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EXTENDED CALIBRATION OF THIN-FOIL MANGANIN GAGE IN ALOX MATERIAL

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ABSTRACT

The purpose of this program was to extend an existing manganin gage calibration curve, correlating stress as a function of change in gage resistance/gage resistance (ΔR/R), and obtain gage repeatability data from stripped manganin thin-foiled gages manufactured by the Measurements Group Inc., Micro-Measurements division. The experiments extended the existing calibration curve range from the current 0.5 GPa to 6.1 GPa by examining impact stresses of 0.1 GPa in the lower range, and 8.0 and 10.0 GPa in the higher range. The manganin gages were embedded in ALOX (42% by volume alumina in EPON 828 epoxy) material. A light gas-gun was used at Sandia National Laboratories Explosive Components Facility (ECF) to drive an impactor material, ALOX or Tungsten, into the ALOX target containing two gages in a centered arrangement. Tilt and velocity of the impactor were measured along with the gage outputs. A total of 11 tests were conducted using the same ALOX target material that was used when obtaining the original calibration curve. Two initial tests were completed using Polymethyl Methacrylate (PMMA) as the impactor and target at an impact pressure of 3.3 GPa for comparison of gage output with analysis and literature values. The installed gage, stripped of it's backing, has a nominal thickness of 5 μm. The thin gage and high speed instrumentation allowed higher output resolution measurements than can be obtained with 76μm manganin wire used previously. The areas of investigation that will be presented include: 1) experimental setup, 2) comparison with existing calibration curve, 3) discussions of the extended calibration data.

INTRODUCTION

Manganin alloy has been used widely as an in-material stress gage in planar shock wave experiments. Gages of the wire design have been studied by Lee[1] and have been used in numerous physics and engineering applications. Because of the physical size of the manganin wire, 76 μm diameter, this design responds relatively slowly to an input shock and the gage output is dependent on the material in which the gage is mounted. The thin foil manganin gage construction, as reported by Rosenberg[2] is much thinner, 5 μm, and provides a better temporal representation of the shock in materials. This design, with gage backing in place, is reported to be insensitive to the target material. Rosenberg[2] reported that the calibration curve for the thin foil manganin gage showed distinct elasto-plastic behavior with a linear part from 0 to 1.5 GPa. The slope of the elastic part of the calibration was ~50 GPa/(Ω/Ω). The higher stresses were represented by a fourth-order polynomial fit. The target and impactor materials used in the Rosenberg work were PMMA, copper, magnesium and aluminum, all homogeneous in nature.
A shock response calibration curve for the commercial foil gages that have the customary Kapton® backing removed and the gages imbedded in ALOX was developed by Benham et al[3] in 1995. The work presented here describes the extension of the existing "Manganin Gage In ALOX" calibration curve to include a pressure range from 0.1 GPa to 10.0 GPa. extending the range from the current 0.5 GPa to 6.1 GPa. The manganin gages used in these experiments were from the same batch of material used for generating the existing curve and manufactured by the same supplier (Micro-Measurements model No. VM-SS-110FB-048, Part No. C-941028-A). Two gages were installed in each target to obtain redundant gage outputs from the same test input (Fig. 1).

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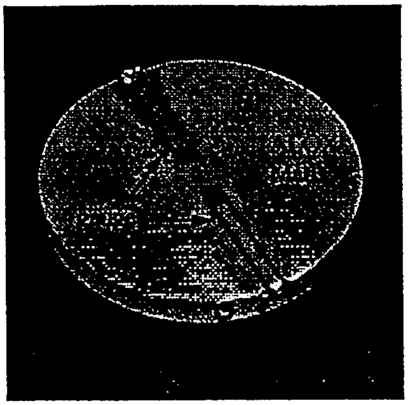

Figure 1. Gages mounted on ALOX target.

EXPERIMENTAL TECHNIQUE

A light gas gun driven projectile was used to introduce well controlled and characterized shock impulses into the selected targets. A schematic of the gun system is shown in Figure 2. The gas gun used has an inner bore of 2.5 in. and a length of 60 ft. The gun has the capability of propelling a projectile at velocities ranging from approximately 25 meters/second up to 1.75 kilometers/second.

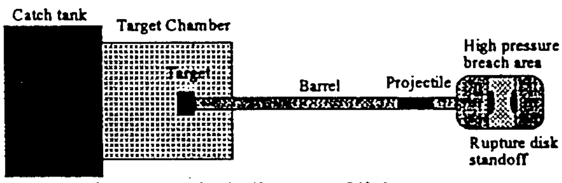

Figure 2. Block diagram of light gas gun.

The gas used to pressurize the breech was nitrogen for low velocity shots (below 600 m/s) and helium for higher velocity shots. The firing pressure of the breach was determined from a gas gun software program which estimates the pressure for the given projectile weight and selected projectile velocity. The projectile was loaded into the barrel, and a dual diaphragm rupture disk assembly was inserted into the breach. The target containing the manganin gages was mounted on the target holder in the target chamber and all cabling and instrumentation hook-ups were completed. Upon completion of the target installation, the target chamber was closed and evacuated. Once evacuated, pressurizing of the breech was begun. When the system is pressurized to the specified level the projectile was fired. The impact velocity of the projectile was measured using five coaxial pins that were shorted by a metallic ring around the projectile on impact. The pins were separated by 10 mm in the axial direction and the last pin was 62 mm in front of the target assembly face. The accuracy of the impact velocity is typically +/- 0.5%.

The impactor tilt was measured by four sets of tilt pins placed on the target cup and shorted by the projectile at impact. The tilt pins were equally positioned around the target axis. The impactor tilt was calculated from the output of the four signals.

Figure 3 is a schematic of the projectile and target assemblies. The impactor material was PMMA made by Rohm and Haas for the preliminary set up and validation tests. **ALOX material (the same material used in the origination of the calibration curve) was used for recalibration series and the extension series.**

The projectile impactor was 2.5 mm thick and was backed by a 5 mm thick disk of carbon foam which had a nominal density of $0.2 g/cm^3$. This backing material reflects a very small percentage (~4%) of the shock wave reaching it from the impactor. The projectile (Sabot) to carry the impactor was made of either aluminum or syntactic foam filled nylon. Using the same material for the impactor and target, as was the case for the lower velocity tests, produced a symmetric impact with the resultant particle velocity in the target material equal to one-half the projectile velocity. For the highest velocity test the impactor was tungsten. The stress level in the impacted material in both cases was determined from the known Hugoniot curves for ALOX [4] and the measured impact velocity determined by the impedance-match technique.

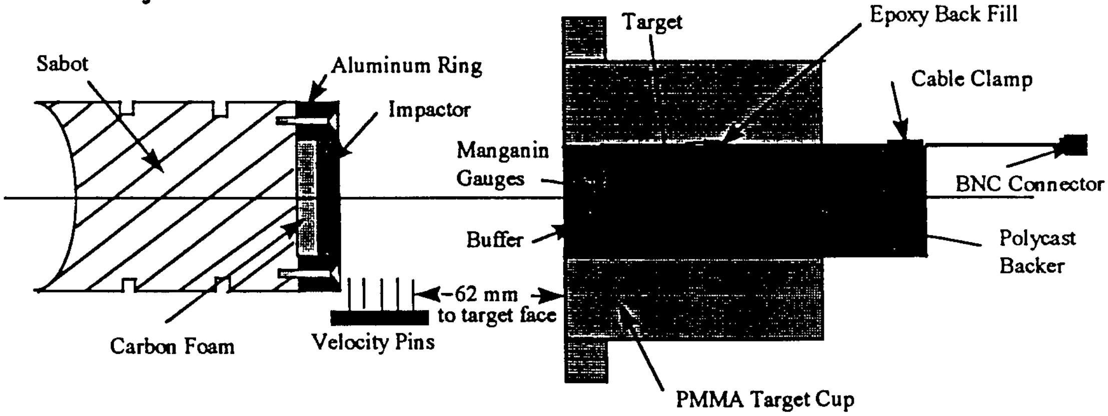

Figure 3. Projectile and target assemblies.

The manganin gages were sandwiched between two pieces of PMMA or ALOX, respectively. The first piece, the buffer, was nominally 5 mm thick and the second, the target, was 25.4 mm. The polycast backer was used to support the instrumentation cable connections shown in figure 4.

The manganin gages are etched foil with 48Ω nominal resistance. The foil was 5.0 μm thick and the Kapton® backing was removed after the gages were glued to the respective target. The total thickness of the gage installation between the buffer and the target was nominally twice the gage thickness. The manganin gage had two thin ribbon extensions for attachment to the instrumentation cable which were coated with a thin layer of copper (~5μm thick) to reduce output caused by a resistance change of the leads during impact.

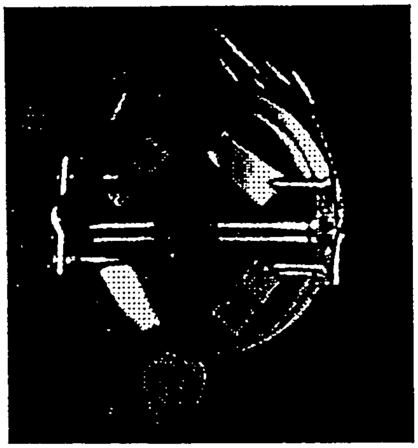

Figure 4. Manganin gage/PMMA target assembly.

TEST SEQUENCE

The calibration tests were set up in three parts. The *preliminary tests* were done to verify the light gas gun set-up and to validate that these tests produced the same results as the previous gas gun tests done on the original shipment of gages in 1995. The purpose of these tests was to validate the experimental process.

The second set of tests, the *recalibration tests* were conducted to establish an agreement of the performance of the new batch of uncalibrated manganin gages with the calibrated gages used to generate the original calibration curve in ALOX.

The third set of tests, the *extension series* were aimed at extending the previous data set to include lower (0.1 GPa) and higher (8.0 GPa and 10.0 GPa) data to extend the calibration curve for these gages.

DISCUSSION AND TEST RESULTS

The preliminary tests (2 each) were conducted with the gages imbedded in PMMA material and designed to produce 3.3 GPa pressure (33 kbar) loading in the material. Gages from the original batch of gages as well as "uncalibrated gages" from the subsequent completion of the original purchase order of gages were used for these tests (2 gages for each shot).

The material, PMMA, which has been characterized for shock loading[5] was used in a symmetrical impact to produce 3.3 GPa shock loading. The manganin gages were stripped of the backing and were installed in the same manner as for the ALOX experiments. The preliminary tests were conducted to provide data for comparison with the original calibration data to assess overall experiment accuracy. The results of the PMMA tests for this and the 1995 tests are shown in Table 1.

1997* Level (kbar)	Target Material	Gage ** Readings (kbar)	Dev. %	1995* Level (kbar)	Target Material	Gage ** Reading (kbar)	Dev. %
Test 1 32.99	PMMA	1=33.36 2=33.30	1.1 1.0	30.4	PMMA	1=31.17 2=31.30	2.5 3.0
Test 2 32.96	PMMA	1=32.62 2=32.69	-1.0 -0.82	30.4	PMMA	1=29.56 2=29.16 3=29.84 4=29.71	-2.8 -4.0 -1.8 -2.3
* Pressure level determined by Gas Gun generated particle velocity and PMMA Hugoniot Data. ** Manganin Gage output pressure determined by the 1995 NDB calibration curve.							

Table 1. Comparison of PMMA gas gun tests done in 1995 and 1997.

The following observations verified that these gas gun tests produced the same results as the previous gas gun tests:

1. The gas gun produced the desired velocities that gave 33 kbar, thus demonstrating the quality of the Gas Gun operation at the ECF.
2. The signals from previously calibrated manganin gages, test #2 (Table 1), produced pressures that were within 1% of the delivered values when the Nave, Duggins, Benham (NDB) existing calibration curve for 0.5 GPa to 6.1 GPa was used.
3. The signals from previously uncalibrated gages, test #1 (Table 1), produced pressures that were within 1.1% of the delivered values when the NDB calibration curve was used.

These observations verify that the calibrated and uncalibrated manganin gages, C-941028, give the same output in PMMA materials, within experimental tolerances, at this test level. Both uncalibrated and calibrated gages were used for the recalibration series. Two tests were conducted at each pressure level (5, 33, 61 kbar), duplicating the pressure range of the original calibration series. Two gages were used in each test (12 gages total). The material the gages were embedded in was the same ALOX material that was used in the original test series. The test results are shown in Table 2 below.

1997* Level (kbar)	Target Material	Gage*** Readings	Dev. %	1995* Level (kbar)	Target Material	Gage** Reading	Dev. %
4.97	ALOX	1=5.04 2=5.05	1.4 1.6	5.54	ALOX	1=5.74 2=5.80 3=5.58 4=5.36	3.6 4.7 0.72 -3.2
4.76	ALOX	1=4.99 2=4.78	4.8 0.42	5.57	ALOX	1=5.57 2=5.46 3=5.45 4=5.45	0.0 -2.0 -2.1 -2.1
33.06	ALOX	1=34.53 2=33.75	4.4 2.1	33.76	ALOX	1=34.09 2=33.70 3=33.22 4=33.53	0.97 0-.18 -1.60 0-.68
32.91	ALOX	1=34.21 2=34.43	3.9 4.6	33.90	ALOX	1=34.10 2=34.18 3=33.30 4= N/A	0.59 0.83 -1.8 N/A
59.46	ALOX	1=61.20 2=61.18	2.9 2.9	61.28	ALOX	1=63.78 2=61.78 3=60.70 4=61.55	4.1 0.82 -0.95 0.44
59.46	ALOX	1=60.46 2=59.96	1.7 0.84	61.66	ALOX	1=60.64 2=61.06 3=60.01 4= N/A	-1.6 -0.97 -2.7

* Pressure level determined by Gas Gun generated particle velocity and ALOX Hugoniot Data.
** Manganin Gage output pressure determined using the 1995 (NDB) calibration curve.
*** Manganin Gage output pressure determined using (MAC97) calibration curve.

Table 2. Test results from the Re-calibration test series.

The following observations come from these data:

1. The set of data from each manganin gage, at each level, are very close together, showing good gage repeatability for both calibrated and uncalibrated gages.
2. The manganin gages indicate a higher (0.42 to 1.6%) pressure than the pressure calculation from the Hugoniot using the particle velocity from the impact produced at the 5 kbar range in the aged (2.5 years) ALOX.
3. The manganin gages indicate a higher (2.1 to 4.6%) pressure than the pressure calculation from the Hugoniot using the particle velocity from the impact produced at the 33 kbar range in the aged ALOX.
4. The manganin gages indicate a higher (0.84 to 2.9%) pressure than the pressure calculation from the Hugoniot using the particle velocity from the impact produced at the 61 kbar range in the aged ALOX.
5. Since the calibrated and uncalibrated manganin gages produce the same results in PMMA and aged ALOX, then this difference in pressure is attributed to possible hardening effects in the ALOX material when it ages.
6. A new calibration curve, the results of the calibration extension tests, (MAC97) was generated from the NDB curve with a linear extension from 30 to 100 kbar and with compensation for the Wheatstone bridge nonlinearity.

Comparison between 1997 and 1995 manganin gage calibration curves can only be made over the pressure range of 5 kbar to 61 kbar since this is the range of the NDB calibration series. The MAC97 Gage Pressure curve was obtained using the new curve fit that is based upon the results of the 1997 gas gun calibration series. The new MAC97 calibration curve was developed using the following steps.

1. Generate a program that uses the 1995 NDB curve to generate output over the approximate range of 0 kbar to 61 kbar.
2. Extend the curve with a straight line fit to the 33 kbar and 100 kbar data. Theoretically the output should be nearly a straight line in this region.
3. Correct the resulting curve for the bridge nonlinearity.
4. Generate a polynomial curve fit that matches this data.

The equation that has been developed as a result of the 1997 calibration series is shown below.

$$P = 5.23994500\,(\Delta r/r) - 0.17979031\,(\Delta r/r)^2 + .0069336032\,(\Delta r/r)^3 - .00009205846\,(\Delta r/r)^4 \quad \text{(MAC97)}$$

Where: P = pressure in kbar

($\Delta r/r$) = Change in resistance divided by the initial gage resistance in percent (The change in resistance of the Manganin gage divided by the initial gage resistance, quantity times 100).

1997* Delivered Level (kbar)	Target Material	Gage** Readings (kbar)	Dev. (kbar)
1.046	ALOX	1=1.097 2=1.341	0.051 0.295
1.002	ALOX	1=.702 2=.857	-0.300 -0.145
			Dev. (%)
80.85	ALOX	1=79.81 2=79.48	-1.29 -1.69
80.57	ALOX	1=79.60 2=81.32	-1.20 0.93
97.37	ALOX	1=99.54 2=97.93	2.20 0.57
98.78	ALOX	1=no data 2=97.84	 -0.95

* Pressure level determined by Gas Gun generated particle velocity and ALOX Hugoniot Data.

** Manganin Gage output pressure determined by the 1997 (MAC97) calibration curv

Table 3. Comparison of the Calibration Extension data with the gas gun delivered pressure.

The results of the calibration extension tests are shown in Table 3. The pressures in the "Gage Readings" column were calculated using the "MAC97" calibration curve using the new curve fit that is based upon the results of the recalibration series. The "Delivered Level" pressure from the gas gun was calculated from the particle velocity and the ALOX Hugoniot. These pressures indicate errors of <± .3 kbar at low pressures and <± 2.2% in the high pressure ranges. Figure 5 is a graph showing the data points from the 1997 calibration series plotted on the new MAC97 calibration curve.

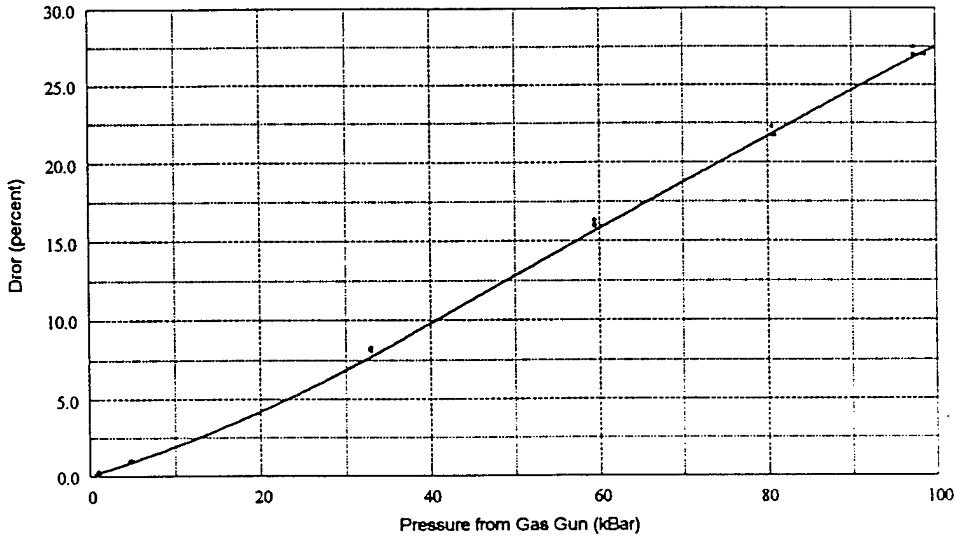

Figure 5. Manganin/ALOX Calibration, 1997 (MAC97).

CONCLUSIONS

A calibration series has been completed for the purpose of extending the calibration range that has produced the same results as the previous gas gun tests, verifying the proper operation of the gas gun, and showing that the manganin gages of the new lot perform identically as the previously calibrated lot in PMMA materials. Since calibrated and uncalibrated manganin gages produce the same results in PMMA and ALOX, it was concluded that the same calibration curve can be used for all gages (uncalibrated and calibrated). The slight differences in pressure are attributed to possible hardening effects in the ALOX material when it ages.

A new calibration curve (MAC97) was generated from the NDB curve with a linear extension from 3.3 GPa to 10.0 GPa and with compensation for the Wheatstone bridge nonlinearity. The 1995 NDB calibration curve is still accurate over its intended range (0.5 to 6.1 GPa), however the new 1997 calibration curve (MAC97) must be used in other areas between 0.1 GPa and 10.0 GPa.

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REFERENCES

1. Lee, L. M., J. Appl. Phys. Vol. 44, Sept. 1973, pp 4017-4022.
2. Rosennberg, Z., et al, J.Appl. Phys. Vol 51 (7), July 1980, pp 3702-3705.
3. Benham, R. A., et al, "Calibration of Thin Foil Manganin Gage in ALOX Material" APS Topical Conference, 1995.
4. Lee, L. M., "Alumina-Filled Epoxy Shock Response as a Function of Temperature." Air Force Weapons Laboratory Report, AFWL-TR-87-133 Sept. 1998.
5. Schuler, K. W. and Nunziato, J. W., "The Unloading and Reloading Behavior of Shock Compressed Polymethyl Methacrylate." J. Appl Phys. Vol. 47 (7), July 1976, pp 2995-2998.

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