Effects observed when using metallic flyers and barriers with the embedded particle velocity gauge technique

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Abstract. A number of experiments were carried out using a modified version of the standard particle velocity gauge technique in plate impact experiments with inert targets. Unusually these utilised dynamic metallic elements. Traditional methodology advises against the use of metallic flyers/barriers with this technique as conductive objects moving in the magnetic field produce perturbations in the output gauge voltage leading to inaccuracies in the derived particle velocities. This body of work investigated the causes of the perturbation effect, methods of minimising its magnitude and possible post-processing correction methods. In experiments with Al flyers, perturbations on the order of 10-15% of signal strength were observed. While the magnitude of the voltage traces were distorted, key features such as shock impact could still be observed, and shock tracker gauges were still effective. The case of metallic barriers was also examined and similar effects observed. This study has indicated that while a coarse empirical correction is possible, uncertainty in the validity of the correction would preclude the use of dynamic metallic elements in experiments where high fidelity data is required.

1. Introduction
Electromagnetic particle velocity (PV) gauges [1] are a widely used technique for observing phenomena such as run to detonation in energetic targets. However their compatibility with metallic flyers or barriers (e.g. in the plate impact technique) is not widely reported. It is desirable to know if these types of materials can be utilised as this greatly widens the available parameter space for experimental design. A paper by Gustavsen et al. [2] details relatively minor interference when using a stainless steel flyer plate with deep mounted gauges. This paper details the outcome of an investigation to expand upon these findings and to see if similar results are observed with differing materials and experimental setups. Although the two sets of experiments detailed here used different facilities, the gauges and magnetic fields used in both are sufficiently similar for broad comparisons to be made.
2. Causes of Perturbation
The main cause of interference effects is thought to be the secondary magnetic field generated by the conductive flyer or barrier. When the metallic plate traverses the experimental magnetic field it experiences eddy currents. These currents in turn generate a secondary magnetic field which interacts with the primary field; as a result one of the key experimental requirements for PV gauges, namely a flat magnetic field, is no longer present. The distortion of the field results in the voltage output from the gauge elements being perturbed; this leads to inaccuracies in the derived particle velocity.

3. Metallic Flyer case
An example of a dataset from an experiment involving a conductive flyer is shown in figure 1. This was a standard plate impact experiment carried out using a 50 mm bore single-stage gas gun at Cranfield University. An aluminium flyer impacted a Kel-F 81 (PCTFE) target at 550 ms$^{-1}$. The target was embedded with a PV gauge, described in [3], and placed in a field of strength 93±2% mT [4].

Normally in this type of experiment, a series of flat topped particle velocity traces would be expected. However in this case anomalous results were observed. A voltage was recorded from all gauge elements commencing at, or very shortly after, the point at which the flyer impacted the target. The fact that voltage was observed in gauge elements prior to shock arrival (note that the shock rise is clearly visible) is indicative of an external perturbing effect. The magnitude of the interference is approximately 10-15% of signal strength. This voltage perturbation manifests as a particle velocity offset once the data is analysed. Interestingly, no significant interference was seen prior to the impact, unlike that observed by Gustavsen et al. [2]. It is likely that this is due to the fact that experiments in [2] utilised a much higher impact velocity which would cause a greater perturbation effect. Also of interest is the fact that the functionality of the shock tracker trace is largely unaffected.

![Figure 1](image)

Figure 1. Uncorrected data from experiment with a Al flyer; the black line shows the expected particle velocity calculated from the impedance matching technique; trace labels indicate the distance of the gauge element relative to the target impact face (mm).

Having observed the interference effect, an empirical method of correction was attempted. The method used here has previously been reported in [3]. Each gauge element should (in an idealised case) record zero voltage until shock arrival; therefore any deviation from the baseline is caused by the perturbation of the magnetic field. The assumption was made that when corrected for gauge element length the perturbation is equivalent for each gauge. In order to correct for this the baseline deviation recorded by the deepest gauge (9.34 mm in figure 1) was subtracted from all of the preceding gauges.

Figure 2 shows the results of the correction. Superficially it appears that the correction is effective in reducing the perturbation observed by the gauge elements, however the actual accuracy of this correction is difficult to assess. The perturbations observed by each gauge element, while broadly similar, actually differ in the fine detail. This obviously places a limit on the effectiveness of a simple empirical technique. The manipulation of the dataset also reduces the accuracy of the particle velocity results due to propagation of errors.
4. Metallic Barrier case

The next step of the investigation was to check if the simple rear gauge correction technique would work with a more complex experimental setup. A number of experiments involving metallic barriers embedded within energetic targets were carried out on the 50 mm bore two-stage gas gun at Los Alamos National Laboratory; this work is a continuation of that reported in [3]. A schematic of the experimental setup is shown in figure 3; the exact details of the technique can be found in [1,3].

For these experiments the flyer velocity was chosen such that the booster explosive was promptly initiated and the shock wave under investigation was a triangular detonation wave. A stainless steel plate was sandwiched between the booster explosive and a Kel-F 800 cylindrical target. The geometries of the Kel-F 800 targets were the same as that of the standard explosive targets described in [1]. The PV gauge embedded in the Kel-F 800 measured the attenuation of the triangular wave through the sample.

The uncorrected data from one of the barrier experiments is shown in figure 4. As with the metallic flyer experiment, perturbations in the gauge traces are visible.
The empirical correction process was carried out as with the metallic flyer experiments. It was noted that the perturbation pattern seen by each individual gauge element was far more homogenous then for the flyer case. This enabled application of an additional refinement to the correction; the additional factor scaled the perturbation subtraction such that the gauge waveforms were corrected to the baseline prior to shock arrival at each gauge element. Equation (1) shows the refined correction.

\[
V_{G}(\text{corrected}) = V_{G} - \left[ V_{BG} \times \left( \frac{L_{G}}{L_{BG}} \right) \times S \right]
\]  

In equation (1) the following terms are used: \(V\) is the voltage recorded by a gauge element, \(L\) is the length of the gauge element, \(G\) refers to the gauge element undergoing correction, \(BG\) is the gauge element used as a baseline and \(S\) is the arbitrary scaling factor applied to the correction to fit \(V_{G}(\text{corrected})\) to zero prior to shock arrival.

The refined empirical correction was then performed and the results compared to 2D hydrocode modelling (AWE 2D Eulerian PETRA code, 0.1 mm uniform mesh) of the dataset. Figure 5(a) shows the refined corrected data along with the hydrocode prediction; it can be seen that there is reasonable agreement. As with the data shown in figure 2, the correction process reduces the resolution of the dataset. Figure 5(b) shows that the refinement to the correction factor slightly improves the fit. However, it is not clear without additional experiments what the physical basis behind this factor is.
5. Future Work
Further work with materials of different conductance is desirable as is a detailed comparison of the influence of gauge design and magnetic field geometry on the perturbation effects observed. A full theoretical and modelling treatment of the problem would be informative.

6. Conclusions
Investigation into the use of metallic flyers and barriers with the electromagnetic particle velocity gauge technique showed that a simple empirical correction can be applied which superficially reduces the perturbation seen. However, the accuracy of this and the effects on the fidelity of the data are difficult to quantify. In the case of the energetic material experiments (as seen in figure 5) a residual deviation between ‘corrected’ experimental data and hydrocode modelling is observed. The source of this deviation is currently unknown. Further experiments and analysis are required to gain a better understanding of the physical processes involved. While this technique appears to work well with experiments involving inert targets and low particle velocities (figures 1 and 2), it is less effective with the larger perturbations generated by the high particle velocities resulting from explosive detonations. Therefore use of this correction technique and dynamic metallic elements is not recommended for high velocity or energetic material experiments if alternative techniques such as interferometry are available.

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