HIGH INTENSITY HIGH ENERGY E-BEAM INTERACTING WITH A THIN SOLID STATE TARGET: FIRST RESULTS AT AIRIX

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Abstract

AIRIX is a 2 kA, 20 MeV, 60 ns linear accelerator dedicated to X-ray flash radiography. During a regular running phase, the primary electron beam is accelerated to and focused on a high atomic number target in order to generate X-rays by bremβtrahlung mainly. The huge energy density deposited into the material is such that temperature rises up to 15000°K and that clusters and particles are violently ejected from the surface. In that mechanism, the backward emission speed can reach 5 km s^{-1} and the debris can gradually accumulate and subsequently contaminate some sensitive parts of the machine. In order to protect the whole accelerating line from the detrimental effect of back-ejected particles, we have investigated the technical feasibility of a thin foil implementation upstream the X-ray converter.

INTRODUCTION

For X-ray sources like AIRIX [1] [2] [3] [4], a high flux short photons pulse results from a high current (2 kA), relativistic (20 MeV) short (60 ns) electron pulse interacting with a high atomic number target. E-beams are generated into a 4 MV pulsed diode cavity and then accelerated through 64 induction cells up to the nominal energy. At the last stage into the vacuum line the beam is strongly focused by means of a solenoid on a Tantalum surface. The fact that electrons deposit enormous amounts of energy into the solid in a small volume during a very short time period leads to a violent backward emission of dusts and debris as a result of the interaction. As a consequence, a tricky system called SAD, made of two full wheels whose each one contains an aperture protect the accelerating section from the debris. The two rotating wheels allow the beam to pass through when apertures are in coincidence but not the debris, provided that the synchronization requirements are fulfilled. In order to simplify the entire machine synchronization and to make the maintenance easier the goal we pursue aims to replace the whole SAD system by a thin conducting foil simply. As a first step prior getting rid-off the whole SAD system, we need to demonstrate the technical feasibility for the machine to deliver X-rays pulses relevant for flash radiography even in presence of a thin foil. The paper presents preliminary results dealing with the implementation of a 15 µm grounded Al foil as a debris stopping barrier.

THEORETICAL BACKGROUND

In order to describe from a theoretical viewpoint how high intensity e-beams are carried away along the accelerator a simulation tool has been developed. Based on the transport of the second order moments matrix, the so-called TRAJENV code is particularly well suited to the AIRIX e-beam description. The paraxial approximation is used and a KV distribution is assumed. The settings of the 70 solenoids and of the 32 high voltage generators from AIRIX can be defined by means of TRAJENV provided that beam properties at the anode level are known either experimentally or from a diode simulation. Moreover, physical models of the beam transport through a thin foil are included [5], taking into account both Coulomb scattering [6] and focusing effect [7]. Such a modelling was formerly checked by a set of experiments carried out on the AIRIX prototype [8]. Here, TRAJENV has been used in order to select the material, to set the foil thickness and to minimise the detrimental effects like straggling or focusing that the foil might induce on the beam propagation. The upper part of figure 1 exhibits the expected evolution of the e-beam envelop along the whole accelerator line. On the lower part, the zoom over the drift section shows that at first glances the thin Al-foil acts on the beam like a short focal lens. Nevertheless, the two guiding coils located downstream can be tuned in such a way that the beam reaches the analyser. The main conclusion drawn from figure 1 is that from the theoretical viewpoint the feasibility to drive a beam from the source to the X-ray converter is clearly demonstrated.

The set of experiments described in the next section aims to confirm the promising results given by the code and to asses the potential application to flash radiography.

EXPERIMENT

The experimental part of this work has been performed at AIRIX facility on March 2005. The first stage of the experimental approach was to make sure that the transport settings defined under TRAJENV were relevant to propagate the beam without any significant losses of particles. Then, the beam profiles have beam measured and the emittance growth has been quantified by means of the three gradients method.

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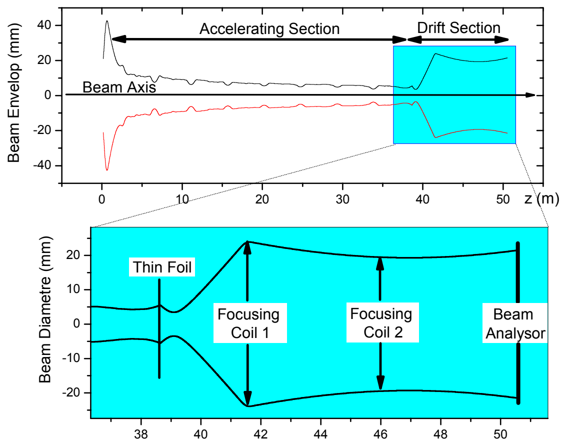

Figure 1: Expected e-beam envelops into the both accelerating and drifting sections from TRAJENV. Reported positions correspond to the experimental arrangement.

Analysis of Electrical Diagnoses

Optimum e-beam transport requires a drastic centring of the beam near the accelerator axis to keep corkscrew effects and Beam Break-Up instabilities at a negligible level. Based on a Beam Positioning Monitor network, the motion of the beam centre in the both (x,y) transverse directions can be monitored.

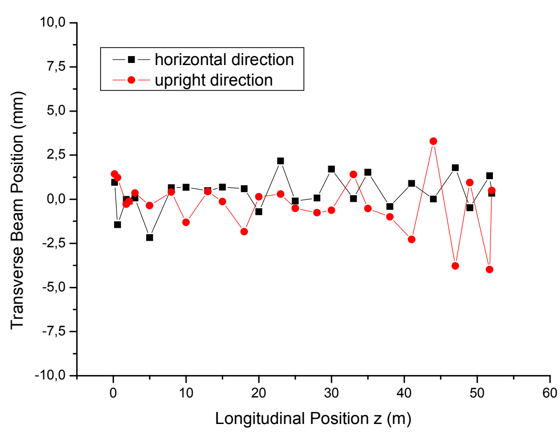

Figure 2: Beam centre motion from the diode to the X-ray converter.

As shown in figure 2, even if a refined and careful centring procedure has not been carried out for this specific experiment, the tuning of the steerers was performing enough to keep the beam in the vicinity of the machine axis.

The conclusion we draw from this curve is that the beam propagation from the diode to the X-ray converter remains under control even if a thin Al-foil is inserted through the beam path. On the two next figures, the potential loss of primary particles has been investigated. The BPM signals recorded right downstream the foil and plotted in figure 3 seem to indicate that mainly the front edges are affected by the electron-solid interaction.

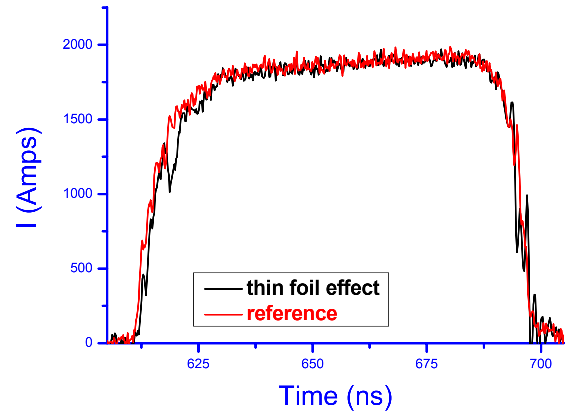

Figure 3: First BPM signal downstream the foil for a beam shot with the foil put into (black curve) or removed from (red curve) the line.

Actually, some particles are also missing on the top of the pulse. Figure 4 represents the net loss of charge per BPM from the diode to the X-ray converter. The primary current intensity is averaged over 45 ns on the top flat signal. Therefore, front edges effects are not included into figure 4. As expected, no loss is observed upstream the foil but a take-off occurs downstream, meaning that the top flat primary current is roughly 7% lower on the Ta target when the foil is used.

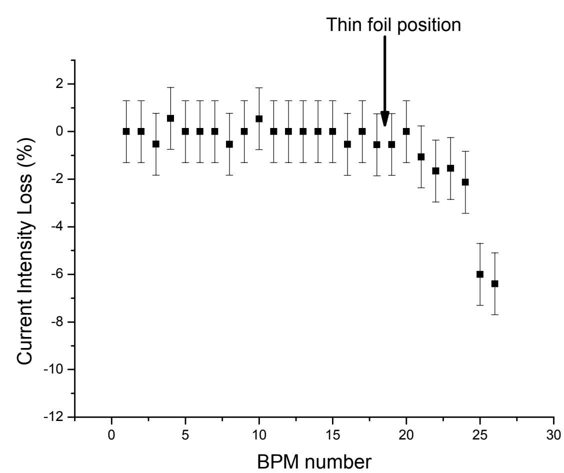

Figure 4: Current intensity loss in percentage as a function of the BPM number.

In order to evaluate how many electrons are missing, an accurate integration over the entire pulse period of time (front edges included) leads to a net total loss of about 10% at the X-ray converter (130μC instead of 143μC). From these results, it may be concluded that the loss rate of primary particles still fits the dose requirements for flash radiography.

Beam Imaging Analysis

With a space charge dominated beam, emittance (ε) is quite difficult to be measured. For our purpose, a 2D gated camera (512 x 512 pixels^2, 8 bits, 5 ns minimum exposure time) has been used to record the Optical Transition Radiation (OTR) that is produced when a primary electron crosses the interface of the analyser. The beam size dependence with the solenoid current intensity has been investigated (focusing coil 2 with respect to the figure 1 arrangement) and ε has subsequently been deduced from the well known three gradients (3-G) method. The experimental data have been reported in figure 5 as well as the result of a TRAJENV calculation in which the 3-G results have been used as inputs. The main outcome from this analysis is that passing through the foil leads to an increase of ε by a factor of 2.1.

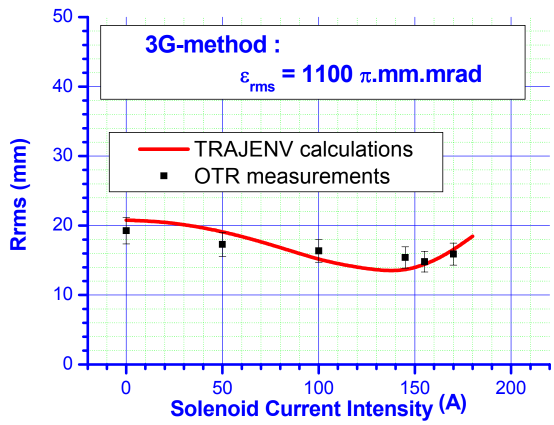

Figure 5: Beam radius evolution as a function of the current intensity drawn into the second focusing coil with respect to figure 1.

X-ray Source Performances

Due to the 10% loss of electrons we expect to get a dose level of about 315 rads instead of the usual 350 rads. This dose level is taken in a specific material [delrin®] not in air and 1 meter away from the source on the beam axis.

The second parameter of interest to qualify a X-ray source for flash radiography is the dimension of the focal spot. The very first measurements performed at AIRIX show that a 3.1 mm diameter focal spot is obtained. The focal spot determination has been performed by means of the well known classical infinite absorbing roll-edge method. The black to white transition analysis makes it possible to deduce the source dimensions. When the thin Al-foil is removed the standard values are ranging from 1.9 to 2.2 mm. The focal spot growth is a direct consequence of the ε growth observed on the electron beam.

CONCLUSION AND OUTLOOK

Some preliminary results dealing with e-beam solid interactions have been reported. The driving force for this kind of investigation is supported by the possibility to replace by a simple conducting foil the present tool dedicated to prevent debris for flowing upstream. The technical feasibility for both guiding and centring a beam even when it passes through a 15 µm thin aluminium foil has been clearly demonstrated. The net electrical charge loss in the pulse and the beam emittance growth have been quantified and found compatible with X-rays flash radiography requirements. At this very moment, all these results look promising but need further confirmations and developments. The main issues we will have to face in a near future concern the mechanical resistance of the foil to the cumulative beam irradiations and to the debris bombardment.

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REFERENCES

[1] E. Merle, M. Mouillet, O. Pierret & C. Vermare "Efforts to Improve Intense Linear Induction Accelerator (LIA) Sources for Flash Radiography", Proc. of LINAC 2002.

[2] M. J. Burns, "DARHT Accelerators Update and Plans for Initial Operations", Proc. of PAC 1999.

[3] E. Merle, J. Delvaux, M. Mouillet, O. Pierret, J.C. Ribes, J. Bardy & A. Devin "Transport, optimization and characterization of the 2 kA AIRIX Electron Beam", Proc. of LINAC 2000.

[4] E. Merle, "Progress with the 2-3 kA AIRIX Electron Beam", Proc. of EPAC 2002.

[5] O. Mouton, "Effets physiques subits par un faisceau relativiste à la traversée d'une feuille mince métallique.", Journées accélérateurs de la SFP, Roscoff (2001).

[6] E.J. Williams, "Multiple Scattering of Fast Electrons and Alpha-Particles, and 'Curvature' of Clouds Tracks Due to Scattering.", Phys. Rev 58, 292-306 (1940).

[7] R.F. Fernsler, R.F. Hubbard & S.P. Slinker, "Foil focusing electron beams", J. Appl. Phys. 68(12), 5985-5994 (1990).

[8] O. Mouton & D. Guilhem, "Thin foil physical effects on the transport of an intense relativistic electron beam", Proc. of EPAC 2002.