IDERIX : AN 8 MV FLASH X-RAYS MACHINE USING A LTD DESIGN

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Abstract

For future flash radiographic needs, an 8 MV radiographic machine, IDERIX, will be developed for the CEA / PEM. This machine will be composed by ~80 super fast LTD (Linear Transformer Driver) stages. The output voltage of each of these stages (100 kV – 75 ns) will be inductively added along a ~20 m stepped magnetically insulated transmission line to deliver the power up to the beam diode. In each stage, 16 bricks, made with two 8 nF capacitors (that can be charged up to +/- 100 kV) and one multi-channels multi-gaps switch, are arranged in parallel (with a star pattern). The number of bricks is chosen to adapt the stage impedance to the diode impedance and operate the LTD generator close to matched mode. Moreover, new magnetic cores using a thinner ferromagnetic tape (50µm) allow reducing the losses and improving the performances of the generator. The insulation inside the stage will be done using dielectric oil.

Downstream, the vacuum transmission line will be connected to a diode. The Negative Rod Pinch diode geometry has been studied and tested up to 6 MV on the ASTERIX generator since 2004. In 2006, a 2 meters MITL with the same geometry than the foreseen end of the future LTD generator, has been added to ASTERIX to mimic the IDERIX power feed and evaluate the possible impact of the large electron flow on the diode performances. Thus a dose of 70 rads at 1 m and a spot size of 2 mm (LANL/CEA definition) have been obtained. Simulations predict that those performances should increase at 8 MV and should satisfy the specification asked to IDERIX.

A global description of the machine followed by an update on generator and diode studies will be proposed

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I. WHAT'S IDERIX?

IDERIX is the future mobile flash X-rays machine of the CEA. IDERIX will allow in a first time, defining future radiographic needs for CEA, and in a second time, completing the flash X-rays accelerator AIRIX for hydrodynamic experiments. Figure 1 is an artist view of IDERIX.

This machine will be a pulsed power generator driving a beam electron diode. The pulse power generator is based on the Linear Transformer Driver (LTD) technology pioneered by the Institute of High Current Electronics in Russia.

The electrical specifications of this machine are a maximum voltage of 8 MV at the diode and a Full Width at Half Maximum (FWHM) of the pulse shape under 75 ns for a load impedance ~ 50Ω. The X-rays specifications are a dose of more than 100 rads at 1 m and a spot size under 2 mm with the LANL/CEA definition.

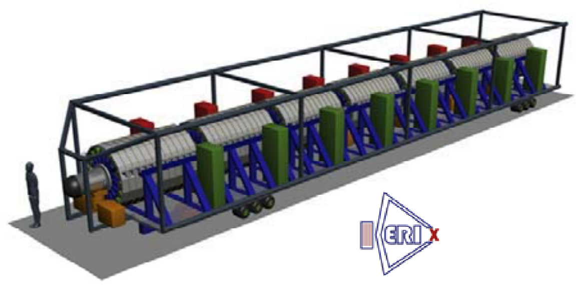

Figure 1. Artist view of the flash X-rays machine IDERIX

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II. DESCRIPTION OF THE PULSED POWER GENERATOR

In the Linear Transformer Driver technology, the low inductance energy storage components and switches are directly incorporated in the individual cavities (named stages) to generate a fast output voltage pulse which is added along a vacuum coaxial line like in an Inductive Voltage Adder (IVA). The output voltage of such system is also a function of the number of stages. Figure 2 describe its principle.

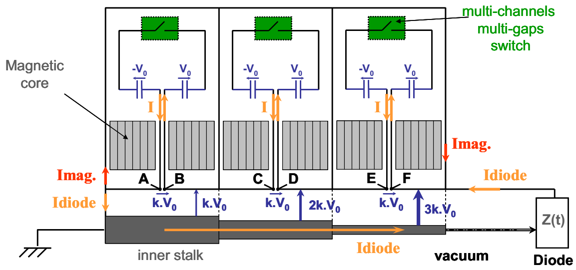

Figure 2. Principle scheme of LTD voltage addition

This technology has been adapted to radiographic application by reducing the pulse duration. The 1 MV module of the Sandia National Laboratories (Figure 3) is the first adapted LTD system. It is constituted of seven LTD stages and delivers more than 1 MV with a pulse duration of about 120 ns [1]. The main difference of this system is that it is using peaking capacitors to sharpen the output pulse. Here such components have not been used to simplify the design and increase its reliability.

Figure 3. Photography of the SNL 1 MV LTD module

The IDERIX generator will be an addition of at least 80 “super fast LTD stages”. A prototype of these stages has been developed by IHCE/ITHPP in order to reduce the pulse duration at 75 ns. Figure 4 is a photography of the prototype. The super fast LTD stage contains 16 bricks with reduced capacitance compared to previous LTD stages. This allows indeed to fastened the output pulse ~ $\sqrt{LC}$. The bricks are made with two 8 nF capacitors and one Multi-Channels Multi-Gaps switch. For the dynamic insulation during the pulse, new magnetic cores made with thinner ferromagnetic material are used and allow reducing magnetic losses. The insulation inside the stage is made with dielectric oil.

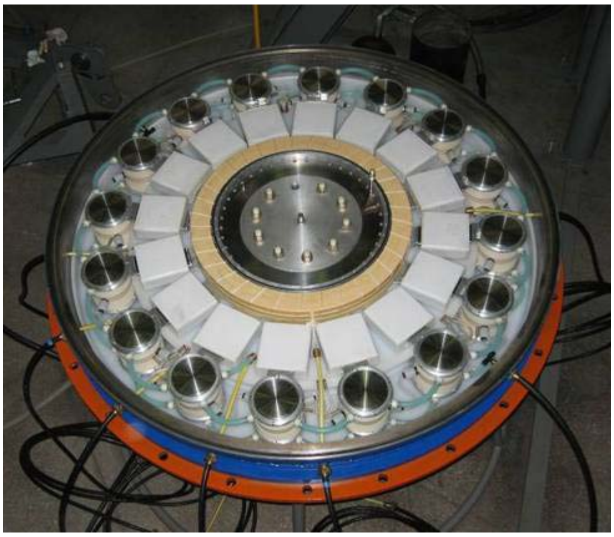

Figure 4. Photography of the first super fast LTD stage

The performances of the prototype stage after tests proceeded by IHCE/ITPP are presented at this conference [2]. In matched mode (R_{load} ~ 0.6 Ω), the output voltage is about 110 kV and the FWHM is about 75 ns. During this campaign, the high reliability of this stage has been proven: than more 1500 shots have been made with only two prefires.

III. SIMULATION OF THE PULSED POWER GENERATOR

A possible approach to simulate the IDERIX pulsed power generator is to use a circuit code like Pspice. The electric scheme of figure 6 can be used to model the super fast LTD stage. In this model, the energy storage is simulated by a simple RLC circuit: C_{stage}, L_{stage} and R_{stage} represent respectively the capacitance, the inductance and the resistance of the 16 bricks in parallel. A parallel resistor (R_{core}) allows simulating the losses in the magnetic cores. Finally the load is simulated by the resistor R_{load}. This model compared with experimental results for 3 values of load resistor (0.32 Ω, 0.6 Ω and 1.2 Ω) give a good approximation of the stage behavior (Figure 6).

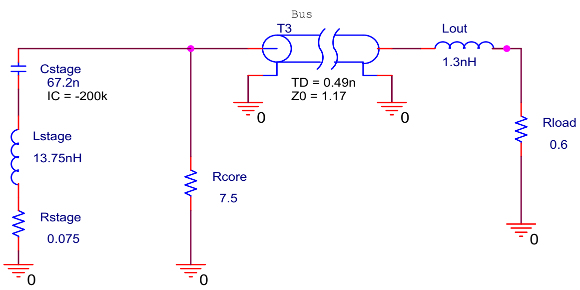

Figure 5. Electric circuit used to simulate the super fast LTD stage

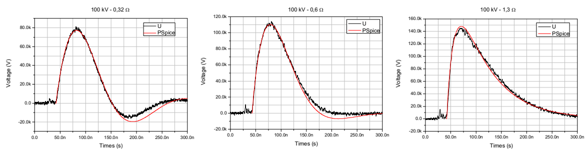

Figure 6. Comparison between circuit simulations and experimental results

Figure 7 shows the Pspice circuit used to simulate the generator in its totality: each stage circuit is connected to an element of the vacuum transmission line which impedance is increasing in order to be matched at the voltage addition. At the end of the generator is connected a resistance representing the diode impedance. The geometric impedances of these line sections are defined in order to operate with equivalent impedances Zeq (according to Creedon's model [3], [4]) when the electric field is higher than the emission threshold and that electrons are flowing with magnetic insulation into vacuum.

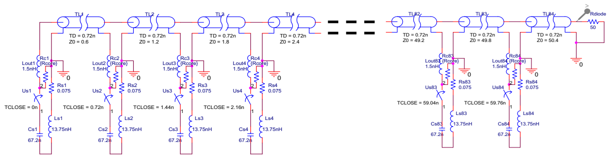

Figure 7. Pspice circuit used to simulate the pulsed power generator of IDERIX

However, the Particle In Cell code LSP is used to more precisely take into account the electron emission and the flow in the vacuum transmission line due to the high electric field. Figure 8 presents the 2D cylindrical geometry used for LSP simulations. The vacuum coaxial line has been designed with the Creedon's approach taken into account in the previous circuit simulations. At each gap is connected a stage circuit similar to the Pspice model. The line ends by a basic large area emissive diode.

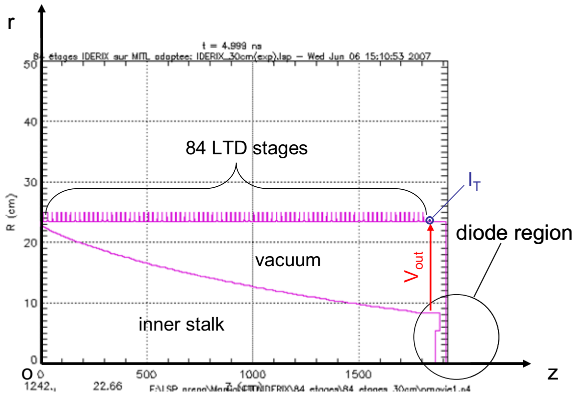

Figure 8. LSP geometry to simulate IDERIX

Figure 9 is a representation of the electron flow in the vacuum line at the time t=65 ns. You can see in this picture the electron front emission loss before the line becomes magnetically insulated. Figure 10 compares output voltages simulated with Pspice and LSP. These voltages reach about 8 MV. The differences during the rise time are due to the line losses when electrons are emitted. In figure 11 are displayed the total current and the electronic current due to the electron flow in the line. About 57 % of total current is flowing into the vacuum region.

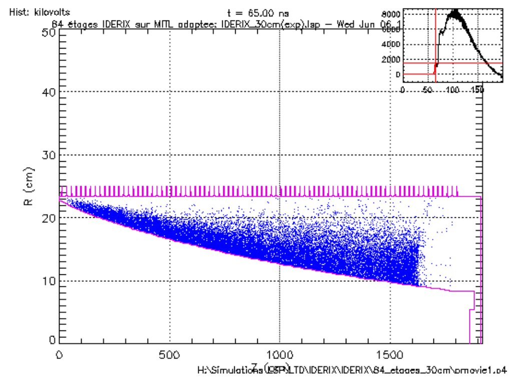

Figure 9. View of the electron flow in the IDERIX vacuum line at the time t = 65 ns.

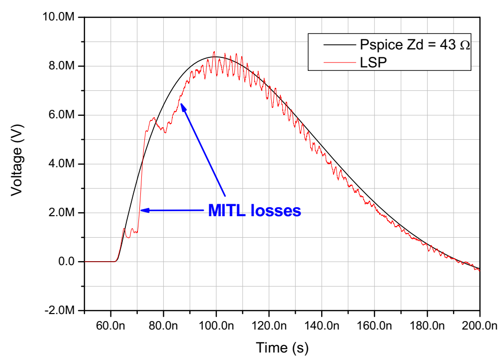

Figure 10. Comparison between LSP and Pspice results for the voltage after the last stage

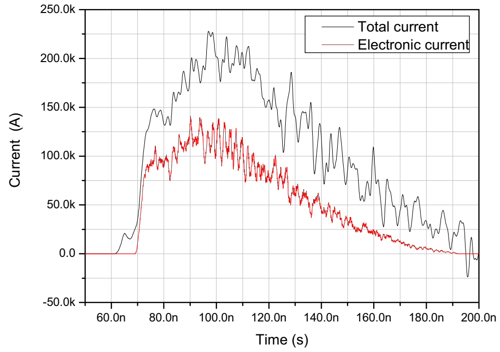

Figure 11. LSP results for the total current and electronic current due to the electron flow in the line after the last stage

IV. THE ELECTRON BEAM DIODE

The main electron beam diodes studied today for radiographic application are the self magnetic pinch diode, the paraxial diode, the rod pinch diode and the Bz diode. At CEA, we have focused our efforts on two of them during the last years.

The first is the self magnetic pinch which was tested on the generator ASTERIX of the DGA/CEG. Figure 12 is a photography of this diode, designed with LSP simulations. At 4 MV (AK gap voltage confirmed with a Compton spectrometer), the performance obtained are a dose of about 140 rads at 1m and a spot size of about 4 mm (LANL / CEA definition).

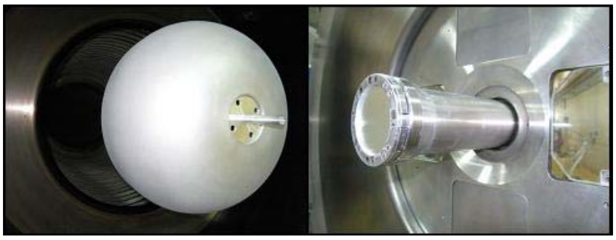

Figure 12. Photography of the cathode (on the left) and the anode converter (on the right) of the self magnetic pinch diode

The second diode studied at CEA is the negative rod pinch diode tested since 2004 on ASTERIX. In 2005, a Magnetically Insulated Transmission Line has been added at the end of the generator to mimic the vacuum line of IDERIX and study the interaction of the electron flow with the diode. Figure 13 is a picture of this MITL and of the rod pinch diode connected at the end of the ASTERIX cathode. With this diode, the performances obtained at 4 MV are a dose of 70 rads at 1 meter and a spot size of about 2 mm (CEA / LANL definition)

Figure 13. Photography of the MITL added to ATERIX generator (on the left) and of the rod pinch diode (on the right)

Today the nominal diode of the IDERIX machine is not chosen. Both studied diodes gave promising results at lower voltage.

V. PERPECTIVES

Collaborations with the SNL around the first 1 MV module in the near term will give us a lot of information about LTD systems: behavior, reliability, benchmark with simulations, etc. Moreover fault studies on this system should also confirm the robustness of this technology.

The building of the IDERIX machine will begin in the early 2008. The first step will be the development and test of a 1 MV LTD module based on the tested prototype stage. This system will allow validating stages integration, system effects and voltage addition along a MITL. In parallel will start the production in series of the stages of IDERIX.

Diodes studies will continue in order to optimize their geometries and their coupling with the power flow in the MITL.

The commissioning of the IDERIX machine at the CEA is planed in 2011.

VI. REFERENCES

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