VELOCE: A COMPACT PULSER FOR DYNAMIC MATERIAL CHARACTERIZATION AND HYPERVELOCITY IMPACT OF FLYER PLATES

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Abstract. Sharing similarities with the GEPI pulser which is dedicated to Isentropic Compression Experiments (ICE), VELOCE, an even more compact electrical pulser, has been designed and built in duplicate for SNL and WSU. This type of machine complements gun and laser facilities in the study of material response. In order to achieve a broad loading capability and fast turn around, the design is built around a solid dielectric transmission line to couple current from low inductance capacitors and electrically triggered switches. Peaking capacitors enhanced by a low inductance, multi-channel sharpening switch reduce the quarter period of the pulser to about 470 ns (0-100%). Gas mixtures in the switch cavity and inductances in parallel allow modification of the shape of the induced pressure wave. At 80kV of charge voltage, the peak current can reach 3.5MA. Design of the pulser, range of pressures and velocities, as well as potential applications are presented. A consistent numerical tool developed for pulsers design based on a circuit code coupled to a 1D MHD code is also introduced.

Keywords: Isentropic compression, pulser, flyer plates, hypervelocity, magnetic
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INTRODUCTION

As known for several years and first demonstrated at Sandia National Laboratories on the Z accelerator, pulsed power capabilities can be used to generate pressure wave slow enough to compress samples isentropically [1,2]. In order to improve the efficiency and the compactness of this technique, ITHPP developed for CEG (France) in 2001, a dedicated pulser based on strip line geometries called GEPI [3,4]. Based on this experience, Veloce, a new pulser in the same energy range but significantly more compact, has been developed and duplicated for Sandia National Laboratories and for Institute for Shock Physics at Washington State University.

The loading principle of the samples is described in Fig. l, with the strip line on which the sample is located.

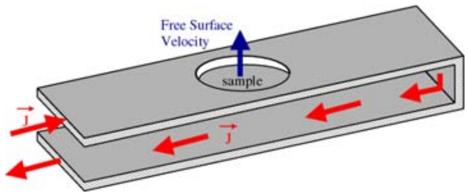

FIGURE 1. Strip line and sample location

This geometry is naturally 1 D and optimum in terms of pressure generated with a given current. The pulser has been specifically designed with the goals of a minimum footprint, quick turn around and a cost per shot as low as possible. In order to meet these criteria, several innovative ideas have been used as well as the experience gathered by the HCEI and from the GEPI pulser.

A photograph of the pulser built to these requirements is shown in Fig. 2.

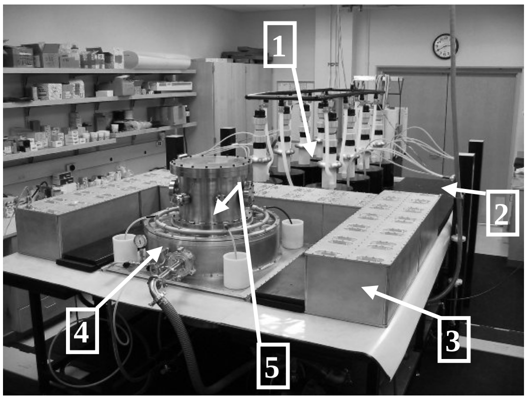

FIGURE 2. General view of the pulser at WSU

VELOCE DESIGN

Pulser overview

A synoptic of the pulser is shown in Fig. 3.

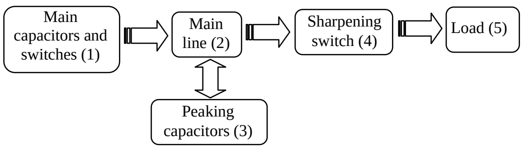

FIGURE 3. Synoptic of the pulser architecture

The overall dimensions are L x W x H = 3,50 x 2,50 x 2 m^3 in order to fit in a regular room. To get a small footprint, the design is based on very low inductance components and solid dielectric insulations.

Primary storage is obtained with 8 high energy density capacitors (4µF and 10nH, each charged at a maximum of 80kV) that are coupled to 8 electrically triggered multi-channel switches. The total stored energy is approximately 100kJ.

To reduce the rise time of the primary energy bank, the design includes 72 peaking capacitors connected to 8 self-triggered compact planar multi-gap multi-channel sharpening switches. A gas mixture adjustment and parallel inductances are used which provide shaping of the current waveform. All components avoid use of oil, SF6, vacuum or water as insulation, reducing drastically the maintenance and turn around time for experiments. Pulser diagnostics currently used for an experiment are a Rogowsky coil for the current and 2 capacitive divider for the voltage. The pulser is commanded and controlled from a PC using LabviewTM.

For a 2.6nH fixed inductance as a load, the range of the possible current shapes is as shown in Fig. 4.

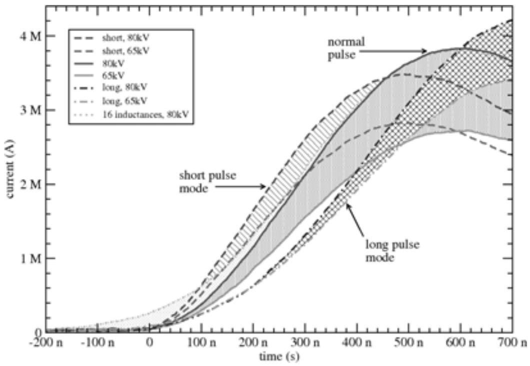

FIGURE 4. Overview of short circuit shots at WSU

Rise times from 0 to 100% are between 470ns and 700ns, depending on the chosen pulse mode.

At an 80 kV charging voltage using actual loads, the peak current is more between 3 and 3.5 MA. Indeed, the peak current depends on the load impedance, which is related to the dimensions and the displacement of the panel used. This impedance mainly depends on the length of the panel, the inverse of the width, the gap and the growth rate of the gap.

Loads design

The load is a strip line insulated with solid dielectrics (mylar or kapton). Samples are placed on the top and bottom electrodes. In this geometry the magnetic pressure is almost constant along the width and can be expressed as:

$$P_{magn} = k_p \frac{\mu_0}{2}\left(\frac{I}{w}\right)^2 , \qquad (1)$$

where I is the current, w the width, μ_0 the magnetic permeability and k_p an edge effect factor (<1) representing magnetic field losses.

To maximize the pressure for a given width, meaning minimizing the impedance to drive for the pulser, 2 samples per shot (top and bottom) loaded exactly identically are typically placed on the strip line. But, to allow more diagnostics, SNL performed experiments using up to 6 samples (2x3) on a long strip line [5].

The maximum tested size of samples on Gepi (same final parts design as Veloce) is LxWxT = 100x70x1.5mm^3 for low pressure needs. Many materials have been tested in this geometry, including metals, composites, and concrete [4].

Optimizations of the load geometry have been performed to get pressures as high as possible, while maintaining uniformity to within 2% for all samples. This means that along the width, the strip line has to be wide enough to avoid pressure edge waves coming from the side within the sample area. Besides, some studies have been performed to optimize the magnetic field uniformity in the load, giving initial experimental results for the pressure within 1% along the width of the samples [6]. Nevertheless, experimental results along the length for a long strip line are not as good [5]. Several solutions are to be tested at SNL and WSU, giving reasonable expectation of reaching the 2% uniformity goal rather soon.

In Fig. 5, free surface velocity profiles for a copper load tested at WSU is presented, with two different thicknesses for top and bottom electrodes.

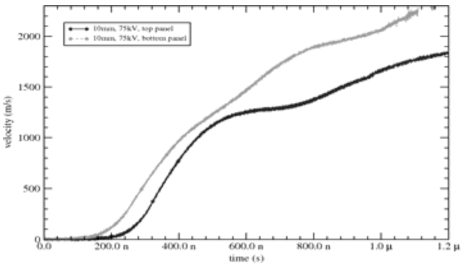

FIGURE 5. Free surface velocities on a 10 mm wide 15mm long copper load with electrodes 1.0mm thick (1.3g) and 1.2mm thick (1.6g) with U_0=75kV

1D MHD code for pulsers design

In order to design such a pulser and predict accurately the performance, a fully consistent numerical tool is now operational, based on an MHD routine coupled to a circuit code. For the pulsed power issues, first, a time dependant resistance model is used for the switches, using an evolution of the Braginskii model. For the current distribution, a 2D mesh of inductances is performed for the complete pulser. This gives a realistic view of the inductance of the pulser, which is difficult to estimate analytically.

To deal with load velocity calculations and load impedance, a 1D MHD Fortran routine takes into account the elasto-plastic phase and the phase changes, with a multi-phases analytical model. Magnetic field diffusion is treated using the equivalent electrical scheme in Fig.6, applied initially for MHD simulations in plasma physics applications [7].

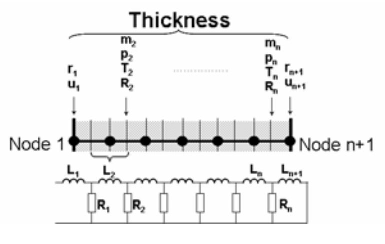

FIGURE 6. Numerical scheme for the MHD routine

A comparison between experiment and simulation is shown on Fig. 7 for a 15mm wide copper load.

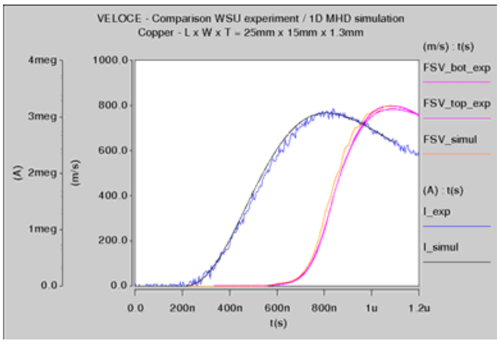

FIGURE 7. Comparison between experiment and simulation - 15mm wide copper load - U_0=75kV

APPLICATIONS

Like the Gepi pulser, Veloce is used to study dynamic behaviors of materials for equations of state by obtaining a continuous path along the isentrope (to several hundred kbar), phase transitions, high velocity flyer plates or fragments (from 100m/s to less than 10km/s)… Fig.8 presents the principle of isentropic compression.

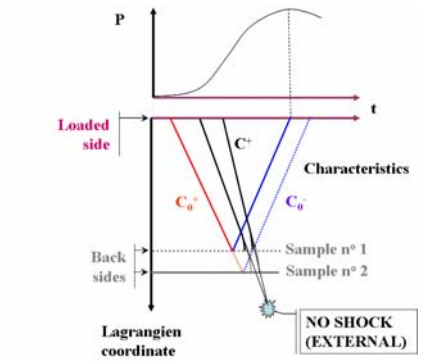

FIGURE 8. Principle of ICE

The trade off is to use samples thin enough to avoid shock formation, but thick enough to reach the peak pressure on the loaded side before the first release wave (C_0^-) reverberates. As a given free surface velocity for 2 different sample thicknesses is coming from a same pressure on the loaded side, the Lagrangian wave velocity can be calculated [5], resulting in density and pressure (depending on wave and material velocity) and thus the EOS.

CONCLUSIONS

A pulser capable of delivering up to 3.5 MA has been developed for ICE applications. Its simplicity allows operations with reduced manpower and with a short turn-around time. Concepts of solid dielectric insulation and multi-gap multi-channel switches have been used, enabling a very compact design. This leads to a versatile pulser fitting in a standard room, without requiring extensive support facilities or pulsed power knowledge. The next evolution of this concept would be in increasing the peak current, as well as reducing the rise time.

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