AIRIX MEASUREMENT CHAIN OPTIMIZATION FOR ELECTRON BEAM DYNAMIC AND DIMENSIONAL CHARACTERISTICS ANALYSIS

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Abstract

AIRIX is a linear accelerator dedicated to X-ray flash radiography at CEA's hydrotest facility. It has been designed to generate an intense X-ray pulse using a 2 kA, 19 MeV and 60 ns electron beam.

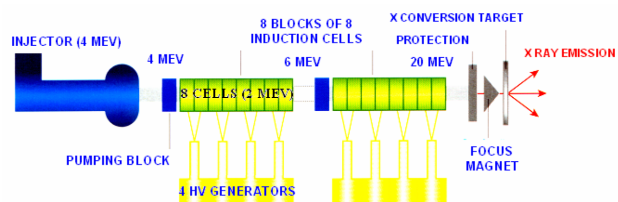

Figure 1: AIRIX accelerator

The electron beam transport in the accelerator is insured by the knowledge of the dynamic and dimensional characteristics of the beam created downstream the injector. These characteristics are assessed from a measurement chain, established by adapted optics and an intensified camera, aiming at observing the Cerenkov radiation produced during the interaction of electrons with a mylar target placed in the beam. This paper deals with the characterization, and comparison with the previous model, of a new intensified camera which was experimentally tested on AIRIX during an injector characterization campaign. This allowed to define profile and emittance beam characteristics. The obtained results are promising and revealed very interesting properties in particular in term of dynamic, temporal resolution, linearity and signal-to-noise ratio.

INTENSIFIED CAMERAS THEORETICAL CHARACTERIZATION

This characterization was achieved in laboratory, both on the intensified camera PROXITRONIC (NANOCAM HF4-S-5N model) currently set up on AIRIX, and on the new PRINCETON camera (PIMAX3 model).

Table 1: General characteristics

Parameters	PROXITRONIC	PRINCETON
Type	Analog	Numeric
CCD captor cooling	No	Down to -25°C air cooled
CCD format	512 x 512	1024 x 1024
Digital conversion	8 bits	16 bits
Gate width	5 ns to 65 ms	2 ns to 20 s
CCD pixel size	11.2 x 11.6 µm²	12.8 x 12.8 µm²
Image area	8.7 x 6.5 mm²	13.1 x 13.1 mm²
MCP-captor coupling	O.F – reducing cone – O.F	O.F – O.F
Usual configuration	Black level : 30% Video Gain : 90% MCP Gain : 90%	

Signal Base Line Adjustment

For PROXITRONIC camera, a "Black Level" parameter allows the adjustment of the signal base line. With a homogeneous pulsed DEL source, we estimate the signal base line mean level relatively to the "Black Level" variation, and we note that decreasing Black Level of 10% reduces the pixel level of 20 ADU. Finally, in the PROXITRONIC camera usual configuration, pixels which are lower than 48 ADU are reduced to 0 (threshold effect). For new PRINCETON camera, the signal base line and video gain can not be changed.

Linearity

The tests are achieved with a 532 nm nanosecond LASER and an integral sphere of 40 mm diameter. By convention, we reach camera sensitivity saturation when linearity defects are higher than ±5%. For the PROXITRONIC camera (figure 2), we note a beginning of sensitivity saturation around 130 ADU/pixel. In linear mode, the ±10% dispersion is representative of the weak signal to noise ratio.

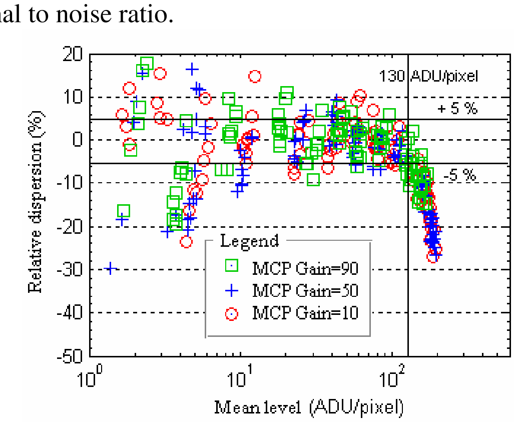

Figure 2: PROXITRONIC camera linearity defects

As for the new PRINCETON intensified camera (figure 3), sensitivity saturation defects are observed around 8000 ADU/pixel. We remark a weak dispersion level in linear mode with CCD captor cooling. Furthermore, captor dimensions allow the possibility to increase the analysis dynamic and signal to noise ratio by binning 2x2 operations.

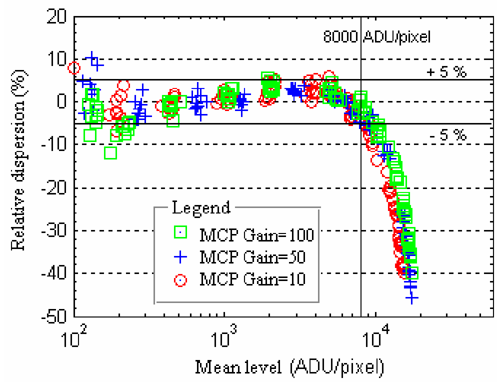

Figure 3: PRINCETON camera linearity defects

Absolute Gain Transfer Function

For this measurement, we use a 525 nm homogeneous pulsed DEL source. A calibrated CCD camera allows to measure the incident energy density. At the end of the experiment, we note that the sensitivity range covered by the PROXITRONIC camera when changing MCP gain from 10% to 100%, is the same as the one covered by the PRINCETON camera when changing MCP gain only from 50% to 100%.

Sensitivity Uniformity

This experiment is driven by a 525 nm pulsed DEL and an integral sphere of 40 mm diameter. For PROXITRONIC camera (figure 4), the response can be explained by the presence of the reducing cone. This study reveals that 95% of pixels are homogeneous in sensitivity at ±17%.

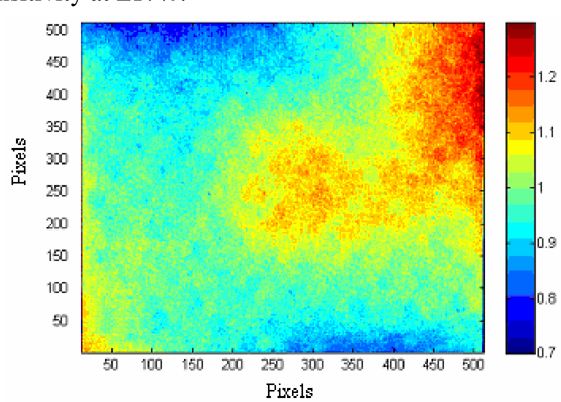

Figure 4: PROXITRONIC camera sensitivity defects

Concerning the new PRINCETON camera (figure 5), this is an unexpected profile. This behaviour reveals a bad O.F–O.F coupling between the CCD captor and the intensifier. 95% of pixels are homogeneous at only ±22%. In this point, the PRINCETON performances are disappointing in comparison with the PROXITRONIC camera which however includes a reducing cone.

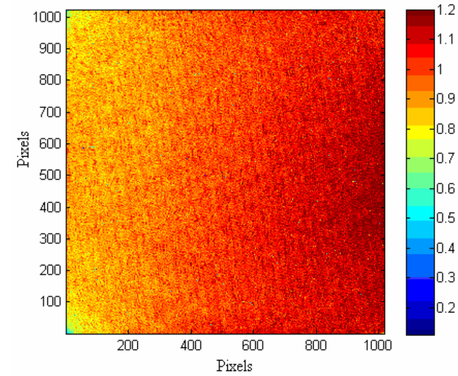

Figure 5: PRINCETON camera sensitivity defects

Signal to Noise Ratio

This characteristic is essential for a rigorous beam dimension measurement. By working with a 90% PROXITRONIC camera MCP gain (figure 6), signal to noise ratio is very low (≤ 5) even in the dynamic high part. Only 10% and 50% MCP gain values allows to reach a 10 signal to noise ratio nearly the saturation boundary (130ADU/pixel).

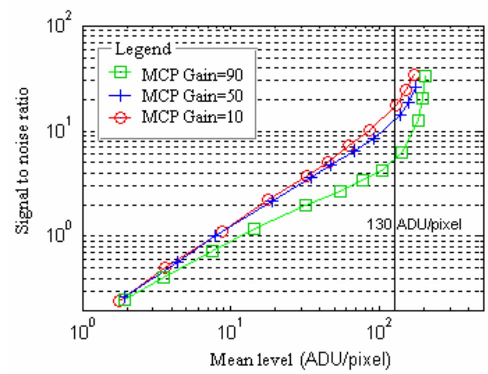

Figure 6: PROXITRONIC camera signal to noise ratio

With a 10% PRINCETON MCP Gain (figure 7), we can reach a 10 signal to noise ratio on a decade. This performance is made possible by the 16 bits CCD image resumption and the CCD captor cooling.

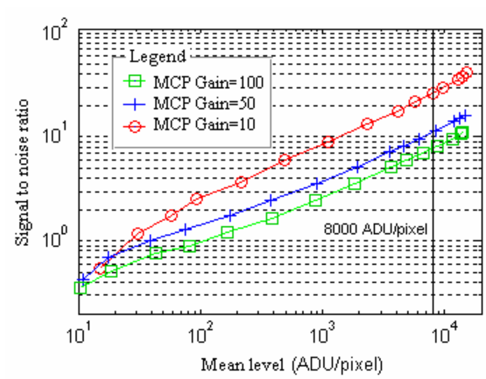

Figure 7: PRINCETON camera signal to noise ratio

Finally, by setting MCP gain to 50% for the PROXITRONIC camera, and to 10% for the PRINCETON camera, we obtain the same energetic sensitivity and we can establish an absolute comparison which reveals that the PRINCETON signal to noise ratio is 2.5 time better than the PROXITRONIC one.

Pixel Dynamic

$$D_{S/B\geq K} = \frac{A^{SAT}_{pixel}}{A^{Min}_{pixel}(S/B=K)} \qquad (1)$$

K corresponds to the minimum signal to noise ratio criterion to check on the [$A^{Min}_{pixel}, A^{SAT}_{pixel}$] range. From K=4, we considerate that is possible to quantify a localised information. Unfortunately, for K=4 and in usual configuration, the best PROXITRONIC pixel dynamic value is equal to 1.3 (against 33 with the PRINCETON camera and a 10% MCP Gain). This means that contrary to the PRINCETON camera, the PROXITRONIC camera does not allow to observe an important incident ray fluctuation except when adapted optical densities are used. Figure 8 is obtained from a 5 mm diameter circular homogeneous central lighting, after pixel level normalization.

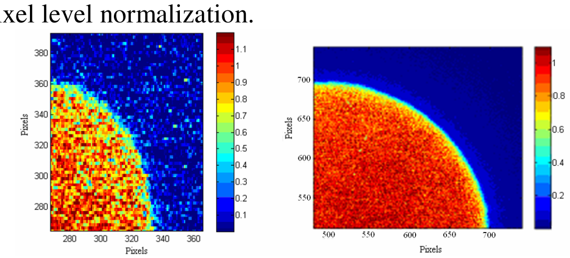

Figure 8: PROXITRONIC and PRINCETON acquisitions

INTENSIFIED CAMERAS EXPERIMENTAL CHARACTERIZATION

Injector Characterization Campaign

2 or 3 times a year, this campaign consists in validating the AIRIX injector working and determinating the beam characteristics to transport up to the X-ray conversion target. By varying the intensity inside the extraction magnet situated downstream the injector, and by studying the beam RMS dimension variations with the Cerenkov imaging diagnostic (3 gradient method), we deduce the beam emittance.

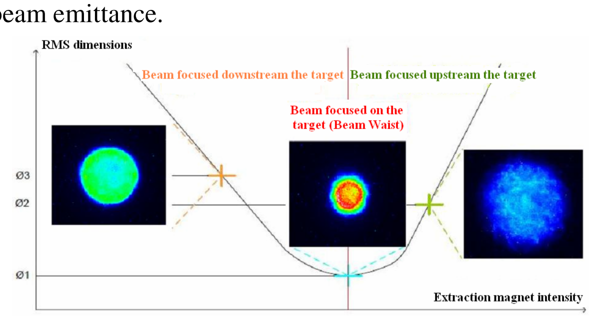

Figure 9: AIRIX emittance measurement

This measurement precision strongly depends on the image quality. This is why we chose this campaign to characterize experimentally and compare with the PROXITRONIC previous model our new PRINCETON intensified camera.

Results

The experimental points (figure 10) are extracted from a single treatment software. The aim consists in discarding all mistakes potentially introduced by different algorithms.

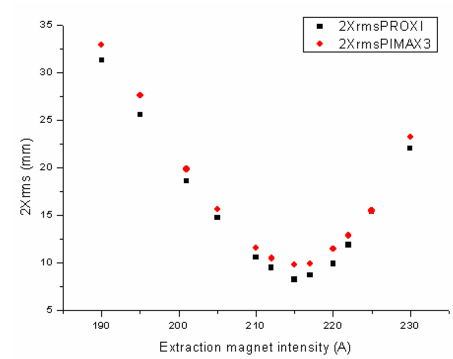

Figure 10: PROXITRONIC and PRINCETON results comparison (Xrms dimension only)

The AIRIX injector characterization campaign achieved with PROXITRONIC and PRINCETON cameras shows a similar variation of the beam RMS dimensions. In both case, the beam waist is obtained for a same intensity inside the extraction magnet. The light offset recorded between the curves can however be perceived as the possibility to optimize the electron beam transport and so the X-ray conversion efficiency.

CONCLUSION

In a first time, we have noted that the PRINCETON camera performances in term of linearity, signal to noise ratio and pixel dynamic was better (up to a 2.5 factor for signal to noise ratio and 25 for the pixel dynamic) than the PROXITRONIC camera ones. Furthermore, by setting up this new intensified camera during the injector characterization campaign, we obtained results witch confirmed our reference experimental points with a better information quality than with our previous camera model. Thus, the PRINCETON camera allows us to optimize the measurement chains currently deployed on AIRIX. The next step is to compare with the PROXITRONIC camera the other PRINCETON camera characteristics (in particular its capacity in term of exposure time), in order to develop new time resolved diagnostics, which could allow to acquire several images during a same pulse.

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