Conf-780813--5

PREPRINT UCRL- 80440

Lawrence Livermore Laboratory

MANGANIN STRESS GAGES IN REACTING HIGH EXPLOSIVE ENVIRONMENT

R. Weingart, R. Barlett, S. Cochran, L. Erickson, J. Chan, J. Janzen,
Lawrence Livermore Laboratory, R. Lee, D. Logan, Kansas State Univ.
J. Rosenberg, SRI International

April 26, 1978

This paper was Prepared for Submission to
Symposium of High Dynamic Pressures held in PARIS, FRANCE
August 28 - September 1, 1978

DISCLAIMER

MANGANIN STRESS GAGES IN REACTING HIGH EXPLOSIVE ENVIRONMENT

(5 Experimental Methods and Techniques)

By R Weingart, R Barlett, S Cochran, L Erickson, J Chan, J Janzen*, Lawrence Livermore Laboratory, R Lee, D Logan, Kansas State University and J Rosenberg, SRI International, U S A

Manganin stress gages have been fabricated and used successfully to study initiation and detonation of high explosives These four terminal, low impedance gages have been specially designed and encapsulated to minimize the effects of various gage failure mechanisms Several candidate dielectric encapsulation materials have been tested in the reactive environment, and of these, poly tetrafluoroethylene has been chosen Gage stations are formed by thermally bonding the manganin foil between layers of this dielectric Gages manufactured in this way have been used to provide u wi stress profiles throughout the region of build up to detonation in PBX 9404 and TATB

I INTRODUCTION

Imbedded manganin stress gages show great promise as a tool for studying reactive hydrodynamic flow The gage records can provide stress time histories at a mass point (Lagrangian point) within the flow The stress time records are useful in two ways First, an integration of the one dimensional hydrodynamic equations may be made, using coefficients computed from the stress time records From the integration of the hydrodynamic equations, one obtains information about the rate of chemical energy release

*United States Air Force

Work performed under the auspices of the U S Department of Energy by the Lawrence Livermore Laboratory under contract number W 7405 ENG-48

at Lagrangian points within the flow Cowperthwaite(1), and Cowperthwaite and Rosenberg(2) have used data from imbedded particle velocity gages and Wackerle(3) Kanel and Dremin(4) have used data from imbedded manganin stress gages to estimate rates of energy release by methods described above

A second useful application for data from imbedded stress gages is in providing experimental tests of the validity of computer models for reactive hydrodynamic flow The imbedded gage records provide a picture of the evolving shock wave, unattainable by most other methods The stress time and stress distance profiles predicted by the computer models are quite sensitive to the details of the chemical reaction rate, so the gage records provide a fairly rigorous test of the validity of a particular computer model

Before imbedded manganin stress gages can be used with confidence, it must be demonstrated that they faithfully record the pressure in the severe environment of the reactive flow in which they are placed We will discuss the various modes by which the gages can fail or give erroneous signals, and some of the limitations of the materials used in gage fabrications

II MANGANIN STRESS GAGES

Manganin is suitable for use as a stress transducer by virtue of its piezoresistive response It is particularly suited to shock wave work because of its small temperature coefficient of resistance, which makes it relatively immune to shock heating effects Manganin was first used as a pressure transducer in a hydrostatic apparatus by Bridgeman(5) Berstein and Keough(6) and Fuller and Price(7), pioneered the use of manganin wires as dynamic stress transducers in inert materials Manganin stress gages have been used in explosives by Wackerle et al (3) to study shock initiation in PETN, by Kanel (1) and Dremin(4) to study shock initiation of TNT, and by Burrows et al (8) to study Taylor wave profiles in detonating Baratol, Composition B and HMX/Inert

III GAGE FABRICATION PROCEDURE

We started our program using commerically available gages We quickly discovered that these gages did not survive long enough in the late stages of the flow in an explosive environment to give useful records We then began a program to produce a more robust gage package which could survive the severe environment

We have investigated a number of candidate dielectric materials for gage protection, including PTFE (polytetrafluoroethylene), polyethylene, Mylar, Kapton and Borosilicate glass Requisite properties of the dielectric are that it must retain adequate electrical insulation properties in the reactive explosive environment, it must provide the best possible shock impedance match to the explosive, and it should be easy to fabricate and handle. Of the materials we have investigated, PTFE seems to meet these requirements best

A sketch of the gage package is shown in Figure 1, together with a exploded view of a typical experiment assembly The four terminal configuration is photoetched from 50 μm manganin foil, and the leads are plated with 2 5 μm of Cu to reduce the lead resistance The gages are then sandwiched between 2 sets of PTFE of appropriate thickness, with thin films (25 μm) of FEP (fluorinated ethylene propylene) inserted between the manganin and the PTFE. This sandwich is placed in a vacuum fixture in a press, and the temperature is raised to the melt point of the FEP, forming a thermally bonded gage package.

IV. EXPERIMENTAL PROCEDURE

a) Electrical Measurements

Figure 2 is a block diagram of the electrical circuit used with the low impedance gages.

The power supply is capable of a 500 volt pulse of adjustable time duration. The internal impedance of the power supply is 39 Ω and it drives about 13 Amps of current through the gage. The isolation transformer in the driving line is used to minimize ground loop effects in the measuring circuit. Because the gage impedance is low (∿20mΩ) compared with the internal impedance of the source, the driving current is not sensitive to resistance changes in the manganin gage, making the current constant for the duration of the measurement.

The current flow and gage voltage are monitored on separate oscilloscopes. A common timing fiducial is applied to the inputs of both the current and voltage-monitoring oscilloscopes. Pressure measurement is derived from the relationship

$$P = k \frac{\frac{\Delta E}{I}}{R_0}$$

where P is the pressure in GPa, ΔE is the voltage change represented by the voltage drop across the gage element, R_0 is the measured initial resistance of the gage element, and k is the gage factor which is determined by calibration shots. At the present time we have not yet completed a series of calibration shots to accurately determine k.

A second output from the power supply drives a similar current through a dummy gage resistor. The voltage-measuring oscilloscope is used in a differential input mode, and the voltage drop across the dummy gage is used to balance the initial voltage drop across the unstressed manganin gage, allowing a higher oscilloscope sensitivity. A DC offset could be used to accomplish the same result, but the former method is convenient.

b) 102-mm Gas Gun

Figure 1 shows an exploded view of a typical experiment involving manganin gages. The impact of a projectile from the 102-mm gun produces a well-characterized shock-wave in the target material. Maximum projectile velocity is 1.7 km/s using a double-diaphragm helium breech and 1.9 km/s using a powder breech. Projectile velocity is measured to within ± 0.5% using 180 kV flash radiographs. Projectile tilt (typically < 1 milliradian) is measured using an array of crystal pins. The target chamber and catcher tank can contain the reaction products of up to 200 g of PBX-9404-equivalent of high explosives. Typical projectile materials are PTFE, Cu, stainless steel or W, depending on the pressure range desired.

The gun is capable of producing initial pressures in the range 1 to 19 GPa in explosive targets. For calibration purposes, projectile-target combinations can be chosen to give pressure that span the pressure range encountered in high explosives.

c) Target Assembly

Inert target materials used for calibration purposes, and to investigate gage failure in inert hydrodynamic flow included PTFE, aluminum, copper, tantalum, and diamonite (Al_2O_3). Explosive targets were machined from PBX-9404 (a HMX-based, plastic bonded explosive) and 92.5% TATB (1-3 5-triamino, 2 4 6-trinitrobenzene) 7.5% Kel-F (polychlorotrifluoroethylene). The targets were assembled using epoxy to bond the ∿ 0.50 mm thick gage packages between slabs of target material as shown schematically in Figure 1. Each gage package contained two gages, and the gages were imbedded at up to three different levels per shot. After assembly, the target impact faces were typically flat to within 0.05 mm.

V. FAILURE MODES

Gage failure can be catastrophic, as in lead breakage and low-resistance shorts to the HE reaction products, or it can occur gradually, as in element stretching, or a gradual shorting to the reaction products. Gradual failure is a critical experimental problem because it raises the question of how long the gage records are credible after shock arrival.

a) Lead Breakage

In almost any shock-wave experiment the leads will ultimately be pulled apart by the large gradients in material velocity that exist along the leads. In practice, however, this is not usually a serious problem except for experiments where the gages are positioned very close to the impact surface of the target. By making the target diameter ∿ 1 cm larger than the projectile diameter, material-velocity gradients are reduced to a level where the leads do not break over the duration of the experiment (until 2 D signals from the edge of the impact area arrive at the gage station ∿ 3-4 μs)

b) Lead and Element Stretching

Because of our four-terminal gage construction, lead stretching does not affect the gage signals until the lead resistance becomes comparable with the resistance of the external circuit and reduces the current through the gage. We monitor the current through the gages on each shot, and if lead stretching does occur, it takes place so quickly it is indistinguishable from breakage.

We have not observed element stretching to be a problem near the center of the target, but for gages near the edges of the target, stretching signals due to velocity gradients can be appreciable. Figure 3 shows signals from gages located in the same plane but at different distances from the center of the PBX-9404 target. In a rarefaction region, element stretching can mask a falling pressure, as is seen in the record from the gage, (identified as curve 3575A) closest to the edge of the target in Figure 3. Element stretching signals are much larger when material velocity gradients are along the direction of current flow in the element.

There is a more subtle stretching effect that occurs even in 1 D flow, due to 2 D flow near the edges of the element. Figure 4 shows the results of a HEMP(9) 2 D hydrocode calculation of the motion of a Cu foil imbedded in PTFE due to the passage of a planar shock wave. The edges of the element do not keep up with the central portion, so some distortion of the element must occur. We investigated this effect experimentally by comparing the signals from the gage elements of different sizes at the same stress level. We could discern no differences in the signals and concluded that the stretching at the edges did not contribute an appreciable effect, however, edge motion may be important as a shorting mechanism.

c) Shorting Effects

Our experiments have shown the most troublesome failure mode to be shorting of the gages to the conducting reaction products. Some knowledge of the shorting mechanisms is necessary before steps can be taken to correct or alleviate the problem. We have done numerous experiments with PTFE and polyethylene which show that shorting occurs through the dielectric to the reaction products rather than between conductors in the gage package. Figure 5 shows gage signals recorded at a depth of 10-mm in PBX 9404 for differing thicknesses of PTFE insulation. We see that the gage signal increased and lasted longer with thicker insulation. Above a thickness of 0 25 mm, the peak signal level did not increase appreciably. The input stress for the data of Figure 5 was 2 7 GPa and detonation occurred at ∿ 13 mm from the impact face. The 10 mm depth represents the most severe environment that the gages encounter, so we tentatively regard a 0 25 mm PTFE film on each side of the gage as the minimum protection which will allow the gages to operate over the full initiation-detonation regime.

We still do not have a clear picture of the physical mechanisms that produce the shorting between gage leads and the reaction products. For a given type of gage package the signals were fairly reproducible even though, by comparison with the other types of gage packages, it is clear that shorting had occurred. We conclude that shorting probably does not arise from structural defects in the dielectric, since failure due to inhomogenities, pinholes, etc., would produce random failure events. The other possibilities we have considered are failure due to pressure-dependent electrical conductivity in the dielectric and failure due to hydrodynamic effects.

Champion(10) has reported measurements of shock-induced conductivity in PTFE and polyethylene over a pressure range similar to that encountered in detonating high explosives. Champion's data indicates that the conducting path through the 25 mm-thick PTFE or polyethylene in our gage package would have a resistance ∿ 10^3 times higher than the 20 mΩ gage element resistance. We are also able to match the shape of calculated Taylor wave profiles in detonating 9404 with actual gage records, indicating that the gage dielectric has not shorten even at detonation pressures. A comparison of measured and computer Taylor waves in 9404 is shown in Figure 6. We do not think that pressure-induced dielectric conductivity is a significant problem with either PTFE or polyethylene gage packages.

Recent work by Graham(11) indicates that conductivity may be a serious problem in Kapton, a polyimide film that has been widely used for protecting manganin gages. This is consistent with our observation that 0.25-mm Kapton insulation fails almost instantly in a full-detonation environment.

Gage failure by shorting seems to depend on the details of the hydrodynamic flow. We have found it much easier to design a gage package which will survive in full detonation than to design a package that will function properly in the late stages of initiation just prior to detonation. The most obvious hydrodynamic failure mechanism is the 2 D flow which occurs near the edges of the target. Two-dimensional effects will be most severe in the later stages of the run to detonation, where the portion of the shock front near the center of the target is accelerating toward detonation velocity, while the shock front near the target edge is still far from detonation.

Even in the central region of the target, HEMP 2 D hydrocode calculations show that the shapes of the leads and elements are distored by the passage of an initially 1 D shock front. We feel that the distortion may be more severe in a 1 D flow where the material velocity is increasing, as occurs in the initiation phase, but we have not fully investigated this. If the distortion is severe enough, the conductor might actually punch through the dielectric. Another possibility for failure is that the heating of the dielectric in the plastic flow region near the lead edges could be severe enough to cause electrical failure.

VI. RESULTS AND DISCUSSIONS

We have investigated stress-time histories in shock initiated TATB and PBX-9404 using the gage package described above with 0 25 mm PTFE insulation on either side of the gage. We will discuss only the qualitative features of the records because we have not yet completed a careful calibration study. We can, however, find much interest in the shape of the stress-time curves, particularly in comparing the initiation of different explosives.

Figure 7 shows manganin gage signals in PBX-9404 with density 1.84 gm/cm³ at depths of 2, 5, 10 and 15 mm in the flow. The PBX-9404 was initiated by a planar shock with an initial stress of 2 7 GPa, giving a run to detonation of about 13 mm. During initiation, the stress at the shock front stays at a nearly constant level until just before detonation occurs, when the shock front is overtaken by a pressure wave from behind.

Figure 8 shows manganin gage signals in 92.5% TATB/7 5% Kel-F with density 1.90 gm/cm³ at depths of 10, 15, and 20 mm depth in the flow. The TATB was initiated with an input stress of 13 GPa, giving a run to detonation of about 14 mm. In contrast with the PBX-9404 behavior, the stress profile in the initiating TATB shows significant growth at the shock front over the run to detonation. We have successfully modeled the stress profiles shown in Figures 7 and 8 using a 1 D hydrocode with an assumed rate law and mixture equation-of-state.

We have made some attempts to discover how much an inert layer (i.e. the gage package) perturbs the initiation process. In one experiment we compared signals from two gages imbedded at the same level in the same shot. One of the gages had a gage package upstream and the other did not. We observed a small delay in the signal from the gage underneath the upstream gage which was consistent with the transit time of the shock-wave through the gage package. Peak pressures measured by the two gages were consistent, but the risetime to peak pressure differed slightly. It is difficult to draw a firm conclusion from this result because the shot was inherently two-dimensional, and the difference in risetime could have been due to a 2-D signal sweeping across the gage element. We have also compared gage signals from different shots, with and without a gage package upstream and find very similar signals. A quantitative comparison is difficult, however, because of uncertainties introduced by small shot-to-shot variations in projectile velocity. The subject of gage perturbations deserves further study.

VIII CONCLUSIONS

Much work remains to be done before manganin gages can be used in a routine fashion in our initiation and detonation studies. We feel that we have a gage package that gives believable records over the entire initiation-detonation regime. We still need to determine more clearly the length of time that the gage records are valid, particularly in the latter stages of initiation. We intend to explore the degree to which the presence of a gage package perturbs the downstream hydrodynamic flow. We plan to do a series of calibration shots in inert materials, so that we can obtain quantitative stress-time records that we can relate to hydrocode calculations and from which we can extract quantitative information regarding chemical energy release rates and other hydrodynamic flow variables.

REFERENCES

1) M Cowperthwaite, p 1259, 14th Symposium (International on Combustion, Combustion Institute (1973)

2) M. Cowperthwaite and J. T. Rosenberg, Proceedings, Sixth Symposium (International) on Detonation, San Diego, August, 1976, (TO BE PUBLISHED).

3) J. Wackerle, J. O. Johnson and P. M. Halleck, Proceedings, Sixth Symposium (International) on Detonation, San Diego, August, 1976, (TO BE PUBLISHED).

4) G. I. Kanel' and An. N. Dremin, Fizika Goreniyz, Varyva, 13, 1, pp. 85-92, January-February (1977).

5) P. W. Bridgeman, Proceedings Royal Society, London A203, 1, (1950).

6) D. Berstein and D. D. Keough, Journal Applied Physics 35, pp. 1471 (1964).

7) P. J A. Fuller and J. H. Price, Nature, 193, 262, (1962).

8) K. Burrows et. al., Proceedings, Sixth Symposium on Detonation (International) on Detonation, San Diego, August, (1976), (TO BE PUBLISHED).

9) M. Wilkins, Calculation of Elastic-Plastic Flow, UCRL-7322 Rev. 1, (1969).

10) A. R. Champion, Journal of Applied Physics, 43, pp. 3362 (1972).

11) R. A. Graham, Bulletin Americal Physical Society, 23, p. 35 (1978).

FIGURE CAPTIONS

Figure 1 - (a) Top and side view of a gage station, and (b) a exploded view of gage stations in target assembly.

Figure 2 - Block diagram of the electrical circuit used with the low-impedance gages.

Figure 3 - Stress signals from manganin gages located at various radial distances from the center of a target assembly, all from shot number 3575. Gage A is 15 mm, D is 10 mm, and G is 5 mm, from target center. Gages were 10 mm deep in the flow with 2.7 GPa input stress.

Figure 4 - 2-D computer simulation indicating relative motion of the metal gage with respect to the surrounding PTFE dielectric.

Figure 5 - Signals from manganin gages protected by different thicknesses of PTFE insulation. Input stress was 2.7 GPa and the gages were located 10 mm deep in the flow. Records are from different shots. Gages on shot 3583 had .13 mm, 3611 had .25 mm and 3505 had .5 mm of PTFE.

Figure 6 - A comparison of calculated and measured stress profiles in detonating 9404. The calculated curves were obtained using a 1-D hydrocode which included a chemical reaction term in energy equation.

Figure 7 - Manganin gage signals in 1.84×10^3 kg/m^3 density, PBX-9404. Input stress was 2.7 GPa, Gages were 2(3545A), 5(3545G), 10(3611E), 15(3611K) mm behind the impact face.

Figure 8 - Manganin gage signals in 1.90 kg/m^3 density, 92.5%/7.5% TATB/Kel-F. Input stress was 13 GPa. Gages were located 10(A), 15(O), and 20(N) mm behind the impact face.

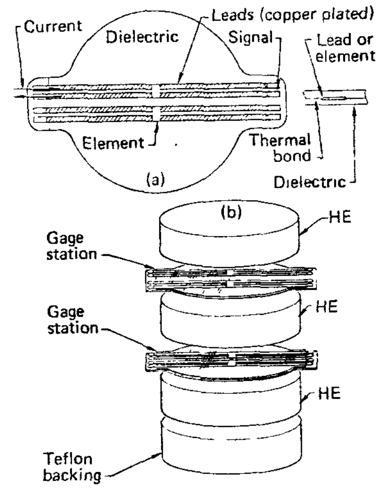

Figure 1

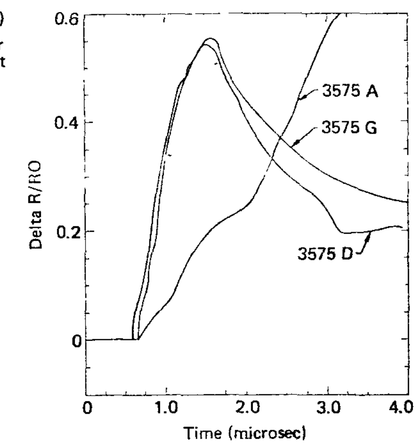

Figure 3

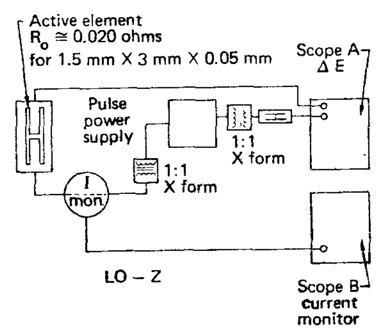

Figure 2

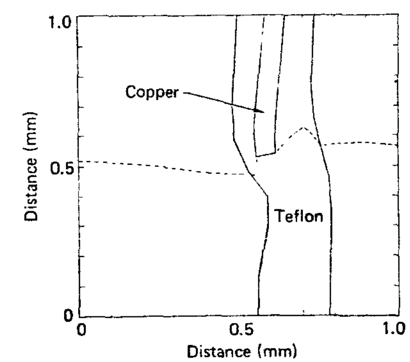

Figure 4

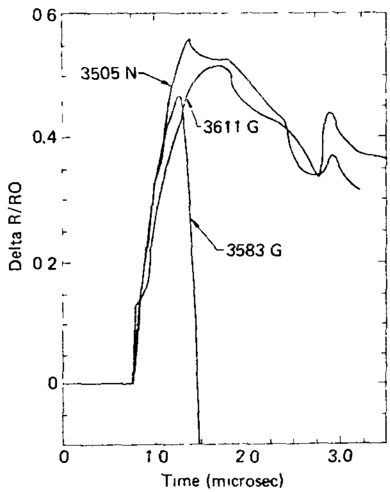

Figure 5

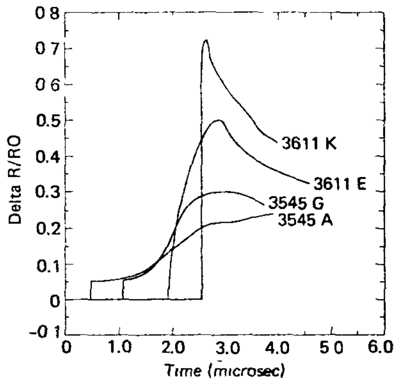

Figure 7

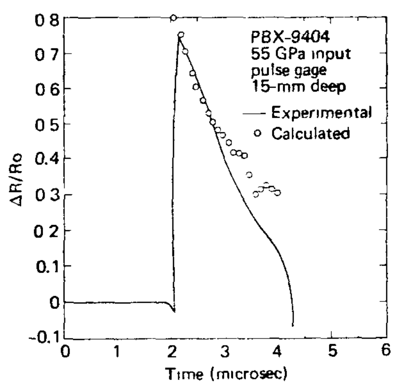

Figure 6

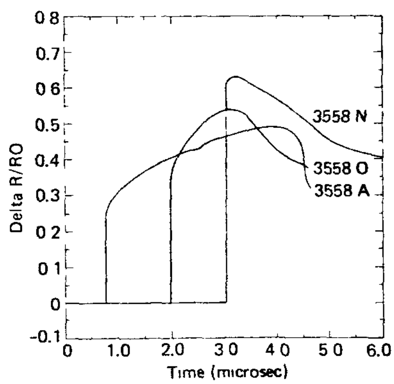

Figure 8