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GAUGES IN SHOCKED LIQUIDS

AUTHOR(S): R. L. Gustavsen, S. A. Sheffield, R. R. Alcon, LANL, M-7

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Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

RESPONSE OF INCLINED ELECTROMAGNETIC PARTICLE VELOCITY GAUGES IN SHOCKED LIQUIDS[†]

R.L. Gustavsen, S.A. Sheffield, and R.R. Alcon
Los Alamos National Laboratory
Group M-7, MS P952
Los Alamos, NM 87545

Multi-element electromagnetic particle velocity gauges are made by sandwiching aluminum conductive elements between sheets of Teflon. The 60 μm thick membrane is then placed in the liquid sample at an angle so that particle velocities are measured at multiple depths. In this paper we report particle velocity measurements in the liquids nitromethane, bromoform and diiodomethane using Teflon gauges inclined to the shock front by 0, 10, 20, and 30 degrees. The particle velocity measured by the inclined gauges was either higher or lower than the "correct" particle velocity measured by non inclined gauges. The error in the measured particle velocity is a function both of the relative impedance of the liquid and Teflon membrane, and of the angle of the gauge to the shock front. Measured velocities can be in error by $\pm 10\%$ for gauges inclined 30°. Analysis shows that some of the error is caused by the liquid slipping past the Teflon membrane.

INTRODUCTION

Since its introduction by Vorthman and Wackerle¹ in the early 1980s, the inclined multi-element electromagnetic particle velocity (EMV) gauge has provided a convenient way to measure particle velocity at as many as 10 Lagrangian positions in a single gas gun driven shock experiment. These gauges are robust enough that they are often used to study the initiation of explosives.

Sheffield, Engelke, and Alcon² were the first to use inclined multi-element EMV gauges in liquids. While studying the initiation properties of liquid nitromethane (NM), they noticed that in the non reacting "inert" part of the NM flow, the particle velocities measured by the inclined gauges were about 10% lower than expected.

Concern that the gauges were not measuring particle velocity properly in liquids, and hence might also be in error in solids has prompted the present study. Our goals were to calibrate the errors in the measured particle velocity as a function of gauge angle and of the relative gauge/liquid impedance. While it is likely that other factors, such as the liquids' viscosity, are important, we felt that in the first stages of this study, it would be

better to vary quantities over which we had good control.

EXPERIMENTAL SETUP

The multi-element EMV gauge packages were made for us by RdF Corp. (Hudson, NH) as follows. First a 25 μm thick sheet of FEP Teflon forms the base. To this base is epoxied a 5 μm layer of aluminum foil. Next, using photo etching techniques, aluminum is removed, leaving a series of nested, square cornered, "U" shaped conducting elements. The bottom of each conducting element is 6 - 10 mm long, depending on its location in the nest, and forms the active portion of the gauge. The active portions are typically spaced ~ 2 mm apart, and when placed at an angle, this spacing will convert to depth according to the sine of the wedge angle. Finally, a second sheet of 25 μm thick FEP Teflon is epoxied on top of the base sheet and active elements. The completed gauge package is typically ~ 60 μm thick.

The plastic targets containing the liquids were similar to those used by Sheffield, Engelke, and Alcon,² and were constructed as shown in the exploded view of Figure 1. Hollow PMMA cylinders

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~70 mm O.D., with a liquid cavity 40 mm in diameter and 10 mm deep, were sliced to form wedges. The EMV gauge membrane was epoxied to the lower wedge while under tension. Next, the upper wedge was epoxied to the lower,

Figure 1. Exploded view of liquid cell and gauge.

reconstructing the complete hollow cylinder. In most experiments, PMMA surfaces were painted with epoxy to prevent the liquid from dissolving the PMMA. When the epoxy had cured, excess Teflon from the EMV gauge was trimmed, and excess PMMA from the upper wedge machined off. Except for the first few mm, which often ended slightly curled up, the gauge membranes were smooth and flat. Axial gauge positions (depths) and active element lengths were then measured using a computer controlled scanning and depth microscope.

Cell tops were made of ~6 mm thick Kel-F and had a single element EMV gauge bonded to the surface contacting the liquid. These single element gauges, which we call "stirrup gauges" were made by bonding an aluminum conductive element to a sheet of Teflon. The "stirrup gauge" was always oriented flat to the shock. It had not been used in Sheffield, Engelke and Alcon's early shots.²

To complete the assembly, the Kel-F cell top was epoxied and screwed (using nylon screws) to the lower hollow cylinder. The completed target was mounted on an aluminum plate containing fixtures for connecting coaxial cables to the electromagnetic gauge elements.

"Zero degree" experiments were constructed in a manner similar to that developed by Sheffield for studying the equation of state and shock induced reaction in liquid carbon disulfide.³ "Stirrup" gauges were stretched and mounted on flat, parallel PMMA rings, as well as on Kel-F disks forming the cell top and bottom. These assemblies were completed by screwing and gluing the cell top, rings, and bottom together. Small holes were cut in the gauge membranes to allow the liquid to flow between rings.

Liquid was introduced into the cells through 6 mm screw holes, which were then capped with nylon screws and sealed using o-rings and epoxy. In all cases, the liquid was introduced into the cell less than three hours prior to the impact experiment.

All experiments were performed on an 8 m long, 72 mm bore light gas gun, capable of projectile velocities greater than 1.4 km/s. An electromagnet was installed in the gun's target chamber to provide the magnetic field (~750 gauss) for the electromagnetic velocity gauging. The magnetic

field was calibrated prior to each shot using an F.W. Bell model 9200 gauss meter and HTB 92-0608 Hall probe. It was uniform to within $\leq 1\%$ throughout the volume containing the gauges and of reproducible magnitude within $\leq 1\%$ from experiment to experiment.

Voltage traces from the electromagnetic particle velocity gauges were recorded using Tektronix 7612 digitizers. These were voltage calibrated within 30 minutes after every experiment using a Tektronix CG 5001 programmable calibration generator. When converting gauge voltages to particle velocities, corrections were made for the aluminum conducting element resistance and the termination resistance.

Shock input to the liquid was obtained using lexan projectiles faced with 57 mm diameter by 12.7 mm thick z-cut sapphire impactors. Impact velocities ranged from ~ 1.2 to ~ 1.4 km/s and were recorded with a precision of $\sim 0.3\%$ using charged pins.

RESULTS

As it was our goal to measure the velocity error as a function of both the EMV gauge angle and the relative impedances of the gauge and liquid, we chose the following liquids: nitromethane, with lower impedance than the Teflon membrane, diiodomethane, with higher impedance than the Teflon membrane, and bromoform (CH_3Br) with approximately the same impedance as the Teflon membrane.

Shock states in the liquids were assumed to be predicted by the "Universal Liquid Hugoniot"⁴

$$\frac{U_s}{C_0} = 1.37 - 0.37e^{-2u_p/C_0} + 1.62 \frac{u_p}{C_0}. \quad (1)$$

Constants for the liquids are as follows: nitromethane; $C_0 = 1.30$ mm/ μs , $\rho_0 = 1.123$ g/cm³, diiodomethane; $C_0 = 0.973$ mm/ μs , $\rho_0 = 3.33$ g/cm³, bromoform; $C_0 = 0.931$ mm/ μs , $\rho_0 = 2.849$ g/cm³. To obtain shock states in the liquid from impedance matching, we also used the z-cut sapphire Hugoniot of Barker and Hollenbach⁵ and the Kel-F Hugoniot of Sheffield and Alcon.⁶

Figure 2. shows results of an experiment in NM using a 30° inclined gauge and a 0° "stirrup" gauge at the Kel-F/NM interface. The "stirrup" gauge at the Kel-F/NM interface is recording the particle velocity of ~ 1.50 mm/ μs predicted from an impedance matching calculation. The inclined gauges, meanwhile, register a value of ~ 1.35 mm/ μs or about 10% lower than expected.

Figure 2. Observed particle velocity traces in nitromethane obtained with a 30° gauge.

We also did an experiment in NM in which flat to the shock "stirrup" gauges were embedded in the liquid. All three flat gauges in this experiment registered the expected particle velocity, indicating that the liquid did not somehow slow down after the Kel-F/NM interface.

Figure 3. shows results of an experiment in which a 30° gauge was embedded in diiodomethane, the liquid with higher impedance than the Teflon membrane. The particle velocity expected from impedance match calculations for this experiment was 0.99 mm/ μs , and is shown by the horizontal dashed line. The inclined gauges are reporting a particle velocity of ~ 1.10 mm/ μs which is about 10% higher than expected. (The flat "stirrup" gauge and one of the five inclined elements did not work in this experiment).

Figure 3. Observed particle velocity traces in diiodomethane obtained with a 30° gauge. The dashed line indicates the expected velocity of 0.99 mm/μs.

An experiment on bromoform, which has a shock impedance well matched to that of the Teflon gauge membrane, was also carried out using a 30° gauge. The gauges reported the expected particle velocity.

Table 1. shows the percentage error in measured particle velocity for all the experiments performed in this study. Inclined gauges in NM, for which lower than expected velocities are observed have a negative error, while inclined gauges in diiodomethane, for which higher than expected velocities are observed, have a positive error. Both the sign and magnitude of the error depend

Table 1. Error in measured particle velocity.

Liquid	NM	CH ₃ Br	CH ₂ I ₂
Liquid/ Gauge Impedance	Undermatch	Match	Overmatch
0° Gauge	± 2 %		
10° Gauge	- (2 - 4) %		+ (1 - 2) %
20° Gauge	- (5 - 6) %		+ (3 - 4) %
30° Gauge	- (8 - 10) %	± 2 %	+ (9 - 10) %

on the sign and magnitude of the relative impedance mismatch between the liquid and the Teflon gauge. For both overmatched and undermatched impedance conditions, the magnitude of the error increases with increasing gauge angle. Gauges oriented flat to the shock always produced the expected velocity.

CONCLUSIONS

It should be noted at this point that the phenomenon of inclined gauges reporting a velocity which is not that of the surrounding material appears to be unique to liquids. After completing the experiments shown in Table 1, we used the gauges in a plastic having much lower impedance than the Teflon gauge membrane. The expected velocity was observed. It also seems unlikely that these gauges, being only 60 μm thick and hence having little mass, could change the velocity of the liquid by as much as 10%.

The likely difference between the solid and liquids is that in the solid, the gauge must move with the material because of friction between the solid and gauge. In liquids, by contrast, there is only viscous friction, and the present experiments indicate that this is inadequate to force the gauge to move with the material. The liquid, through shock interactions, must perturb the gauge velocity. There is an ongoing study of these effects in our group.

REFERENCES

- [1] J. Vorthman and J. Wackerle in "Shock Waves in Condensed Matter 1983", North-Holland, Amsterdam, (1983) pg. 613. J. Vorthman, J. Andrews, and J. Wackerle, in "Proceedings of the Eighth Symposium (International) on Detonation" pg. 99
- [2] S.A. Sheffield, R.P. Engelke, and R.R. Alcon, in "Proceedings of the Ninth Symposium (International) on Detonation" pg. 39
- [3] S.A. Sheffield, J. Chem. Phys. 81, 3048 (1984)
- [4] R.W. Woolfolk, M. Cowperthwaite, and R. Shaw, Thermochim. Acta 5, 409 (1972).
- [5] L.M. Barker and R.E. Hollenbach, J. Appl. Phys. 41, 4208 (1970)
- [6] S.A. Sheffield and R.R. Alcon in "Shock Compression of Condensed Matter 1991", S.C. Schmidt, R.D. Dick, J.W. Forbes, and D.G. Tasker eds. North Holland, Amsterdam (1992) pg. 909.

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