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CHARACTERIZATION OF SIMPLE EXPLOSIVELY DRIVEN PARTICLE ACCELERATION*

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Experiments are carried out to characterize the performance of a compact cylindrical (2-inch × 3-inch-long) single-point detonation ring-lit fast shock tube that has been designed to accelerate particles to velocity in excess of 10 km/s. The experimental results from the study of propellant flow and plate acceleration will be presented and compared with the code calculation. Various interesting measurement techniques will also be discussed.

1. INTRODUCTION

The production in the laboratory of a several-gram mass moving at a hypervelocity of 10 km/s or more can be valuable for the study of equations of state, dynamic strength of materials, and impact phenomena. In this paper, we shall report some results from our investigations of a 2-inch-diameter, compact, explosively driven mass accelerator. This simple device is chosen to provide easier diagnosis and to make it more affordable for higher firing rates. Several experiments designed to diagnose the performance of the various components of the device are discussed below.

2. DESCRIPTION OF THE MASS ACCELERATOR

The accelerator is illustrated in Fig. 1 and the pertinent dimensions and components are labeled. In this system, the high explosive (HE) is initiated by a single point detonation. The propagation of the burn wave in this ring geometry radially compresses the plastic foam propellant and squeezes it forward axially to form a very high shock velocity which eventually out-runs the detonation wave of 8.8 km/s. At the entrance to the barrel a rarefaction wave begins to propagate backward and the foam expands rapidly into the barrel with the low density wave front moving ahead at an extremely high velocity. A thin plate of suitable thickness and material is located at a chosen stand-off distance downstream. The expanding propellant quickly reaches the plate and stagnates against it. The large pressure buildup behind the plate then quickly accelerates the plate forward.

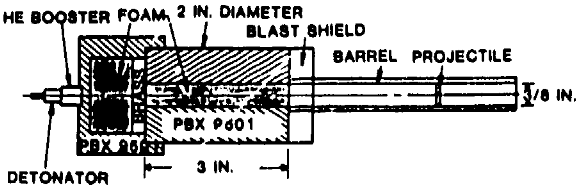

FIGURE 1
Hypervelocity from Acceleration

3. CHARACTERIZATION OF SHOCK FORMATION IN THE FOAM

A low density (0.3 g/cc) polyurethane foam is used as the propellant. Three experiments were performed to study the shock formation in the foam. 1) A microwave interferometer technique[1] was employed to measure the foam shock velocity by placing a micro-coaxial cable (0.35-mm-diameter) inside the foam. As the cable was shorted by the shock front, the propagation distance and time were measured. The maximum shock velocity was determined to be about 10.8 km/s, which corresponds to a

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pressure of ~250 kbar. 2) A 100-μm-diameter quartz fiber was similarily inserted into the foam. The intensity of light emission from the shock-heated quartz fiber indicated a quartz pressure of 600 kbar which can be matched to 250 kbar foam pressure.[2] 3) By stagnating the exiting shocked foam against a xenon flasher assembly that consisted of alternate layers of light emitting Xe and Plexiglas which turns opaque when shocked, the details of shock propagation were then be deduced directly from the smear camera record.[3] We found that the shock front was flat and axially symmetric at the end of the shock tube and that the foam was moving ahead of the HE detonation. The shock velocity in the plexiglas was measured to be 10.6 km/s, which indicates a stagnation pressure of 660 kbar in the Plexiglas. The results of all of these experiments are consistent with the predictions from code calculation.

Two experiments were also performed to measure directly the foam particle velocity. 1) We determined the velocity of a thin 10-mil Al foil placed at the end of the shock tube. By making a $\dot{B}$ measurement using an axially symmetric magnetic probe (ASM), we found the particle velocity in the foam to be U_p ~14 km/s. 2) A similar U_p was measured also by using Faraday probes when the foam was allowed to shock and ionize Ar gas. The measured U_p from these experiments was consistent with the expectation from a two-dimensional code calculation.

4. FOAM EXPANSION INTO A LOW DENSITY MEDIUM

We have attempted to measured the time and spatial density profile of the propellant by optical shadowgraphy. In these experiments the foam was allowed to expand into an evacuated 3-inch-diameter Plexiglas tube and backlighted by a 2.5-eV temperature argon flasher. The dynamics of the expansion was then recorded by four different image-intensifier cameras at different times. Altogether, eight pictures were recorded covering the several microsecond interval between the time when the foam exited the shock tube and stagnated against a plate about 6 cm downstream. Although we are unable to ascertain the density of the expansion, we could track the recognizable features and determine their axial and radial expansion velocity. By plotting the velocity as a function of distance at a given time we found the asymptotic velocity at the wave front to be ~21.6 km/s. This is in agreement with the code calculation. However, detailed comparison of the expansion profile between the observation and the calculation remains to be done.

Another way to investigate the foam expansion is to stagnate the expanding foam against layers of pressure-sensitive, light-emitting bromoform. The time profile of the pressure buildup in the bromoform can then be measured and compared with the results of computer modeling. Experimentally, a minimum of 10 km/s was measured in the shocked bromoform which corresponds to a pressure in the bromoform of more than 1.8 Mbar. Our code predicts ~2.1 Mbar.

5. PLATE ACCELERATION EXPERIMENTS

Several experiments with 1- to 3-mm-thick Mo plates with 4- to 10-cm stand-off distances between the foam and the plate have been carried out. Typically a 1/8-inch-thick steel barrel is used to facilitate x-ray radiography of the plate-barrel dynamics during the experiments. Other diagnostics such as laser interferometry and optical framing are also used to determine the plate velocity and integrity. In the experiments with 4-cm stand-off, we have found that 1-mm Mo can be accelerated to

4 km/s in 2 mm before breaking up. During this short period of about 1 μs, the plate experienced an acceleration of 4×10^{11} cm/s^2 or 408 Mg and the driving pressure is deduced to be ~400 kbar. After the plate was violently fractured, the fragments continued to travel at a speed in excess of 7 km/s. The Fabry-Perot interferometry data clearly show the appearance of preshock due to the presence of air in the barrel region between foam and plate. Also, velocity steps are observed which may suggest the presence of shock in the accelerated plate. These results are all in good agreement with the code predictions. The code also predicts that if the air in the barrel is evacuated the signatures of both the preshock and the steps in the velocity history should disappear. If this is so, the plate may stay intact longer and reach higher velocity. Thus, an experiment with the evacuated barrel will provide the crucial check against the reliability of the code calculation.

Several experiments with 10-cm stand-off and 3-mm-thick Mo plates have also been carried out. We found the stagnation pressure to have been slightly reduced and the measured plate acceleration only about 80 Mg. However, even with a more gentle push the plate again fractured after having moved only a few millimeters distance, but the manner of fragmentation did not appear to be as bad as predicted by the code.

6. CONCLUSIONS

The hydrodynamics that governs the plate acceleration are extremely complicated. The possible lack of planarity in the expanding propellant and the vortex formation in the propellant flow as a result of interaction with the plate and barrel have presented a severe challenge to our effort of accelerating plates to hypervelocity. On top of all these problems we must eventually also face the issue of instabilities. It is clear that more work is needed before we will be able to determine if our goal of flying a plate at hypervelocity by using a simple explosive device is in fact possible.

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