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TITLE

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MASTER

DESIGN OF A SPHEROMAK COMPRESSOR DRIVEN BY HIGH EXPLOSIVES.*

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INTRODUCTION

High energy density spheromaks can be used to accelerate a thin section of the flux conserver wall to high velocities. The energy density of a spheromak, formed by conventional helicity injection into a flux conserver, can be increased by reducing the flux conserver volume after the spheromak is formed. A method of accomplishing this is by imploding one wall of the flux conserver with high explosives. The velocity of a wall driven by high explosives is about 3-5 km/sec, which is not exceptionally fast. Magnetic equilibrium calculations show that for some imploding flux conserver geometries, the energy density of the spheromak can be suddenly increased on an Alfvén time scale by the tendency of the spheromak to maintain a state of minimum energy per unit helicity, which is equivalent to minimizing $\lambda = \mu_o j/B$. In this process, as the initial flux conserver dimensions are reduced under the explosive drive, the characteristic λ of the configuration increases. Then, if there is an attached flux conserver region whose dimensions are such that its λ becomes lower than for the imploding region, the spheromak will quickly transfer to this region, even if its volume is smaller, thus increasing the energy per unit volume. We call this the "natural switching" feature of spheromaks. The simplest such geometry is a cylindrical flux conserver with one end being driven by high explosives. An attached, smaller-diameter on-axis cylinder has a thin end wall which is accelerated when the spheromak switches into the smaller cylinder [1].

We have embarked on a program to demonstrate that a spheromak can be used as an energy transfer medium, and that a velocity gain over high-explosive driven plate velocities can be achieved. To do this, a plasma gun helicity source that will inject a spheromak with suitable initial energy density and lifetime [2] is needed. Also, an implodable flux conserver that remains intact and clean during the implosion must be developed. The flux conserver problem is probably the more challenging one, because very little experimental work has been done in the past on explosively driven metal plates into a high vacuum, with sizes and travel distances appropriate for our application.

FLUX CONSERVER COMPRESSION WITH HIGH EXPLOSIVES

There are two necessary practical requirements for an explosive compression of a flux conserver. The first is that the imploding wall does not rupture. The second is that gasses or other debri are not ejected which could penetrate and poison the spheromak plasma, and thus reduce the spheromak lifetime below what is necessary to carry out the spheromak compression and the subsequent acceleration of the flyer plate. Our first inclination was to go with the cylindrical flux conserver geometry. However, two early small-scale experiments of an explosively driven end plate in a cylinder showed that the sliding seal against the cylinder walls allowed explosive by-products to penetrate into the cylinder volume. In addition, scaling to larger sizes would have been difficult, because it is complicated and expensive to initiate a plane wave detonation over a large area. Therefore, we decided to design and test a deforming geometry, with no sliding seals, in which an initial shallow dome is inverted during the implosion. For economic reasons, we decided to use a simple circular slab of explosive, detonated at a single point in the center. The curvature of the dome and other dimensions were optimized through numerical hydrodynamic simulation of the explosion and the subsequent motion of the metal wall.

We decided on the following full-scale dimensions for the first test: 61-cm spherical radius, 69-cm circular radius, and 0.3-cm thickness for the aluminum (1100-H14 alloy) dome; 58.4-cm diameter and 7.6-cm thickness for the high explosive, placed 1.0-cm from the apex of the dome. Total needed on-axis displacement of the dome is about 30 cm. The expected final on-axis velocity of the aluminum surface was 4.5 km/sec. The diagnostics consisted of a sequence of 25 fast-framing-camera stereo color photographs taken at 3.0-μsec intervals. Fiducial markings were made on the dome and on a transparent plastic plate 30 cm from the pole of the dome to allow measurement of the dome profile from the stereo photographs. The space between the dome and the plastic plate was to be filled with helium to eliminate glow from air being shocked by the imploding dome. Unfortunately, the helium purge was not complete, and the photographs were obscured by the bright glow after about 40 microseconds from the time of detonation of the HE, during which time the dome displacement was only about 12 cm. Until then, we could see the aluminum surface deforming, as expected, but small surface irregularities were formed as the explosive force struck the dome. It is suspected that by that time, some of these small bumps may have already perforated, and we do not know what happened at later times.

Based on the results of the first test, we changed the dome thickness to 0.95-cm of 5052-H32 aluminum alloy. Other dimensions remained the same. Also, we sealed and evacuated the space in front of the dome to about 20 mTorr, and the space between the dome and the explosive to about 50 mTorr. This time, no bright light emission was observed in the vacuum region. The bumps on the dome surface were still present. but they were larger in diameter and farther apart, suggesting a scaling with dome thickness. The detailed nature of the bumps is still not understood. Measurements of the dome profiles at various times were made from the stereo photographs. These agreed well with the computer simulation, as shown in Fig. 1. There may have been some perforations of the metal surface near the edge of the dome at 87 microseconds, but these are in locations and at late enough time, such that they should not affect the performance of the speromak compression. The predicted velocity at the center was 3.1 km/sec, and the measured velocity was 3.0 km/sec. The velocity reaches a nearly constant value about 60 microseconds after the detonation is initiated. It would be desirable to have a higher implosion velocity, but otherwise, these results appear to be satisfactory.

We still have to assess the vacuum quality in front of the imploding metal surface. To do this on future tests, we will produce a better vacuum, and install fast ion gauges to make pressure measurements during the implosion.

DESIGN OF PLASMA GUN

We have designed and fabricated a plasma gun to be used for injecting the initial spheromak plasma into the collapsible flux conserver. The diameter of the gun was dictated by the requirement that the injection had to take place along the periphery of the flux conserver. Figure 2 shows a cross sectional diagram of the gun. The inner and outer electrode diameters are 53.3 and 68.6 cm, respectively. The gun electrodes are stainless steel. A 21-cm long copper entrance region leads to the flux conserver. The gun will be powered by a 12-mF, 20-KV (max.) capacitor bank available at the firing site. The dome to be imploded is attached to the end, and forms one wall of the flux conserver. The opposite wall is shaped so that the entrance gap will at all times during the implosion be narrower than the smallest characteristic dimension of the flux conserver. This will prevent the spheromak from escaping back into the gun. Eventually, the entrance gap will be closed completely, thus trapping the spheromak. When the magnetic pressure becomes large enough, the thin "flyer plate", which will be scored at the edges, will break away and the spheromak will transfer into the cylindrical space behind it. While this (domed-end) geometry of the flux conserver may not be as efficient as a cylindrical one to utilize the "natural switching" effect, we expect to be able to demonstrate a velocity gain of the flyer plate over the velocity of the imploding flux conserver wall.

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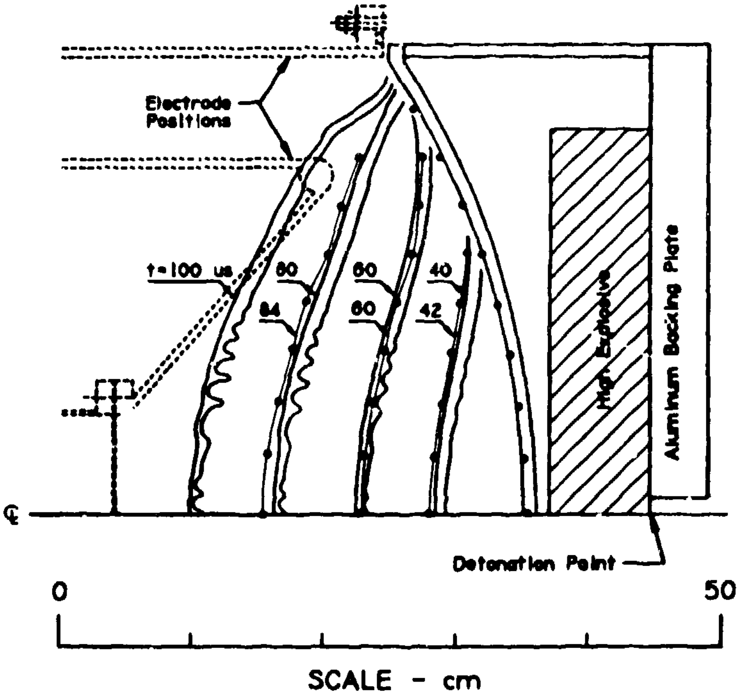

FIG. 1. Profiles of the high-explosive driven 0.95-cm thick aluminum dome at various times after detonation at t = 0. The solid lines are plots of the numerically simulated positions of the aluminum layer, and the dots show the measured positions of the surface, at the times indicated. The dashed lines outline the entrance region and the opposite wall of the flux conserver, if they were present as in Fig. 2.

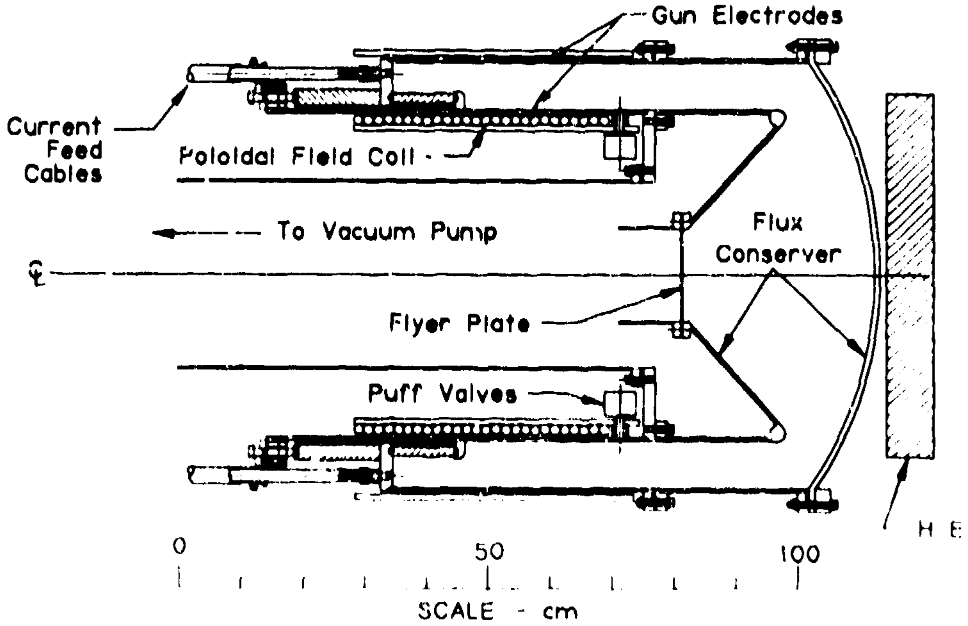

FIG. 2. Cross sectional diagram of the plasma gun, flux conserver, and high explosive assembly.