CONTRIBUTORS TO AIRIX FOCAL SPOT SIZE

N. Pichoff*, M. Caron, A. Compant-La-Fontaine**, D. Paradis, L. Hourdin, F. Cartier, D. Collignon, G. Grandpierre, M. Mouillet

SREF, CEA-DAM, Polygone d'Expérimentation de Morronvilliers, 51475 Pontfaverger, France

*SCEF, CEA-DAM, BP12, 91680 Bruyeres-Le-Chatel, France

**Département de Physique Théorique et Applications, CEA-DAM, BP12, 91680 Bruyeres-Le-Chatel, France

Abstract

High intensity electron beam focusing is a key issue for the successful development of flash radiography at hydro test facilities. AIRIX is a 2 kA, 19 MeV, 60 ns, single shot linear accelerator that produces X-rays from the interaction between relativistic electrons and a Tantalum solid target (Ta). A simulation tool has been developed to model the pulsed-beam dynamics through the accelerator from the cathode to the target. This simulator has allowed to estimate the contribution to the beam size on the target (focal spot) of beam emittance, pulse energy dispersion, pluse rising and falling fronts and the ion production on the target. The quantified contributions of these phenomena are review here.

INTRODUCTION

AIRIX accelerator [1] is providing high flux short X-rays pulses for radiography purpose. The X-ray pulse is produced from a high current (2 kA), 19 MeV, short (60 ns) electron pulse colliding a Tantalum target. The beam is produced on a velvet cathode in a 4 MV pulsed diode and accelerated through 64 induction cells to its maximum energy. It is then focused on the target with a solenoid.

The electron pulse is generated in the diode by a 110 ns pulsed high voltage (3.85 MV) with a two slopes 30ns rising front, a 60 ns steady state plateau and a 20ns falling front (Figure 1).

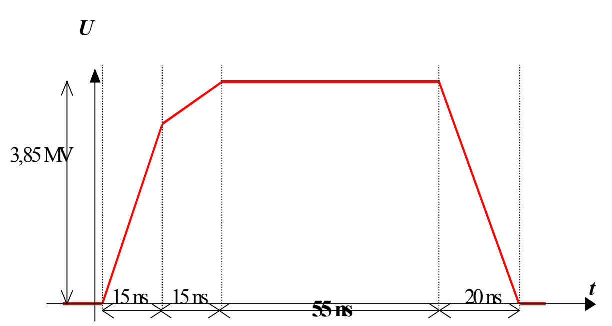

Figure 1: AIRIX diode voltage shape.

* nicolas.pichoff@cea.fr

A set of numerical tools have been developed and linked together in order to simulate the beam creation and transport to the target coupled to the X-ray production [2]. It allows predictions on the beam distribution on the target and the associated X-ray focal spot size.

5 contributors to this spot size have been identified:

- the transerve beam emittance,
- the beam energy dispersion,
- the pulse rising and falling fronts,
- the beam interaction with the target,
- the electron to X-ray transfer function.

The effect of all this contributions given by the code is reviewed in this paper and there relative influences are given.

CONTRIBUTION OF ELECTRON TO X-RAY TRANSFER FUNCTION

Experimentally, the X-ray spot size is measured on AIRIX, as it plays an important role in the resolution of the radiography.

The transfer function from electrons to X-ray is calculated with MCNP code injecting an initial zero size electron beam on the target. The induced X-ray spot size is then computed.

The contribution to beam size is mainly due to electron diffusion in the target.

The calculated contribution represents about 5% of the measured X-ray spot size. This is a marginal contributor.

CONTRIBUTION OF EMITTANCE AND ENERGY DISPERSION

Let's consider a parallel beam entering into the final focusing lens. The lens focal lens at nominal energy is f_0. The distance between the lens centre (modelled by a thin lens) and the target is L (figure 2).

The transfer matrix in one transverse direction between the lens entrance and the target is:

$$\begin{pmatrix} 1-\frac{L}{f} & L \\ -\frac{1}{f} & 1 \end{pmatrix}$$

$f = f_0 \cdot (1+\delta)$ is the focal length of the lens at a given momentum $p = p_0 \cdot (1+\delta)$.

This transfer matrix allows calculating the transport of the rms size from the lens entrance to the target, giving:

$$\left\langle x^2 \right\rangle = L^2 \cdot \frac{\varepsilon_x^2}{\left\langle x_0^2 \right\rangle} + \left\langle \left(1 - \frac{L}{f}\right)^2 \cdot x_0^2 \right\rangle .$$

with ε_x, the beam un-normalised rms emittance, and x the particle positions on the target and x_0 the particle positions at the lens entrance.

In order to minimize the beam size on the target, one takes $L = f_0$, leading to:

$$\left\langle x^2 \right\rangle = L^2 \cdot \frac{\varepsilon_x^2}{\left\langle x_0^2 \right\rangle} + \left\langle \delta^2 \cdot x_0^2 \right\rangle$$

Where the first term gives the contribution of emittance to the beam size and the second term gives the contribution of momentum dispersion.

Assuming no correlation between particles position and momentum, one gets:

$$\left\langle x^2 \right\rangle = L^2 \cdot \frac{\varepsilon_x^2}{\left\langle x_0^2 \right\rangle} + \left\langle \delta^2 \right\rangle \cdot \left\langle x_0^2 \right\rangle$$

Emittance and momentum dispersion contribute quadratically to the beam size on the target.

It can be shown that this size on the target can be optimised by choosing properly the beam size $\left\langle x_{0opt}^2 \right\rangle$ at the entrance of the last focusing lens.

$$\left\langle x_{0opt}^2 \right\rangle = \frac{L \cdot \varepsilon_x}{\left\langle \delta^2 \right\rangle} .$$

The associated beam size on the target is then:

$$\left\langle x_{\min}^2 \right\rangle = 2 \cdot L \cdot \varepsilon_x \cdot \delta .$$

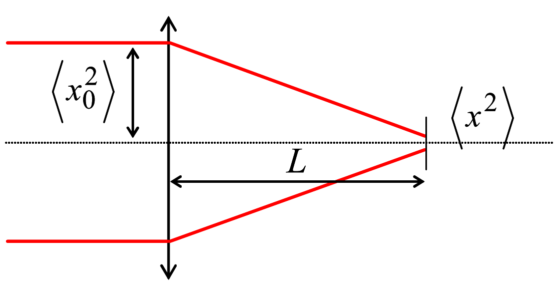

Figure 2: Focalisation with a thin lens.

On AIRIX, the beam emittance of the steady-state plateau is the results of the contribution of:

- the size of the emission surface on the cathode,
- the equivalent temperature of the emission at the level of the cathode,
- the non-linearity of the electric field in the diode, especially close to the cathode and the anode.
- the mismatch in the accelerating structure.

The beam energy dispersion is the results of the contribution of:

- the space-charge potential well between beam centre and beam borders,
- the induction cells voltage variation along the pulse,
- the varying beam loading along the pulse.

On the plateau of AIRIX pulse, the contribution to focal spot size of the emittance of a central slice of the beam (no energy dispersion induced by induction cells voltage variation) is about 20% of the measured one.

The contribution of the full plateau including the energy dispersion induced by induction cells voltage variation is about 30% of the measured one.

FRONTS CONTRIBUTION

At diode output, the pulses fronts contain about 20% of the beam particles. These particles do not have the right energy and do not carry the right current. Moreover, then do not gain the right amount of energy in the cells because of the transient beam-loading in the induction cells. One then observes a loss of a large amount of these particles in the accelerator and a very different transport in the accelerator. The model developed in the preceding paragraph is still valid but the beam size, its emittance, its divergence, its energy and its momentum spread is changing with time within the fronts.

In these conditions, the fronts are less properly focused on the target leading to an increase of the integrated beam spot size on the target.

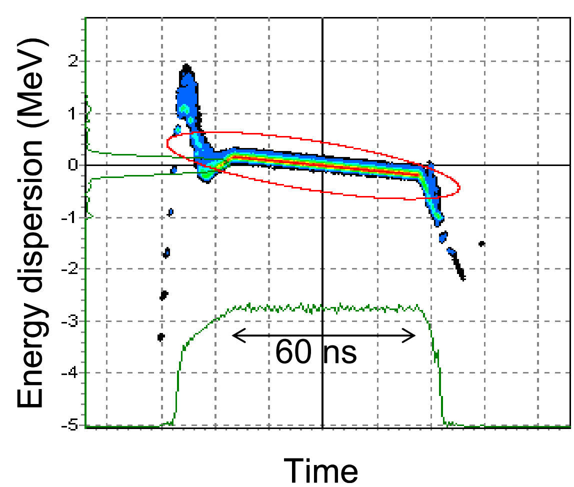

Figure 3: AIRIX beam calculated particle energy distribution with time.

The contribution of the full pulse including the energy dispersion induced by induction cells voltage variation and the fronts is then about 40% of the measured one.

BEAM TARGET INTERACTION

The beam is focused on the target within a very small size. It deposes a very high power density leading to a fast increase of target temperature. The target is then submitted to outgassing of previously absorbed water, hydrogen and evaporation of metal atoms. These atoms and molecules are ionized and dissociated by the beam. They are then accelerated by the beam space-charge electric field. These ions, accelerated upstream in the beam, produce intense electric field that modifies the beam focusing on the target (figure 4). The beam size evolves with time.

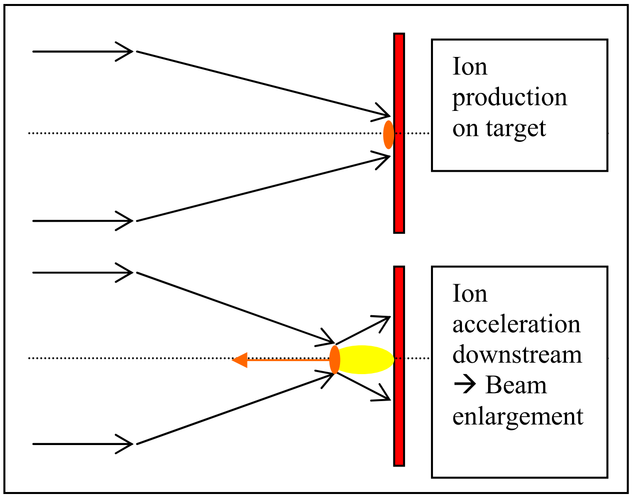

Figure 4 : Beam-target interaction.

The ion production is calculated and the associated particle dynamics is computed [3].

The ion production depends on the target composition especially at it surface. It depends on the residual gas pressure and composition in the vacuum chamber. This pressure has been experimentally investigated and injected in the model.

Calculations are made without any parameter adjustment and lead to a prediction of the focal spot size very close to this observed experimentally. As an example, figure 5 shows the evolution of the normalised X-spot size as a function of the current in the focusing solenoid. Experimental results have been compared to simulation results. Calculations are also done without ion emission for comparison.

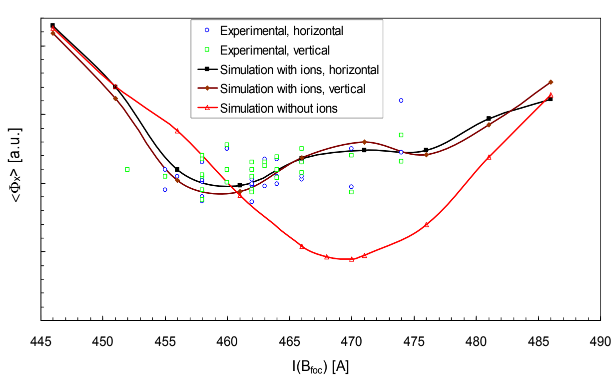

Figure 5 : Evolution of the AIRIX X-Ray focal-spot size as a function of the current in the focusing solenoid..

CONCLUSION

Contributions of different parameters to the focal spot size have been investigated. They are summarised on table 1.

Table 1: Calculated contribution of each parameter or effect on the focal spot size compared to measured one.

Electron-photon transfer	8%
+ Plateau emittance	20%
+ Plateau energy dispersion	30%
+ Fronts	40%
+ beam-target interaction	100%

The main effect is given by the beam interaction with the target. From this simulation, some modifications of the target configuration have been proposed leading to sensitive reduction of the focal spot size.

REFERENCES

[1] E. Merle et al., Progress with the 2-3 kA AIRIX electron beam, EPAC 2002, Paris, France, pp. 2649.

[2] N. Pichoff, A. Compant la fontaine, End to End Multiparticle Simulations of the AIRIX Linac, EPAC 2004, Lucerne, Switzerland, pp. 2598.

[3] A. Compant La Fontaine, Emission and Control of H+ Ions near an Electron-photon Conversion Target, EPAC 2002, Paris, France, pp. 1332.