High Energy Density Physics 26 (2018) 38–43

Contents lists available at ScienceDirect

High Energy Density Physics

journal homepage: www.elsevier.com/locate/hedp

Simulation of magnetically driven flyer plate experiments with an improved magnetic field boundary formula

Mingxian Kan*, Zhaohui Zhang, Bo Xiao, Long Yang, Shuchao Duan, Ganghua Wang, Guilin Wang

Institute of Fluid Physics, CAEP, P. O. Box 919-105, Mianyang 621900, China

ARTICLE INFO

Keywords:
Primary test stand
Two-sided flyer plate
Magnetically driven experiment
Magnetic field boundary formula

ABSTRACT

To consistently simulate magnetically driven flyer plate experiments with a magnetohydrodynamics code by taking the measured current as the input, a relation is needed that connects the measured current and the magnetic field on the loading surface. Lemke's magnetic field formula [Lemke:2011, Davis:2014] gives deep insights into this relation, but it also leads to noticeable discrepancy from experiments if the formula is directly used for flyer plate simulation. In this paper, we find that, by adding to Lemke's formula a new term that reveals the ablation effect of the loading surface, the simulation can be much improved. With this modified version of Lemke's formula, we simulated one-sided and two-sided flyer plate experiments performed on the Primary Test Stand facility in China, which show satisfactory agreement with the velocity interferometer system for any reflector measurements.

1. Introduction

The intense magnetic field generated by a pulsed power device such as a Z accelerator is used as a pressure source to accelerate flyer plates to high velocity. This magnetically driven flyer plates technique is widely used in studies of the high-pressure equation of state of materials, high energy density physics, and weapons physics [1–10].

Numerical simulation is an important tool in magnetically driven flyer launch technique studies. It can not only reproduce and predict the experiment, but also aid the design and optimization of experiments. There are two types of approaches to obtaining consistent simulations of magnetically driven flyer experiments. One is by coupling the circuit calculation with a magnetohydrodynamic (MHD) simulation, in which the power source parameters, including the voltage $V(t)$, circuit model, and load properties, are taken as the input, and the current $I(t)$ is an output that can be compared with the measured current as a check of the consistency of the simulation. The other approach is by taking directly the measured current as the input of the MHD simulation, and a necessary component of this approach is the relation of the measured current to the magnetic field on the loading surface. Lemke et al. [2–7] have carried out many theoretical works on the magnetically driven flyer launch technique. Lemke [2] carried out detailed simulations with the coupled-circuit-MHD approach and obtained results consistent with measurement. Lemke et al. [6,7] also developed a formula that connects the measured current to the magnetic field on the loading surface, and used it for the initial guess of the magnetic field in an iterative approach.

In this paper, we show that, by introducing to Lemke's formula a new term that represents the loss of conductive ability due to ablation on the loading surface, the formula is able to be used to simulate correctly the flyer velocity directly from the measured current, that is, with the second type of MHD simulation approach described above. With this modified version of Lemke's formula, we describe in this paper our simulations of magnetically driven one-sided and two-sided flyer plates experiments, performed on the Primary Test Stand (PTS) facility [11].

2. Experiment settings

The PTS facility is a high-power pulse accelerator located at the China Academy of Engineering Physics, and contains 24 modules with identical components [11]. There are two operating modes for the PTS facility: synchronous discharge mode for Z-pinch experiments, and wave shape tailored mode for quasi-isentropic/shock compression experiments. The synchronous discharge mode produces a short-pulse high current whose maximum current can be up to 8–10 MA with a rise time of 90 ns. In the wave shape tailored mode, the maximum current of the PTS facility can be up to 5–7 MA with a rise time of 200–400 ns. Z-pinch, flyer launch, quasi-isentropic compression, and other magnetically driven experiments have been carried out on the PTS facility [12–14].

The experiment of shot 151 is a magnetically driven one-sided flyer plate experiment with 0.370 mm thick aluminum flyer plates on the

---

* Corresponding author.
E-mail address: kanmx@caep.cn (M. Kan).

https://doi.org/10.1016/j.hedp.2017.12.002
Received 25 August 2017; Received in revised form 20 December 2017; Accepted 22 December 2017

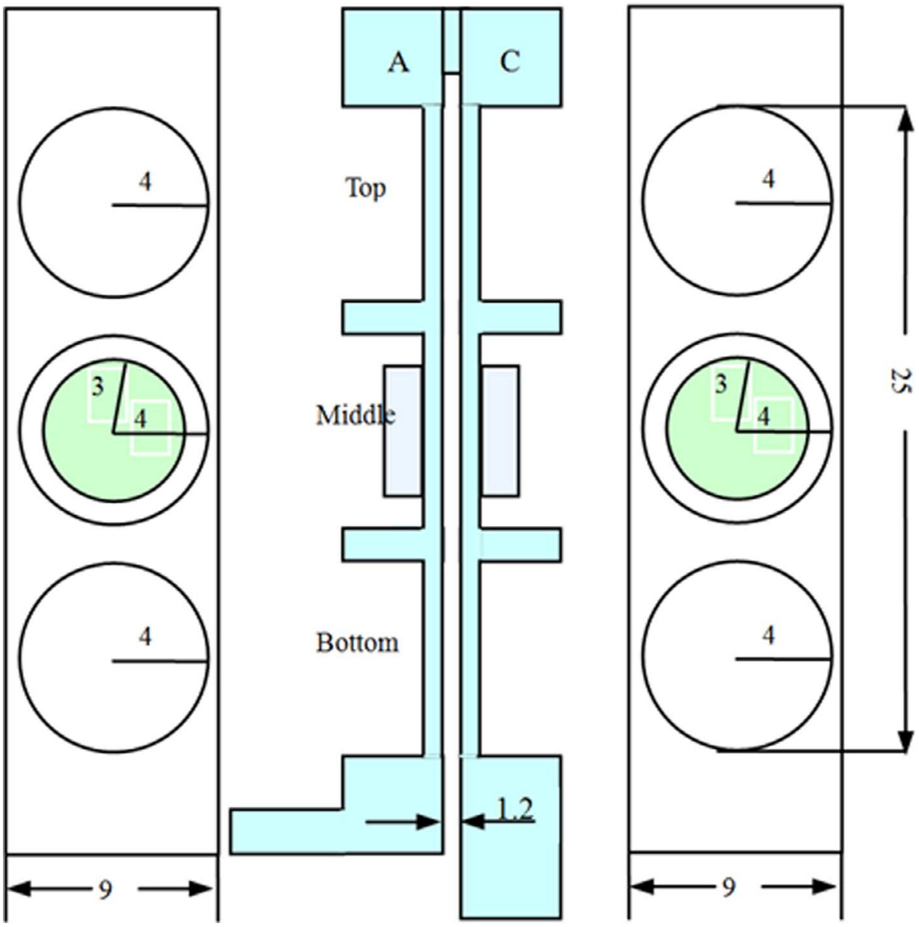

Fig. 1. Cross section of 3D flyer configuration for experiment pts-120 and pts-122. (Units for the numbers in the figure are mm).

Table 1
Details of shot 120 and shot 122 experiments.

	Anode thickness (mm)		Cathode thickness (mm)	
	Aluminum	Lithium fluoride	Aluminum	Lithium fluoride
PTS-120Top	1.047	-	0.986	-
PTS-120Middle	1.067	5	1.299	5
PTS-120Bottom	1.041	-	1.016	-
PTS-122Top	1.459	-	1.089	-
PTS-122Middle	1.171	5	1.281	5
PTS-122Bottom	0.962	-	1.570	-

PTS facility. The details of this experiment can be found in [11]. Experiments of shot 120 and shot 122 on the PTS facility are magnetically driven two-sided flyer plates/isentropic compression experiments. The configuration for the experiments of shot 120 and shot 122 is shown in Fig. 1. Electrodes were fabricated by aluminum, and each had three cylindrical spot-faced holes (counter-bores) approximately 4 mm in radius. Each of the two middle flyer plates was connected to 3 mm radius samples. The distance between the anode and cathode was 1.2 mm. The width of the cathode and anode plate was 9 mm. The thicknesses of the flyer plates are given in Table 1. The principal diagnostic instrument was the velocity interferometer system for any reflector (VISAR).

3. Physical model and simulation code

The magnetically driven flyer plate experiment was simulated by the MHD code called MDSC2 (2-dimensional Magnetically Driven Simulation Code) [15,16], with the measured current taken as the input (that is, with the second approach described in Section 1). The physical model included in MDSC2 is described by Eqs. (1)–(4).

$$\frac{d\rho}{dt} = -\rho\nabla\cdot\boldsymbol{v} \tag{1}$$

$$\rho\frac{d\boldsymbol{v}}{dt} = -\nabla p + \frac{1}{\mu_0}(\nabla\times\boldsymbol{B})\times\boldsymbol{B} + \nabla\cdot\boldsymbol{\sigma} \tag{2}$$

$$\rho c_v\frac{dT}{dt} = -p\nabla\cdot\boldsymbol{v} + \left(\frac{\eta}{\mu_0^2}\nabla\times\boldsymbol{B}\right)\cdot\nabla\times\boldsymbol{B} + (\boldsymbol{\sigma}\cdot\nabla)\cdot\boldsymbol{v} - \nabla\cdot(k_e\nabla T) \tag{3}$$

$$\frac{d\boldsymbol{B}}{dt} = -\nabla\times\left(\frac{\eta}{\mu_0}\nabla\times\boldsymbol{B}\right) - (\boldsymbol{B}\nabla\cdot\boldsymbol{v} - \boldsymbol{B}\cdot\nabla\boldsymbol{v}) \tag{4}$$

where ρ, T, and $\boldsymbol{v}$ are the fluid density, temperature, and velocity, respectively; $\boldsymbol{B}$ is the magnetic field; η is the resistivity [17]; p is the pressure; $\boldsymbol{\sigma}$ is the artificial viscosity tensor; k_e is the thermal diffusion coefficient; c_v is the specific heat capacity; and μ_0 is the magnetic permeability of free space. The Lagrangian derivative is:

$$\frac{d}{dt} = \frac{\partial}{\partial t} + \boldsymbol{v}\cdot\nabla \tag{5}$$

The equations are numerically solved by a time-split method. The physical process is time split into thermal diffusion, resistive diffusion, and ideal MHD subprocesses. Each subprocess is solved by the implicit time differencing and finite volume approach in space [15].

The magnitude of magnetic pressure $p_B(t)$ on the boundary, which is applied to the loading surface of the flyer plates, is given by

$$p_B(t) = \frac{B_0^2(t)}{2\mu_0} \tag{6}$$