate this cathode and see whether or not after beam acceleration the promising results obtained so far could lead to a significant reduction of the focal spot size.

AKCNOWLEDGEMENTS

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