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IMPROVED SHOCK-DECTECTING PIN ARRANGEMENT

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Shockwave speeds are often measured by comparing arrival times at the tips of electrical shorting pins in a hexagonal array over two elevations (called up and down). In the conventional arrangement, the center pin is solely responsible for measuring the curvature of the wavefront. Without this datum the shock speed cannot be precisely determined. In some experiments this pin fail frequently enough to be a problem. We report a simple rearrangement between up and down designated pins which eliminates the critical reliance on a single pin.

INTRODUCTION

An important equation of state measurement is the velocity of a shockwave generated in a sample by the impact from a high velocity (several km/s) disk projectile. Such experiments[1-5] are vitally important in physics for establishing high pressure material behavior to high precision, including materials used by researchers as standards. In many cases, shock wave experiments are the only method available to attain the necessary pressure and temperature, or to perform an accurate measurement over a sufficiently large sample volume. The shock velocity experiment is the preferred method to determine the equation of state of standards because the developed shock parameters depend through simple relations[3] on only four values which can potentially be measured very precisely: projectile velocity and initial density, sample initial density, and the measured shock velocity (U_S).

Experimental techniques have been developed[1,2] to accurately measure these parameters using a two stage gas gun[6]. These account for the bowing distortion the projectile suffers from the acceleration of launch. In experiments involving thin samples and high projectile velocities the shock transit times are short; thus, it is increasingly important to precisely account for the projectile distortion. We report[7] a simple modification in the target design which will significantly reduce the uncertainty in the shock speed determination.

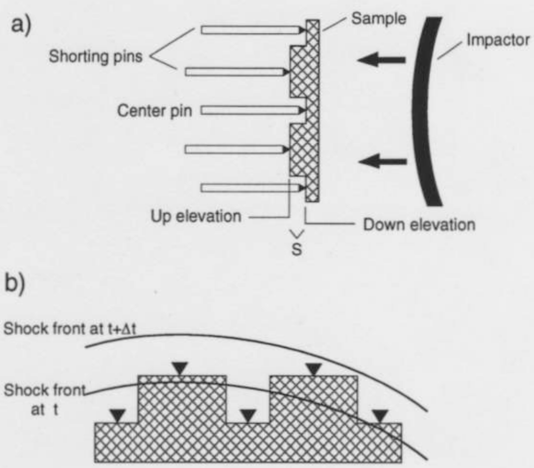

Figure 1. Target for measuring shock speed, side view. a) Sample is a "tophat" having elevations at two levels "up" and "down" differing by height S. Other supporting structures not shown. Impactor is a metal disk, which generally has a bow and tilt due to acceleration of launch. Electrical shorting pins pressed against elevation surfaces detect arrival of shock wave. b) Detail of shock front in relation to pin tips (triangles). Vertical dimension is exaggerated. The shock front preserves its shape as it moves perpendicular to target face. Shock front shown at two moments separated by time interval Δt.

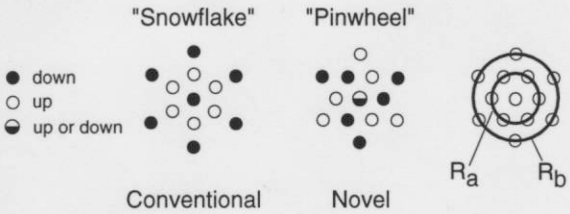

Figure 2. Arrangement of "up" and "down" designated electrical shorting pins on the sample, projected on the target face. The inner six pins are on a diameter of radius R_a, outer six on R_b. Both the snowflake and pinwheel arrangements have 13 pins, split 7/6 between down and up elevations. However, the pinwheel has pins of both kinds on each radius. The center pin in the pinwheel can be up or down. The snowflake center pin should be the same kind as the outer pins to best resolve the bowing. The up/down roles as groups can be interchanged.

METHOD

Figure 1 is a schematic of the target used to measure shock speeds. A metal disk projectile 1 - 3 mm thick is accelerated up to 8 km/s by a two stage gas gun[1,6]. Impact with the sample creates a shock wave propagating toward the sample rear. Passage of the shock through specific locations around the sample is observed by a set of electrical shorting pins. They are placed in two planes (elevations) parallel to the face, called "up" and "down", which are separated by a distance S (the step height). For samples 15 - 20 in mm diameter, S is 1 - 3 mm.

The pins generate an electrical pulse upon passage of the shock which is sent via cable to recording electronics. The shock arrival times at the target can be determined to ~0.5 ns overall precision[1], including cable length uncertainties. (At 10 km/s, this time precision corresponds to measuring pin elevations to 5 μm precision.) In the measurement of shock speed in a stiff material such as sapphire[7], the shock transit time can be as low as 100 ns. Thus this subnanosecond time precision is important.

There is an uncertainty in the shock arrival time pulse generated by a pin, due to variations in the thickness or shape of the tip, or the presence of foreign matter under the tip, all which change the effective elevation. The pins must be pressed securely against the sample by springs to ensure their location at the measured elevation surface. In some pin types, vibration from handling the target can rub off the metal film at the tip, causing the pin to fail. For these reasons, targets have as many pins as possible for redundancy. Due to the width of pins and springs, it is difficult to space pins closer together than ~ 3 mm center to center. Avoidance of the release waves from sample corners reduces the available area on the up elevation. Previous[5,6] researchers using larger targets have used pins side by side in a line. For our smaller samples this is not practical. Instead, a hexagonal pin arrangement provides the most efficient packing.

Figure 2 diagrams the arrangement of pins. Each pin is either on the up or down elevation. There are two configurations, labeled "snowflake" and "pinwheel". Both use 13 pins divided into 6 down, 6 up and one center pin. The snowflake pattern is the conventional configuration used in some previous equation of state studies[1-3].

Figure 3 shows how the transit time (Δt) is found by interpenetrating the up and down pin data sets along the time axis. This is similar to the 1-d interpenetration algorithm of Holmes[8], but done in an additional dimension. Fig. 3b shows that without the center pin, Δt cannot be determined because the amount of radial bowing is indeterminate. Neglecting the effect of bowing[1,2,7] can alter Δt by up to ±15 ns for impactor velocities up to 8 km/s.

Furthermore, even with valid center pin data, the net transit time uncertainty cannot be less than ~75% of the center pin uncertainty. Thus, there is essentially no benefit from the 12 other pins, contrary to intuition. This because the net transit time uncertainty[9] is given by $\sim\sqrt{\delta t^2/N + 0.75^2\ \delta t_c^2}$, where δt is a typical individual pin uncertainty, and δt_c is the center pin uncertainty (which is similar). The number of up and down pins is assumed to be the same and given by N.

The alternative configuration ("pinwheel") is introduced as a solution to this problem. In this arrangement the center pin is not needed (Fig. 3c) to accurately determine the shock transit time. Fundamentally, this is because there are both up and down pins on the same radius R_a or R_b.

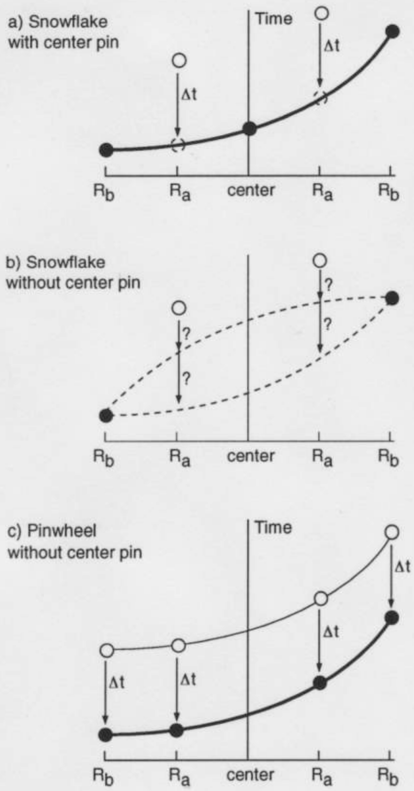

Figure 3. Finding the transit time through interpenetration of data. Arrival times of shocks at pins are plotted versus 2-dimensional pin location across the face. Only one dimension is shown on horizontal axis. Open and closed circles represent up and down pin data respectively. Here, the center pin is a member of the down set. The up data are translated in time by Δt to form a mutual best fit surface. This yields the shock speed $U_s=S/\Delta t$, where S is step height. a) Pins in snowflake arrangement. b) If center pin missing in snowflake arrangement, Δt cannot be determined because curvature of shock surface is indeterminate. Fundamentally, this is because R_a and R_b contain only up and down pins respectively. c) In pinwheel arrangement, lack of center pin does not prevent accurate determination of Δt because the circles R_a and R_b each contain both up and down pins.

For the pinwheel, we expect the net transit time uncertainty to be approximately $\sim\sqrt{2}\ \delta t/\sqrt{N}$. This estimate is appropriate for a combination of N + N pins fitting two best fit surfaces with standard deviation δt.

CONCLUSION

We believe the pinwheel pattern is the most robust to pin loss, has the least uncertainty in transit time, and most space efficient arrangement of 13 pins for shock wave transit time experiments. This is important in experiments where the degree of radial bowing is significant to the shock transit time. Such is the case in stiff materials having high shock and sound speeds, since the transit times are short, the sample dimensions need to be small, and the projectile distortion significant and not reproducible from shot to shot.

ACKNOWLEDGMENT

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9. The net uncertainty is analyzed in Ref. 2. However, their formulas Eqns. 26 and 28 are incorrect because they treat two correlated quantities (δt_1, δt_c, Eq. 6) as uncorrelated. The correct expression for the net uncertainty at the single standard deviation level is

$$\delta(\Delta t)=\sqrt{\frac{\sigma_d^2}{N_d}\left(\frac{R_a^2}{R_b^2}\right)^2+\frac{\sigma_u^2}{N_u}+\delta t_c^2\left(1-\frac{R_a^2}{R_b^2}\right)^2}$$

where σ_d and σ_u are the standard deviations of the best fit planes to the up and down pins, and N_u and N_d are the number of valid up and down pins, and δt_c is the uncertainty of the center pin.