EFFORTS TO IMPROVE INTENSE LINEAR INDUCTION ACCELERATOR (LIA) SOURCES FOR FLASH RADIOGRAPHY

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Abstract

Flash radiographic facilities like AIRIX, DARHT Axis 1 or FXR, are based on an intense single pulse LIA (2-3 kA, 20 MeV, 60 ns).

Improvement of X-ray source performance can be accomplished by reducing the source size. Source size improvement can be made by decreasing emittance, energy spread or beam motion.

For the above accelerators, intense electron beam generation uses a field emission velvet cathode and can be improved to minimize the beam emittance. Recent theoretical studies have demonstrated that a Pierce geometry of the cathode assembly can reduce the emittance. Subsequent beam transport must preserve this emittance by reducing growth due to beam thermalization effects (for example).

Associated with the beam transport studies, the development of advanced diagnostics is necessary. We describe here the OTR/Cerenkov based diagnostics that will permit simultaneous measurement of the beam radius and mean divergence (from 4 MeV to 20 MeV).

The last topic listed here is the physics of the electron beam impinging on the target. The approach chosen is based on a time resolved X-rays spot size measurements to directly evaluate those effects on the radiographic performance.

1 INTRODUCTION

The AIRIX [1] and DARHT Axis 1 [2] flash radiographic facilities have been in operation for two years. The X-ray source performances are very similar and satisfy the project objectives. Nevertheless, to insure the performances during the time life of those machines, it appears crucial to keep a curious and innovative spirit. More, those installations can be improved by working on needed upgrades pointed out during the commissioning and construction phases. A good example is the FXR facility, based on a linear induction accelerator constructed 20 years ago, which is still active and upgraded [3].

We present in this paper the first ideas that we think important for the AIRIX improvement. What are the predicted ways we can explore, to minimize the AIRIX focal spot? We can distinguish two different fields: one concerns the accelerator, from the injector until the last focusing magnet, the other groups all the aspects of the physic of the electron-X-ray conversion.

Based on the effective exchanges with the DARHT project, in place since the beginning of the construction phase, some of those studies are made in collaboration with the DARHT team.

The first part deals with the electron source that can be improved by modifying the cathode geometry. The second part is dedicated to the electron beam transport and the specific optical diagnostics development needed. The last part is about the necessity to develop a time resolved X-ray spot size diagnostic as a preliminary observation to improve the electron-X-ray target conception.

2 DIODE MODIFICATION

An emittance reduction of the beam focused on the target should decrease the spot size. The two correlated processes for that are to minimize the emittance at the source (the injector) and to minimize its growth along the beam transport down to the target.

The AIRIX injector is very similar to the DARHT Axis 1 one [4]. The plastic insulator stack used does not permit a vacuum level less than 4.10^{-6} Torr and this limitation leads the use of a cold cathode. The plans we are developing, are to change the design of the cathode itself, with respect of the overall existing hardware of the diode [5].

For the diode modeling, a Maxwell-Vlasov 2D code (M2V [6]) is used. It is based on an explicit finite volume method for the grid description and a particle-in-cell method for the beam. The particles are injected using the Child-Langmuir theory. Their propagation is calculated step-by-step taking into account the field created by the external structures and the self-consistent field generated by the beam itself.

In the actual cathode of AIRIX (flat geometry), the emittance tuning can be achieved using the velvet recess with respect to the shroud of the cathode. We have then to find the optimum of the main two parameters of the flat cathode design: the velvet diameter which is proportional to the square root of the emitting current and the velvet recess that increasing as the emittance decreases.

Nevertheless, the cathode geometry can generate some electromagnetic instabilities coming from the field stress existing in very local parts of the cathode support: small radius curvatures are a well-known example. To minimize those instabilities, that are propagated during the beam transport, a new cathode geometry, where all the cathode support curvatures are maximised, can be defined.

Figure 1 shows a schematice of the flat cathode and its evolution to a Pierce geometry one.

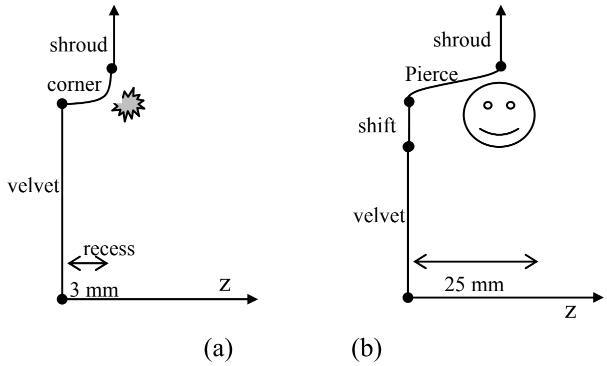

Figure 1: Cathodes geometry: a: flat; b: Pierce.

The M2V code simulations can give the envelope of the beam. The results obtained are consistent with the values calculated using the classical envelope code 'ENV'[7].

We observe the change of phase space beam parameters along the z propagation axis and particularly the emittance. In a first approach, this parameter was considered as a constant along the beam propagation, but this PIC code calculation shows us that this parameter changes quickly. The Figure 2 presents a first calculation made for a 3 kA flat cathode (a), and a second calculation made with a 3 kA Pierce cathode (b). We can see that the flat cathode emittance can be more than twice the Pierce geometry one after 1 m. But this gain is lost at the entrance of the accelerating cells.

This emittance behaviour can be explained by the beam thermalization effects (non-linear space charge effects in the A-K gap compensated non-linear field in the solenoid). This effect can be minimized by optimising the transport in the drift tube existing between the injector and the first gap. For that purpose, we can adjust a solenoid in this section [8] to preserve the emittance. The results obtained are plotted on the same Figure 2 (c and d) for the two cathodes.

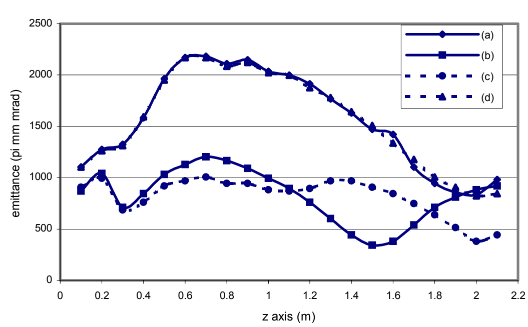

Figure 2: Emittance evolution along the z propagation axis for a beam emitted by a: (a) flat cathode, (b) Pierce geometry, (c) flat cathode with a new solenoid, (d) Pierce geometry cathode with a new solenoid.

In the DARHT Axis 1 accelerator case, the distance between the injector and the entrance of the accelerator is less than 1.7 m. So, it is not useful to adjust a solenoid at this time. An experiment planed at the end of this year, will demonstrate experimentally if this theoretical conclusion is valid. To perform this check, we plan to measure the emittance at three locations between the injector and the accelerator. We will compare the Pierce and flat cathode experimental results with the calculations. The beam parameters will be measured with a OTR diagnostic that is presented in the next part.

3 OTR/Cerenkov OPTICAL DIAGNOSTIC

To describe the beam, accurate diagnostics need to be used to measure the different parameters. Emittance is the most difficult parameter to measure, with a space charge dominated beam. The pepper-pot and the three gradients methods are the essential well-known tools to measure the emittance. Currently, we use the second former.

The properties of the Optical Transition Radiation (OTR) can be used for a complete description of the electron beam parameters. Recent works show that those properties are usable for intense (> 1kA) and medium energy (3-20 MeV) electron beams [9]. The OTR, that is produced when a charged particle passes through an interface, has a non-isotropic emission of light [10]. The next figure presents an artist view for the backward OTR lobes produced by a 4 and 20 MeV single electron.

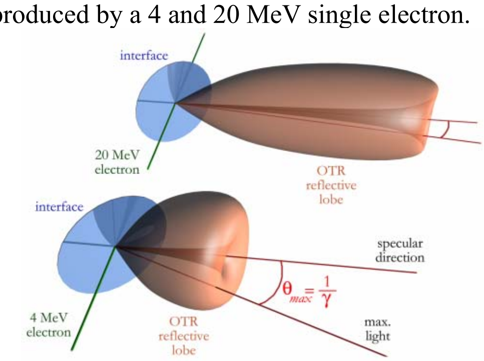

Figure 3: backward OTR lobes produced by a 4-20 MeV single electron.

Each single electron constituting the beam will produce an analytically defined light depending on its energy and its trajectory with respect to the normal vector of the interface. The total light emitted contains some mean parameters of the beam phase space.

To measure the angular image of the total lobes, an image is formed on a diffuse screen, placed in the focal plane of a lens system. The 'donut' like image obtained is a projection of the total emission cone.

To analyse the image obtained, a Fortran / IDL code system has been developed. This solution contains a beam generation program, the main 3D OTR ray-tracing code and IDL tools for analysis. The idea is to build a data-base of OTR images corresponding to different beam phase space and use the results to fit experimental data. The input of the ray-tracing code is a file containing the incident beam description. This can be generated by a specific code already written or by any PIC or transport code. The "OTR_ray" program simulates the generation of OTR photons and transports them up to the final image plane. Many runs have been made for elementary cases in order to study the influence of the different e-beam parameters on the global OTR pattern: offset and tilt of the incident beam with respect to the accelerator axis, energy effect, RMS angular distribution, RMS beam size, phase space distribution model. The relevant one are summarised on the Figure 4.

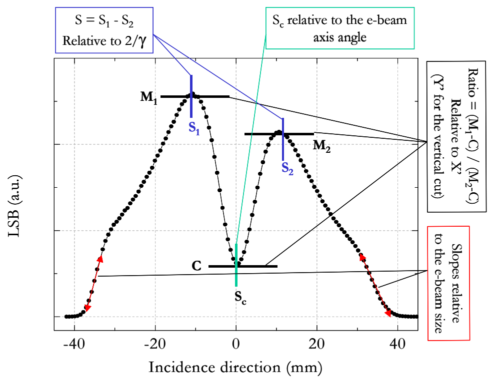

Figure 4: OTR lobe parameter sensitivities.

For the transport physics, the most important parameter is the mean angular dispersion (X'rms or Y'rms) of the beam. Using the Cerenkov light on the other side of the target, we can obtain the Rrms. Rrms and R'rms are directly linked to the beam emittance if the measurement is made at a waist. If it is not the case, a direct comparison with the simulation value of R'rms could be done. The precision of this measurement was evaluated around 1 mrad at 20 MeV.

This new kind of measurement has been developed and tested on DARHT-1 [9]. Some improvement of the optical part and calculations are yet under development [11]. Having the same optical diagnostic system on the both machines will be crucial to make efficient comparisons and common studies.

4 THE X-RAY CONVERTER

The other way to obtain a smaller focal spot size is to continue the studies made around the electron-X-ray conversion. A recent change on the DARHT first axis target box design lead to a significant smaller spot size without clear explanation. Because it was a difference listed between the two machines, the approach chosen was to adapt an AIRIX like design.

One possible explanation is based on the effect of positive ions. Experiment and calculations are in progress on DARHT Axis 1 about this subject for DARHT Axis 2 [12]. We have not demonstrated that this could be a limitation for the AIRIX and DARHT Axis 1 focal spot size. To observe this, it will be necessary to develop a diagnostic that could measure the evolution during the pulse of the focal spot.

The measurement of the focal spot is made with the classical infinite absorbing roll-edge method. The value of the focal spot is deduced from the analysis of the black/white transition of the image obtained. To replace the film, we can use a fast (few ns) scintillator associated with a fast gated camera or a streak camera.

We have begun experiments on the 1.5 MV machine ANGELIX. At 20 MeV, this measurement could be complicated by the diffusing X-ray that become crucial. Also, the electronic system has to be out of the X-ray lobe. So, one part of the challenge is to develop a scintillator that produces sufficient light with a minimum temporal resolution. The other part is to optimise the optical measurement system that contains the streak camera as to extract the significant information from the X-ray source.

5 CONCLUSION

We have presented, in this paper, some ideas to upgrade the AIRIX or DARHT facilities in the next year. Of course this list is not exhaustive. Also, under consideration is minimization of the BBU oscillations. This will minimize the emittance growth and beam motion at the target but no experiments are planned as yet. Specific beam transport codes are also under development

Efforts will be focused on advanced optical or X-ray diagnostics development. The two teams will continue to exchange knowledge and efforts to insure the development of wanted improvements.

6 AKNOWLEDGMENT

We would like to associate to this paper the both team of DARHT and AIRIX. And place a special thanks to M.J. Burns who was an initiator of those exchanges and also to H. Davis.

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