Experimental Calibration of Manganin Pressure Gauges

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Abstract

Manganin pressure gauges are used to measure pressures up to tens of GPa and are commonly used in impact or detonation experiments to get time resolved pressure measurements at a specified location. The measurements rely on the property of manganin to change its electrical resistance under pressure. To convert the measured electrical signal to a pressure signal a calibration of the manganin gauges is necessary. In this work two different calibrations of commercial manganin gauges have been tested by impact experiments. It was found that only one of the calibrations describes the results of our experiments.

Keywords: Impact, Detonation, Manganin Gauge, Pressure Measurement

Introduction

Manganin pressure gauges are used in impact and detonation experiments as lagrangian pressure probes which make time resolved measurements of pressures of up to 50 GPa at certain locations possible. To conduct a pressure measurement the gauges are supplied with a constant current for a time of 100 µs. The change in pressure can then be measured as an increase in voltage ΔV relative to the offset corrected base voltage V_0 as the resistance of the manganin element in the gauge is changing, see eq. (1).

$$\frac{\Delta V}{V_0} = \frac{V_P - V_0}{V_{0'} - \mathrm{Offset}} \tag{1}$$

In this work commercial manganin gauges type Mn10-0.050-EFEP-MET-S from Dynasen Inc. are used. The manganin element has a thickness of 25.4 µm and is sandwiched between two sheets of Polyfluorethylenpropylene (FEP) with a thickness of 25.4 µm each bonded by an epoxy resin (**E**FEP). They have an approximate impedance of 50 mΩ. Dynasen delivers the manganin gauges with a calibration polynomial which connects the relative voltage increase $\Delta V/V_0$ to the pressure. To calibrate the manganin gauges they are exposed to different impact shock pressures by shooting a target with embedded manganin gauges with an impactor. If the shock Hugoniot data of the impactor and the target are known the pressure in the target can be calculated from the measured impact velocity by the impedance matching method [1]. The calculated impact pressures and the relative voltage increases can then be used to fit a calibration curve. Therefore the geometrical setup of the experiments has to make sure that the measurements are not influenced by lateral or rear rarefaction waves too early.

For many years a calibration published by Vantine et al. from Lawrence Livermore National Laboratory was used [2], see eq. (2).

$$P[GPa] = 0.40 + 35.86 \cdot \left(\frac{\Delta V}{V_0}\right) + 11.88 \left(\frac{\Delta V}{V_0}\right)^2 - 4.58 \left(\frac{\Delta V}{V_0}\right)^3 \qquad (2)$$

Recently Dynasen Inc. came up with a new calibration polynomial derived for slightly different manganin gauges shown in eq. (3).

$$P[GPa] = (-0.0038 \left(\frac{\Delta V}{V_0}\right)^2 + 4.8179 \left(\frac{\Delta V}{V_0}\right) \;)/10 \qquad (3)$$

The goal of the presented work was to check the applicability of the existing calibrations in the pressure range between 15 GPa and 30 GPa for the Mn10-0.050-EFEP-MET-S type gauge package. To do this impact experiments with targets of different materials and embedded manganin gauges which were impacted with modified projectiles fired from a 20x139 mm cannon were conducted. The results of the experiments were used to check the calibration shown in eq. (2). Hydrodynamic simulations were made to check the results and to study early non equilibrium oscillations of the gauge signal during the experiments.

Experimental Setup

It was decided to not change the velocity of the projectile by changing the charge mass to achieve different pressures but to use different target materials. The tip of the projectile is normally aluminum but was modified to amend a 2 mm thick copper tip. The modified projectile tip is shown in figure 1. The thickness of the copper was chosen so that reflection or rarefaction waves from the interface between the copper and the aluminum would arrive late and would not interfere with the measurement.

Figure 1: Modified projectile tip with 2 mm copper plating

To achieve the desired shock pressure in an equal spacing between 15 GPa and 27.5 GPa zinc, copper and tantal were chosen as the target materials. With an approximate projectile velocity of 1000 m/s shock pressures of 17.5 GPa, 22.0 GPa and 27.3 GPa were calculated for the zinc, copper and tantal targets. Sputter targets with a purity of 99.999 % for copper and 99.995 % for zinc and tantal with a diameter of 50 mm and a thickness of 2 mm and 10 mm respectively were used to sandwich two manganin gauges per target, see figure 2. The target materials together with the manganin gauges were positioned in a polymer mount to make the handling easier, see figure 3.

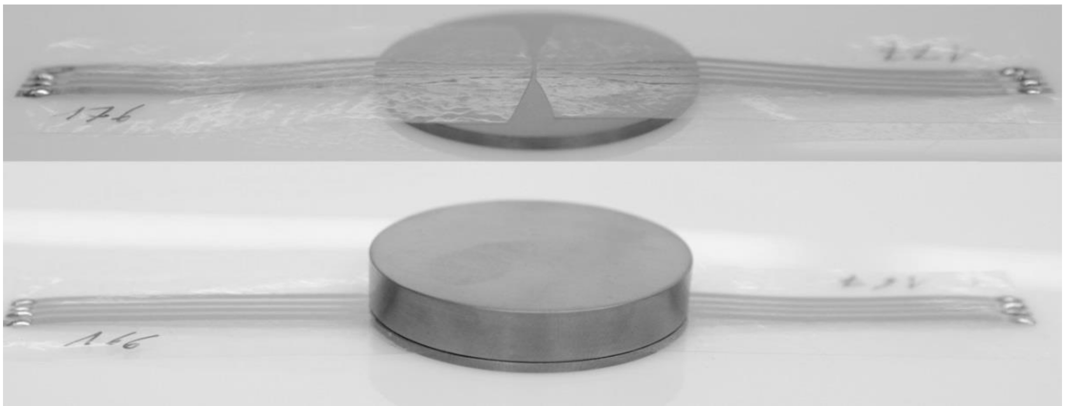

Figure 2: Positioning of two manganin gauges between two discs of target material

Figure 3: Ready to use targets with manganin gauges embedded in three different target materials

The modified projectiles were shot and their velocity was measured with a light gate positioned 2 m before the impact point. It is reasonable that the velocity of the projectile will only vary slightly between the light gate and the target. The light gate also triggered the pulse power supply which feeds the 100 µs long constant current to the manganin gauges. The flight and impact of the projectile were also recorded by high speed video to control the flight and to ensure a planar impact of the projectile on the target. For every target material five individual shots were conducted.

Simulation

To simulate the expected signal one dimensional hydrodynamic simulations were conducted with the commercial hydrocode SPEED [3]. Since no shock Hugoniot data for the FEP and the manganin were available the gauge package was modeled with teflon and copper instead. A mesh size of 3 µm was chosen for the simulations. All material data was taken from the SPEED database. The simulation setup is shown in figure 4.

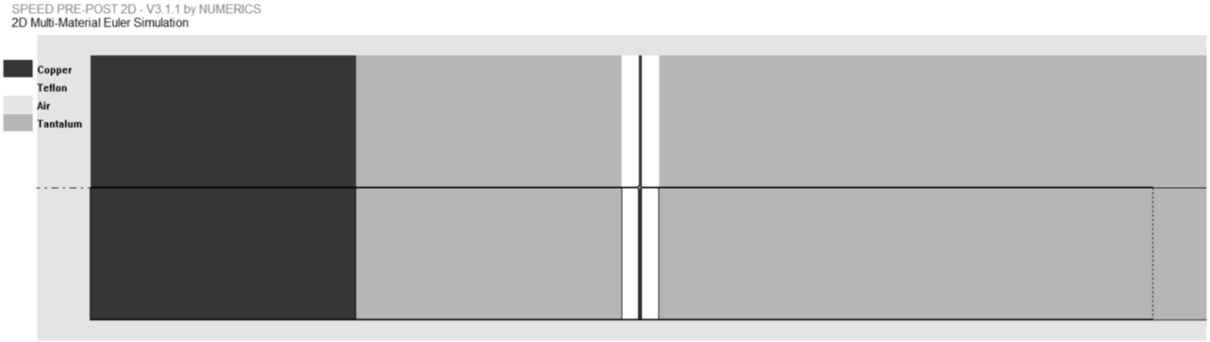

Figure 4: Setup for hydrocode simulations

Results

12 of a total of 15 shots were successful. From the recorded signals 16 were used in the analysis. The others were rejected because the signals indicated early arrival of lateral or rear rarefaction waves seen as a premature damping of the signals. An exemplary signal of a shot used in the analysis with a tantal target is shown in figure 5.

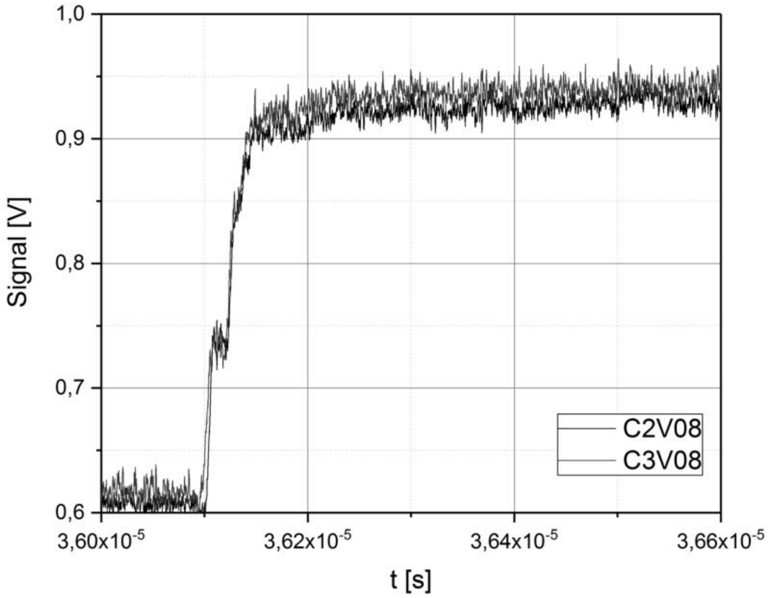

Figure 5: Exemplary raw signals from manganin pressure gauges in a tantal target

It can be seen that after a short oscillatory period due to the impedance mismatch between the gauge package and the target material a constant pressure plateau as expected from 1D shock wave theory and the signals also agree well with the expected signal from the hydrocode simulations, see figure 6.

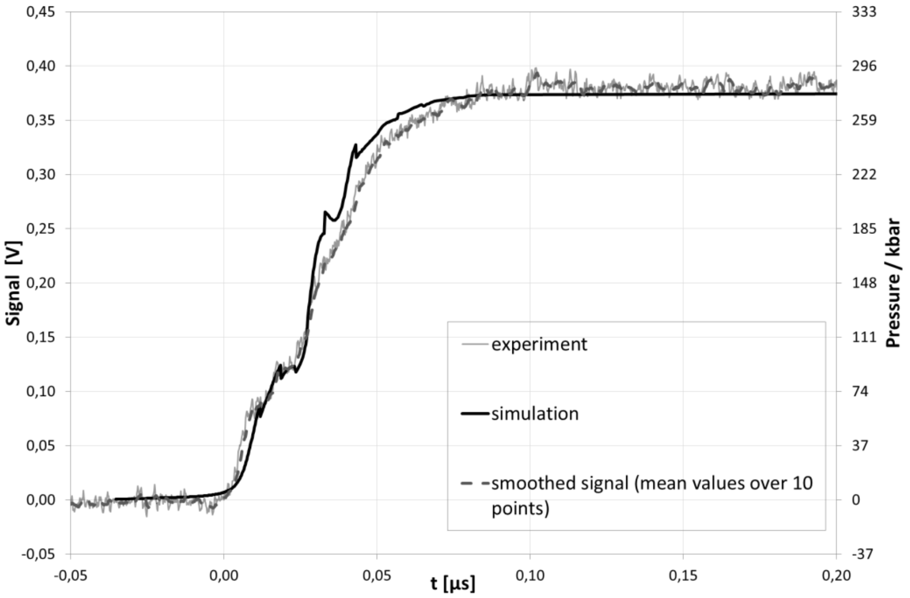

Figure 6: Comparison between early gauge response for simulated and measured signal

Any deviation from the plateau would indicate a non 1D flow e.g. from lateral rarefaction waves around the gauge package. In figure 7 the results of the experiments and the existing calibrations are shown.

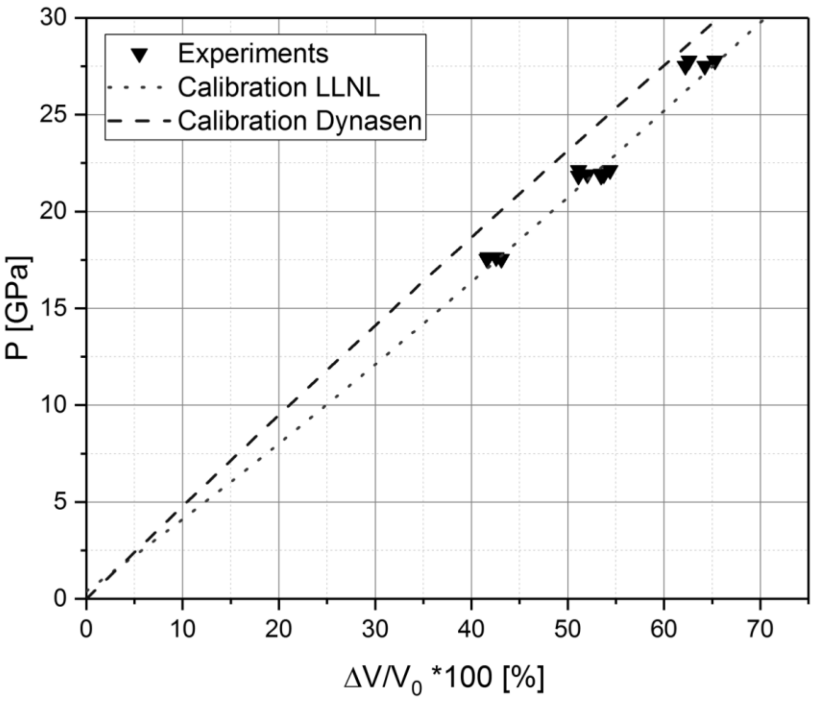

Figure 7: Experimental results compared existing calibrations

It was found that for the same relative voltage increase $\Delta V/V_0$ the shock pressures calculated from the experimental data are in good agreement with the old calibration but systematically lower than the pressures calculated from the newer calibration polynomial.

Summary

Experiments were conducted to test two different calibrations for commercial manganin pressure gauges in a pressure range between 15 GPa and 30 GPa. The gauges were embedded in three different target materials, zinc, copper and tantal and impacted with 20 mm projectiles with a modified tip with a 2 mm copper plating. From the shock Hugoniot data of the involved materials and the measured projectile velocities the impact pressures were calculated via the impedance matching method. Then the relative voltage increase of the gauges during the experiments was correlated with the calculated impact pressures and compared to the available calibrations. It was found that the agreement with the old calibration was good but a systematic deviation to the new calibration exists indicating that the newer calibration cannot be used for this specific kind of manganin gauges.

Acknowledgments

This work is supported by the Bundeswehr Technical Center for Weapons and Ammunition (WTD 91) in Meppen.

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