GEPI : AN ICE GENERATOR FOR DYNAMIC MATERIAL CHARACTERIZATION AND HYPERVELOCITY IMPACT

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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 1 GPa to 100 GPa range, and to non shocked high velocity flyer plates in the 0.1 km/s to 10 km/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

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]. 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]. This idea has been adapted using a strip line geometry in order to improve the efficiency and the compactness of this technique [3][4], by CEG and the company ITHPP. A generator called GEPI has thus been developed by ITHPP for CEG to study dynamic behaviors of materials [5] : 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 presented in order to show the potentialities of such a technique.

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.

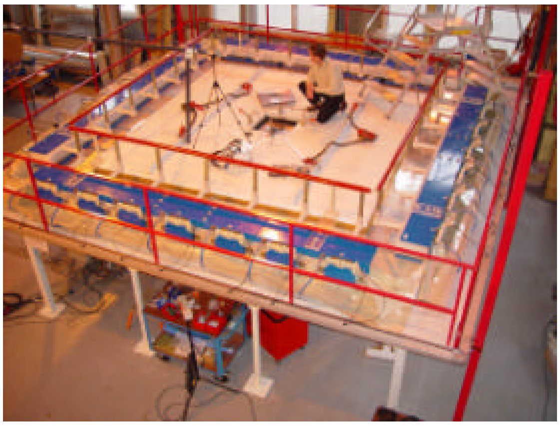

FIGURE 1. Picture of GEPI.

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 70 kJ for a 85 kV charging voltage. The total capacitance is 20 µF. Each stage holds 4 caps and a low inductance multi-gaps multi-channels switch. The switches are working at atmospheric pressure, with a simple dry air replacement.

The trigger system is divided into two subsystems which, located under the platform, trigger 14 stages each. A strip line connects the 28 stages to the load. Dielectric insulation is made with mylar and kapton films, allowing a minimal inductance.

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

Load design and diagnostics

A scheme of the load region is shown in Fig. 2. 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.

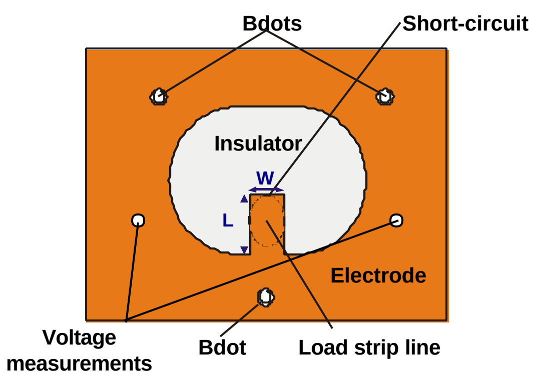

FIGURE 2. Scheme of an electrode in the load region .

At this time, the current is measured using three 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. For voltage measurements, capacitive dividers are used.

The main load diagnostic used for material study is VISAR interferometer. At least two VISAR measurements are performed on two samples facing each other (Fig. 3).

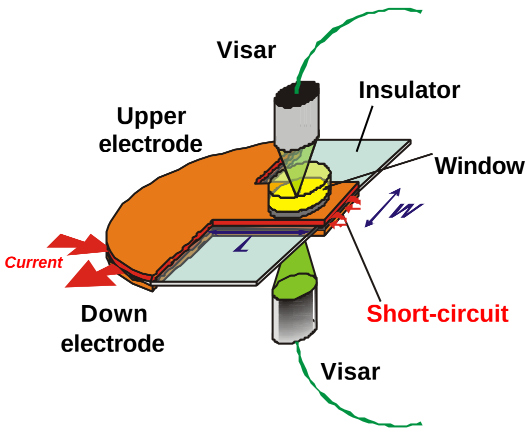

FIGURE 3. VISAR measurements on samples.

The other measurements that have been used or are planed to be used on the samples are : temperature with fluxmeters, magnetic field diffusion with µBdots and planarity with Line Imaging VISAR. Although very high pressure may be involved in this region, only a 250 cm^2 area is changed at each shot.

EXPERIMENTAL RESULTS

To design loads in the GEPI regime, 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 :

$$P = k_P \frac{B_{th}^2}{2m_0} = k_P \frac{m_0}{2}\left(\frac{I}{w}\right)^2 \qquad (1)$$

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. Coefficient k_P is mainly a function of the effective gap out of the width. This effective gap is the real gap plus a mean skin depth of the magnetic field [6].

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 ideal one.

Equations of State (EOS)

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

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.

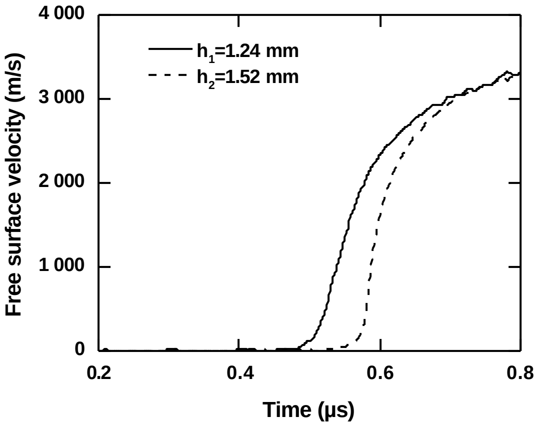

FIGURE 4. Free surface velocity diagrams obtained on two copper samples (shot #252). The width W of the line is 5 mm.

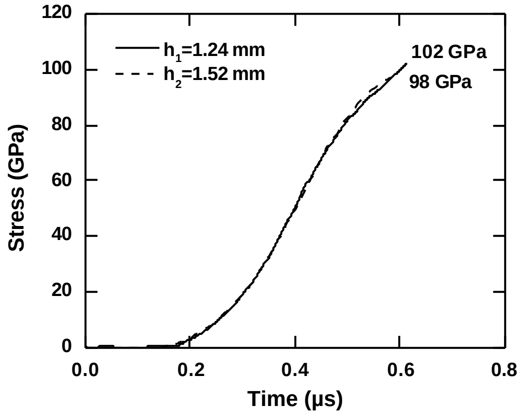

FIGURE 5. Stress diagrams on copper calculated with backward method for shot #252.

The main result showing the potential of GEPI for the EOS is shown on Fig.4, where the free surface velocities have been measured on two copper samples 1.24 mm and 1.52 mm thick. The line width is 5 mm. Using the backward method developped by Hayes [7], we get a quasi isentropic loading stress around 100 GPa (Fig.5). Using these measurements, the stress-volume states in copper can be obtained with a specific analysis [8]

Polymorphic transitions

The classical polymorphic transition of iron at 13 GPa has been studied by choosing two line widths : 18 mm for shot #118 and 15 mm for shot #119. The free surface velocities obtained on these

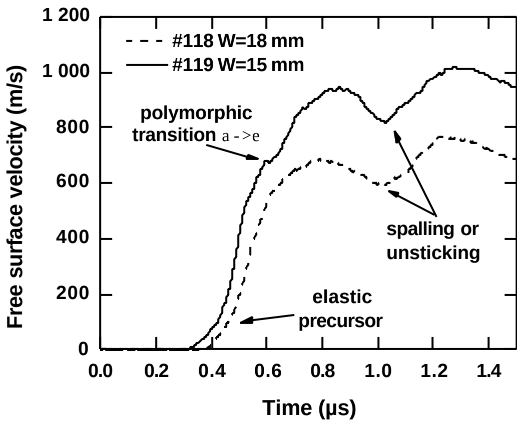

FIGURE 6. Free surface velocities diagrams obtained on iron sample showing the α-ε transition at 13 GPa.

two shots are shown in Fig. 6. The loading portion of shot #118 is smooth, but the one of shot #119 presents a singularity at around 680 m/s, which corresponds to the well-known bcc-hcp transition [9][10] at 13 GPa. Such a result shows the potentiality of GEPI to explore the kinetics of polymorphic transition.

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.7). The line width is 6 mm and the sample thicknesses are 0.40 mm and 0.90 mm.

The stabilized velocity of the thick sample is 7.65 km/s. The thin sample reaches 10.24 km/s before extinction of the reflected beam, due to optical matter. As the pressures applied to the two samples are the same, the stabilized velocity of the thin electrode can be estimated at around 17 km/s. This shot will be performed once more in the future to get this measurement.

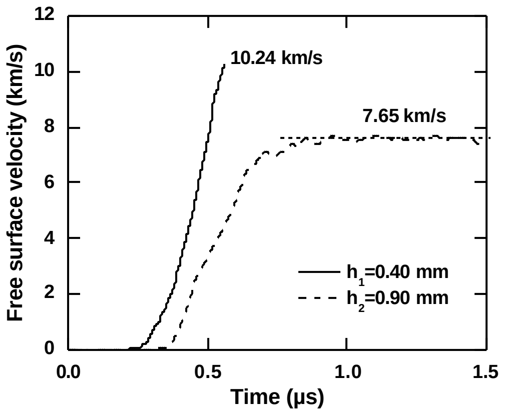

FIGURE 7. High velocity aluminum flyer plates obtained with a line width of 6 mm. Sample thicknesses are 0.40 mm and 0.90 mm.

CONCLUSIONS

GEPI has shown its potentiality as a facility for dynamic material testing. An isentropic pressure of 100 GPa has been obtained in copper and flyer velocity of 10 km/s has been achieved in aluminum. Today, this generator has to be fully qualified by quantifying stress homogeneity and magnetic field diffusion in the electrodes. After that, it is planned to use this new facility at CEG for various studies such as equations of state, phase transitions, elasto-plastic transitions, spalling and high velocity flyer plates impacts.

ACKNOWLEDGEMENTS

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