GEPI : A COMPACT PULSED POWER DRIVER FOR ISENTROPIC COMPRESSION EXPERIMENTS AND FOR NON SHOCKED HIGH VELOCITY FLYER PLATES *

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Abstract

GEPI is a pulsed power generator developed by ITHPP for Centre d'Etudes de Gramat (CEG), devoted to Isentropic Compression Experiments in the 1Gpa to 100Gpa (1Mbar) range, and to non shocked high velocity flyer plates in the 100 m/s to 17km/s range.
The main idea is to generate a high magnetic pressure in a strip line where the samples are located. The whole design is based on low inductance technologies.
Depending on the load, the current reaches between 3 and 4 MA in 600 ns. The entire design has been done in a cost effective way and in order to achieve an easy-to-use capability. A description of the generator is shown and typical results of the studies led by CEG are presented. The matters of concern are equations of state, phase transitions and impact of high velocity flyer plates.

I. INTRODUCTION

Usually, high pressure experiments use shock loading techniques to determine the pressure-volume-energy response of a material, along a path referred to as the Hugoniot. But there are many applications where loading paths differ from the Hugoniot and are closer to isentropic loading ones [1]. The first studies concerning Isentropic Compression Experiments (ICE) using a magnetic field generated with pulsed power techniques were performed at Sandia National Laboratories on Z and published in 1999 [2][3]. This idea has been adapted using a strip line geometry in order to improve the efficiency and the compactness of this technique [4][5], by CEG and the company ITHPP. A generator called GEPI has thus been developed by ITHPP for CEG to study dynamic behaviors of materials [6] : equations of state (EOS), phase transitions, elasto-plastic transitions, high velocity flyer plates,…
The GEPI facility is first described, and main experimental results are then discussed in order to show the potentialities of such a technique.

II. THE GEPI FACILITY

The first version of GEPI went on line in 2001. A modification was performed in order to improve the maximum current and its shape in 2002.
The global dimensions are LxWxH=6mx6mx2.5m. A picture is presented in Fig. 1.

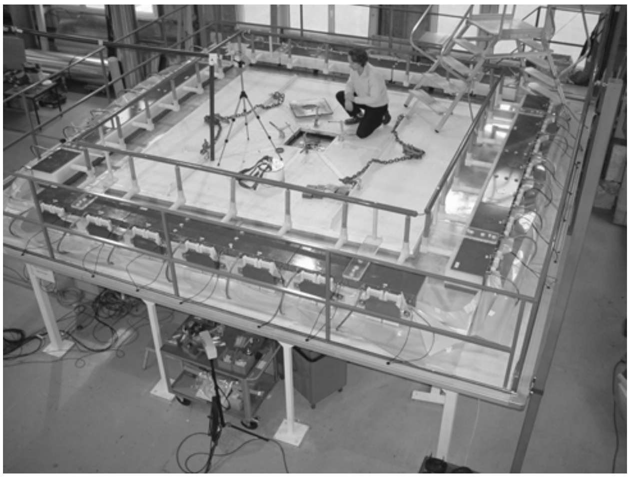

Figure 1. Picture of GEPI.

A. Technology and characteristics

GEPI is a low inductance generator. The primary storage is made of 28 stages connected in parallel. The total energy stored is around 70kJ for a 85kV charging voltage. The total capacitance is 20µF.
Each stage holds 4 caps and a low inductance multi-gaps multi-channels switch. The stages have been developed by the High Current Electronic Institute (HCEI).
The switches are working at atmospheric pressure, with a simple dry air replacement.
The trigger system is divided into 2 subsystems which, located under the platform, trigger 14 stages each.

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A strip line connects the 28 stages to the load. Dielectric insulation is made with mylar and kapton films, allowing a minimal inductance.
The command/control of the GEPI is managed with a PC using Labview™.

An improvement of the generator was performed by adding peaking capacitors. They have increased the peak current and have modified the current shape in order to push away shock formation when pressure waves propagate in the material. A comparison of the measured current waveforms with and without peaking capacitors is shown in Fig. 2.

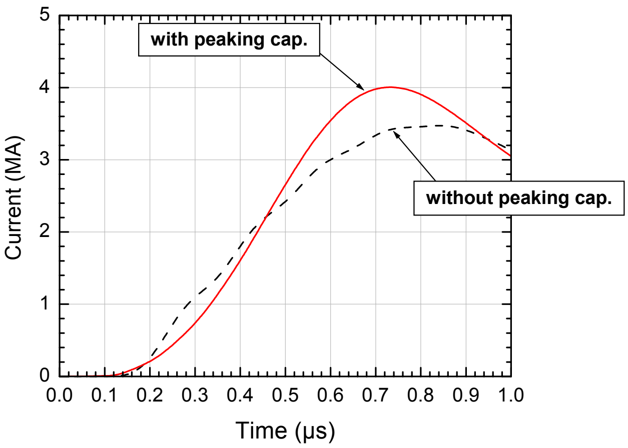

Figure 2. Experimental current waveforms with and without peaking capacitors for a 2.5nH load inductance.

With peaking capacitors, the current reaches 4MA in 600ns on a 2.5nH inductive load. Depending on the velocity of the real loads, the maximum current reaches between 3 and 4MA for material testing shots.

B. Load design and diagnostics

A scheme of the load region is shown in Fig. 3. The current coming from the stages flows to the center of the generator and is concentrated in the load strip line, enhancing the magnetic field in this area.

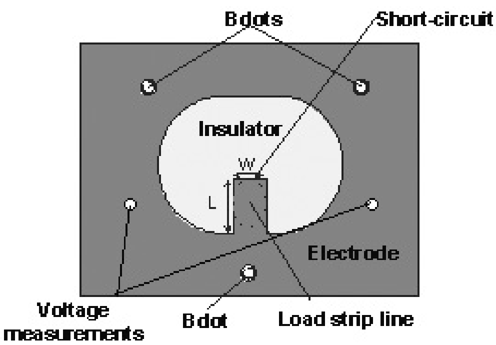

Figure 3. Scheme of an electrode in the load region (top view).

At this time, the current is measured using 3 Bdots located at 120° around the load region. As the current is not flowing in a purely radialy way at the Bdots positions, some corrections in the current density measurements have to be made depending on the position of each Bdot. Since these corrections depend on the load sizes, numerical simulations are needed. Also, to avoid these load dependant corrections, there are plans to install a low inductance Rogowsky coil in the near future.
For voltage measurements, capacitive dividers are used.
The main load diagnostic used for material study is a free surface velocity measurement made with a VISAR interferometer. A least 2 VISAR measurements are performed on 2 samples facing each other (Fig. 4).

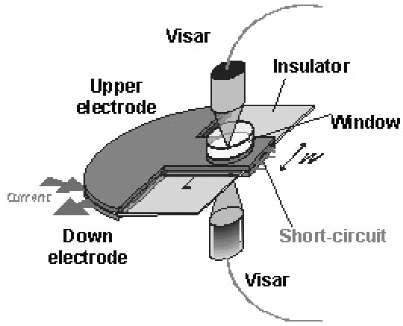

Figure 4. VISAR measurements on samples.

The other measurements that have been or are planed to be used on the samples are : flatness, thermal flux and magnetic field diffusion with small Bdots.
Although very high pressure is involved in this region, only a 250 cm^2 area is changed at each shot.

C. The main advantages of GEPI

Compared to traditional gun launch techniques with graded density impactors to perform ICE, GEPI is much easier to operate and very cost effective. Indeed, it is quite a compact facility that has a reduced destroyed area during a shot. Thus, only 2 persons are needed to operate the generator at a rate of two shots a day.
Moreover, since no oil, no water, no vacuum are used for insulation, maintenance is very limited.
Another point is that the pressure is naturally 1D due to the strip line geometry with a very small gap compared to the width.

III. EXPERIMENTAL RESULTS

To design loads in the GEPI regime (and above), the losses in pressure due to edge effects in the final strip line have to be taken into account.
The magnetic pressure in the strip line is given by :

$$P = k_P \frac{B_{th}^2}{2\mu_0} = k_P \frac{\mu_0}{2}\left(\frac{I}{w}\right)^2 \quad (1)$$

where k_P is the edge effect coefficient, B_{th} is the magnetic field in a theoretical strip line, μ_0 is the magnetic permeability, w is the width of the strip line.

k_P is mainly a function of the effective gap out of the width. The effective gap is the real gap plus a mean skin depth of the magnetic field [7].

During the current pulse, as the electrodes move and the magnetic field diffuses inside, the effective gap at the peak pressure can be much larger than the initial gap. Therefore, for high pressure shots, the maximum pressure can be reduced to more than 30% compared to the theoretical one.

A. EQUATIONS OF STATE (EOS)

The principle for EOS experiments is to measure the free surface velocities on 2 samples of the same material but with different thicknesses. As a given velocity for the 2 samples comes from the same pressure wave generated on their opposite face (loading face), the lagrangien wave velocity can then be calculated, and thus, the specific volume for a given pressure is deducted (EOS).

The design of an EOS shot is a matter of compromise. The previous argument is valid as long as the first pressure wave has not returned to the loading face. So, the maximum pressure has to be reached before this time, which means the samples have to be thick enough. On the contrary, with the fast rise time of a high pressure, if the samples are too thick, a wave can catch up to a previous one and then generate a shock. In this case, the loading is no longer isentropic.

A tool have been developed to quickly optimize the thicknesses. It is an hydrodynamic model based on the characteristics method coupled with a circuit code. Once this step is done, the design can be completed using an MHD code.

The main result showing the potential of GEPI for the EOS is shown on Fig. 5, where the Free Surface Velocities (FSV) have been measured on 2 copper samples.

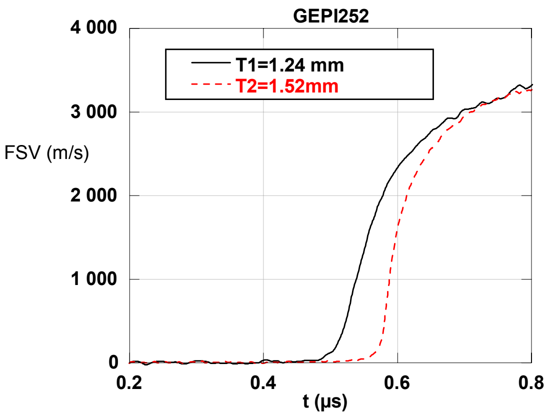

Figure 5. Shot 252 - EOS on copper : Free Surface Velocities for LxWxT=6mmx5mmx(1.21 and 1.54 mm).

Using the backward method, we get a maximal stress on the samples around 100 Gpa (Fig. 6).

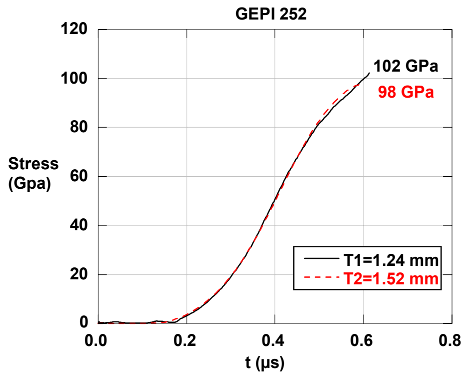

Figure 6. Shot 252 - EOS on copper Stress calculated with backward method.

Using these measurements, the stress-volume states in copper can be obtained.

B. PHASE TRANSITIONS

To shoot at a given pressure, the easiest way is to choose the needed current density in the strip line by adjusting its width (see Eq. (1)). Doing so, an example of phase transition can be shown comparing GEPI shots 118 and 119 on iron (Fig. 7).

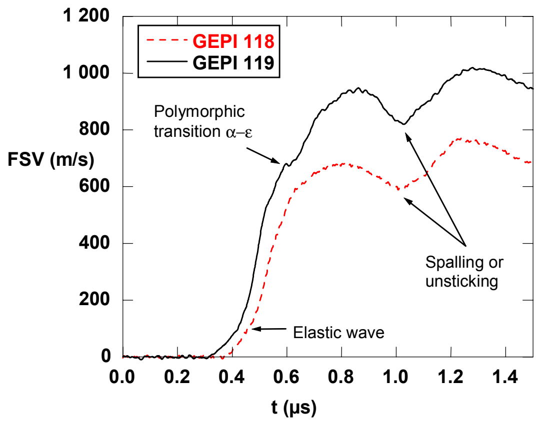

Figure 7. Shots 118 and 119 : Free Surface Velocities showing α-ε transition in iron.

The FSV waveform of shot 118 is smooth, but the one of shot 119 presents a singularity at around 680m/s, (corresponding exactly to the maximal velocity got on shot 118). Previous results on iron under shock compression [8] and confirmed on ICE [2][3], allow us to conclude that this singularity is an evidence of a polymorphic transition α-ε at around 13 GPa.

C. HIGH VELOCITY FLYER PLATES

Planar high velocity flyer plates are traditionally used for strong shocks generation through impact on tested materials. The main advantage of an isentropic loading of the impactor is to keep its temperature quite low, in particular for experimental precision considerations. Flyer plates are also used to study materials resistance to micro meteorites impacts.

At this point, the highest velocities on GEPI have been reached on aluminum samples (Fig. 8.).

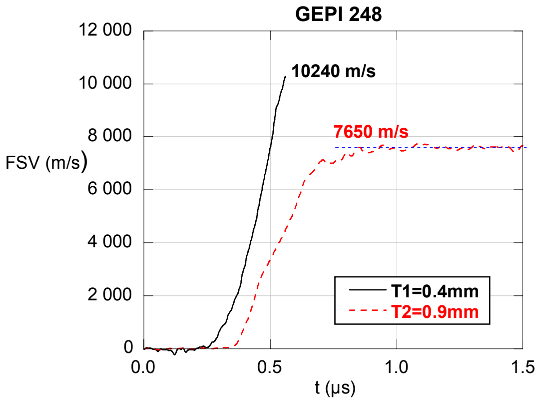

Figure 8. Shot 248 - High velocity aluminum flyer plates LxWxT=6mmx5mmx(0.4 and 0.9 mm).

The stabilized velocity of the thick sample is 7650m/s. The thin electrode reaches 10240m/s before extinction of the reflected beam, due to optical matter. As the pressures applied to the 2 samples are the same, the stabilized velocity of the thin electrode can be estimated at around 17000m/s. This shot will be performed once more in the future to get this measurement.

IV. CONCLUSIONS

GEPI has shown its potentiality as a facility for dynamic material testing. It is used at CEG for various studies such as equations of state, phase transitions, elasto-plastic transitions and high velocity flyer plates impacts.

Complementary tests on copper and aluminum are foreseen in the near future. For example, several experimental and numerical works will be performed to quantify the planarity of the displacements.

Moreover, magnetic field diffusion effects will be studied and some other materials will be tested such as porous materials, windows…

V. ACKNOWLEDGEMENTS

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