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Utilization of Pencil Probes in Blast Experiments for the Explosive Effects Branch

by Benjamin Showalter

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Utilization of Pencil Probes in Blast Experiments for the Explosive Effects Branch

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| 14. ABSTRACT This report provides an overview of how pencil probes are used in blast experiments conducted by the Explosive Effects Branch (EEB) of the US Army Combat Capabilities Development Command (CCDC) Army Research Laboratory's (ARL's) Weapons and Materials Research Directorate. Key processes and techniques are explained, along with selection methods for choosing the appropriate probe for the pressure event. Methods of mounting and protecting the probe to ensure uncontaminated pressure measurements are also provided and pre-experiment verification and troubleshooting techniques of the complete air-blast probe system are detailed. This report will serve as a key resource for current and future EEB experimenters. | | | | | |
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1. Introduction and Background

The Explosive Effects Branch (EEB) of the US Army Combat Capabilities Development Command (CCDC) Army Research Laboratory's (ARL's) Weapons and Materials Research Directorate performs a diverse array of experiments that require the need for blast pressure data from various threats and surrogate charges. The pressures recorded in these experiments are used to assess air shock interactions with biological tissues, ordinance, and equipment. This report discusses the processes and techniques used within EEB to reliably and accurately capture pressure data with pencil probes. An introduction to the design of the probe and the equipment needed for utilization is presented first. The probe's functionality and selection of a probe with the proper pressure range is discussed next. Mounting and installation techniques for the probe are then presented. An important consideration also covered is pre-experiment system verification and troubleshooting techniques.

2. Basic Pencil Probe and Equipment Information

2.1 Pencil Probe Description

Pencil-type pressure sensors are most effectively used in experimental scenarios where the direction of shock wave propagation is clearly defined. The characteristic pencil shape minimizes the influence of the sensor geometry on the blast wave propagation. The probe is pointed radially toward the center of the explosion and effectively measures the side-on pressure of the propagating blast wave.¹ A pencil probe with its unique shape is shown in Fig. 1.



Fig. 1 PCB 137B23B pencil probe²

2.2 Key Parts of a Pencil Probe

Pencil probes consist of three parts: a body, sensing element, and a connection interface. PicoCoulomb (PCB) ICP pencil probes (Piezotronics, Inc., Depew, New York) are cited as an example. These are common probes that encompass features similar to most other commercially available pencil probes. There are two rings on the flat side of the body, 6.2 inches from the probe's point (Fig. 2). The center of the inner ring is the actual sensing element. The sensing element is located several inches from the tip so that any turbulence caused by the tip will be dissipated before it reaches the sensing element. The sensor is composed of a stable quartz piezoelectric element in an Invar (nickel-iron alloy) housing.³ On the rear of the body is the connection interface. It will have one of two types of connectors—a 10-32 connector or a Bayonet Neill–Concelman (BNC) type of radio frequency connector. The EEB typically uses the BNC connector because it is compatible with EEB's other electronic equipment interfaces.

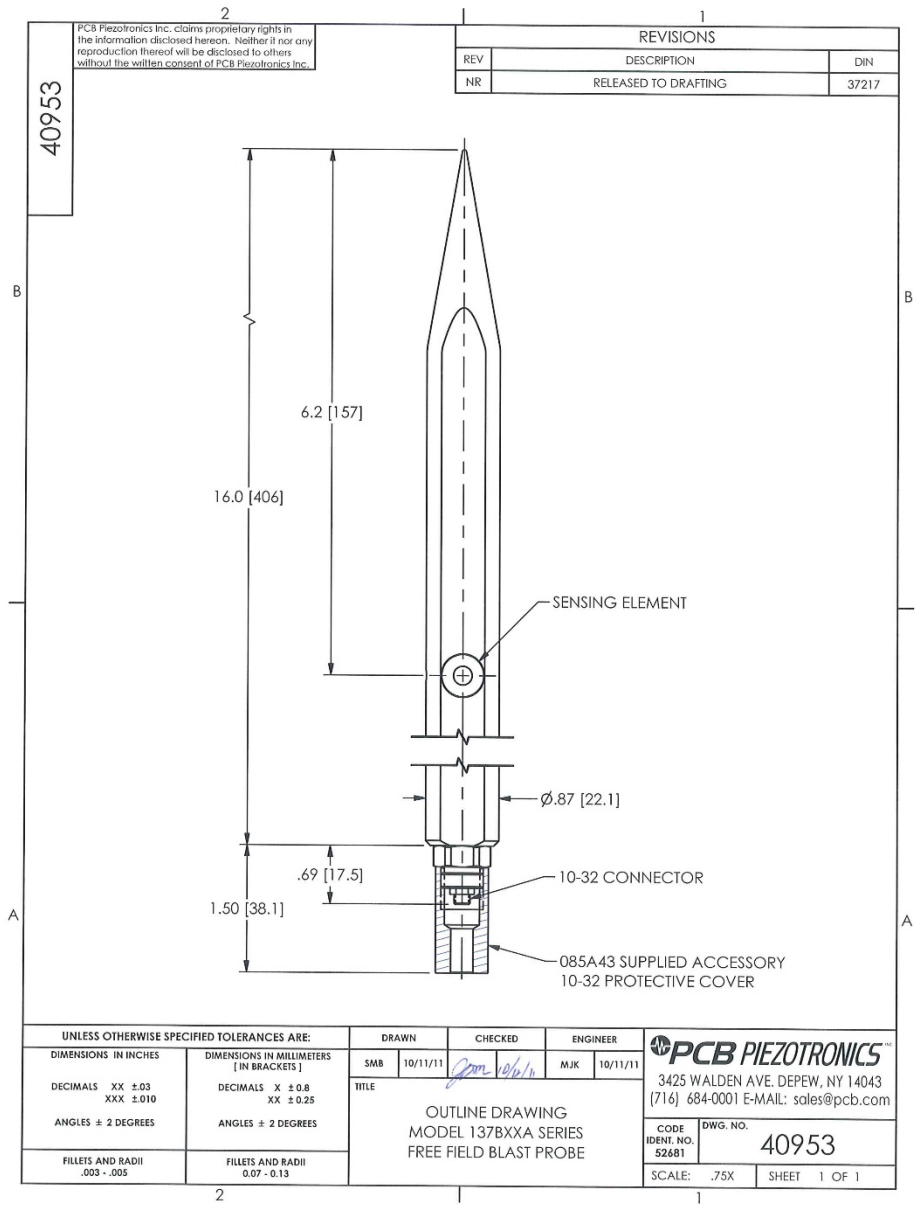


Fig. 2 Components of a pencil probe³

2.3 Models and Signal Conditioners Used

Currently, EEB is only using PCB Piezotronics ICP pencil probes. The EEB operates pencil probes with three different pressure ranges; all the probes are the same dimensions. Models 137A23 (50 psi), 137A22 (500 psi), and 137A21 (1000 psi) are the probes that EEB has in its current inventory. PCB has changed their model numbers since EEB acquired its inventory. Thus, to exchange an existing probe with a newer PCB model, make sure the replacement is the correct pressure range and connection interface.

The EEB generally uses the PCB 481A01 ICP multichannel signal conditioner (Fig. 3) to amplify and convert the pencil probe signal into a compatible form for data acquisition.⁴ The signal conditioner is installed inline between the probe and data acquisition unit. It powers the probe’s built-in amplifier and decouples the signal from the typical 9-11 VDC bias voltage.



Fig. 3 ICP multichannel signal conditioner³

3. Gauge Function

3.1 Sensitivity (referred to as “Cal Factor”)

Within the EEB facilities, sensitivity is commonly called “Cal Factor”. Sensitivity is the ratio between the output signal and the measured property.⁵ The sensitivity value is provided by the manufacturer for each gauge. This number is used to convert from the value delivered by the sensor (typically volts) to pressure units. With a PCB pencil probe, millivolts (mV) is converted into pounds per square inch (psi). The manufacturer’s specification sheet identifies the probe’s pressure range (highlighted in blue), and sensitivity (highlighted in red) as shown in Fig. 4.


| Model Number 137B23A | ICP® PRESSURE SENSOR | | Revision: C ECN #: 44078 |
|---|-----------------------------|--------------------|---|
| Performance | ENGLISH | SI | OPTIONAL VERSIONS Optional versions have identical specifications and accessories as listed for the standard model except where noted below. More than one option may be used. NOTES: [1] For +10 volt output, minimum 26 VDC supply voltage required. Negative 10 volt output may be limited by output bias. [2] Typical. [3] Zero-based, least-squares, straight line method. [4] See PCB Declaration of Conformance PS023 for details. |
| Measurement Range(for ±5V output) | 50 psi | 345 kPa | |
| Useful Overrange(for ± 10V output) | 100 psi | 690 kPa | |
| Sensitivity(± 15 %) | 100 mV/psi | 14.5 mV/kPa | |
| Maximum Pressure | 1000 psi | 6895 kPa | |
| Resolution | 0.01 psi | 0.069 kPa | |
| Resonant Frequency | ≥ 400 kHz | ≥ 400 kHz | |
| Rise Time(Incident) | ≤ 6.5 μ sec | ≤ 6.5 μ sec | |
| Non-Linearity | ≤ 1.0 % FS | ≤ 1.0 % FS | |
| Environmental | | | |
| Temperature Range(Operating) | -100 to +275 °F | -73 to +135 °C | |
| Temperature Coefficient of Sensitivity | ≤ 0.05 %/°F | ≤ 0.090 %/°C | |
| Electrical | | | |
| Discharge Time Constant(at room temp) | ≥ 0.2 sec | ≥ 0.2 sec | |
| Excitation Voltage | 22 to 30 VDC | 22 to 30 VDC | |
| Constant Current Excitation | 2 to 20 mA | 2 to 20 mA | |
| Output Impedance | ≤ 100 Ohm | ≤ 100 Ohm | |
| Output Bias Voltage | 8 to 15 VDC | 8 to 15 VDC | |
| Physical | | | |
| Sensing Geometry | Compression | Compression | |
| Sensing Element | Quartz | Quartz | |
| Housing Material | Aluminum | Aluminum | |
| Diaphragm | Invar | Invar | |
| Sealing | Epoxy | Epoxy | |
| Electrical Connector | 10-32 Coaxial Jack | 10-32 Coaxial Jack | |
| Weight | 12.5 oz | 353 gm | |
| SUPPLIED ACCESSORIES: Model 085A43 Connector Protector (1) Model PCS-6 Calibration of Series 134, 137, and 138 (1) | | | |
| Entered: AP | Engineer: RPF | Sales: RWM | Approved: RPF |
| Date: 4/9/2015 | Date: 4/9/2015 | Date: 4/9/2015 | Date: 4/9/2015 |
| | | | Spec Number: 40954 |
|  <p><small>All specifications are at room temperature unless otherwise specified. In the interest of constant product improvement, we reserve the right to change specifications without notice. ICP® is a registered trademark of PCB Group, Inc.</small></p> | | | PCB PIEZOTRONICS™ 3425 Welden Avenue, Depew, NY 14043 Phone: 716-684-0001 Fax: 716-684-0987 E-Mail: info@pcb.com |

Fig. 4 Specification sheet of a typical pencil probe³

3.2 Probe Verification and Response

It is important to verify that the probe required for the experiment responds appropriately to the expected input. This is achieved by connecting the probe as intended and applying medium pressure on the sensing element with your finger. The data acquisition system should indicate an amplified change in voltage from the resting baseline voltage. If the probe does not respond appropriately, see Section 6 for troubleshooting techniques.

3.3 Data Requirements: Identification and Understanding

A general understanding of the expected pressure at the required distance allows accurate selection of the probe's proper pressure range. Selecting a probe with too small of a pressure range can clip the data, resulting in loss of the peak pressure. Selecting a probe with too large of a pressure range can cause poor resolution of the data.

3.4 Data Acquisition System Settings

There is not one particular setting that works for all experiments. Each event is unique to the pressure being captured. This is why understanding the event and expected pressures is so valuable. Best practice is to double up the sensor with two data acquisition channels—have one channel at 110% of the sensor's maximum range and the second channel at half the sensor's range. It is also important to have 20% of the acquisition range below the sensor's baseline voltage to capture the negative phase of the pressure wave. This is where the gauge response will drop below the baseline after the shock wave passes over the sensor element. When the recording duration is not specified, EEB's general practice is to record for a duration that is double the expected pressure time of arrival at the farthest probe on that data acquisition system. This will generally capture the desired pressure event of interest.

4. Mounting and Installation Techniques

4.1 Protecting the Probe's Sensing Element

In some cases, where flash temperatures such as those generated by blasts and shock fronts are present, it may be necessary to thermally insulate the diaphragm (sensing element) to minimize signals generated by these effects. Common black vinyl electrical tape is an effective thermal insulating material in many cases. Per

the manufacturer's recommendation, one layer may be used across the diaphragm and adaptor (Fig. 5).³



Fig. 5 Electrical tape wrap on sensing element³

4.2 Isolating the Probe from the Fixture

Ground and air shock are major issues in contaminating the data. The shock from the experiment can cause vibrations in the probe's fixture that result in measurement noise and a false time of arrival to the probe. The EEB isolates the probe from the fixture by installing 1/2 inch of ISODAMP (Rathbun Associates, Fremont, California) between the probe and the fixture. ISODAMP is installed on the rear of the probe body behind the sensing element (Fig. 6), typically using duct tape or nylon zip ties. It is also important to secure the cable to the fixture to prevent cable whipping. Cable whipping can also produce the same contaminating phenomenon in the data as the ground and air shock.

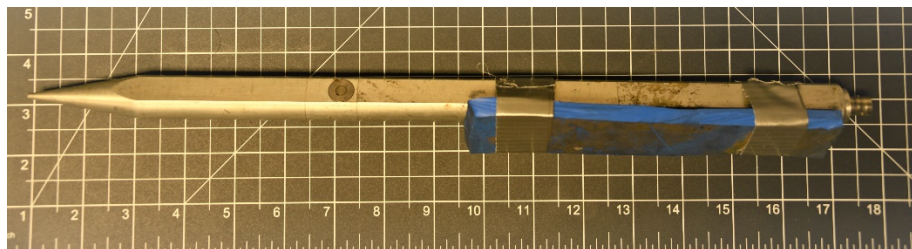


Fig. 6 Typical pencil probe with ISODAMP installed

4.3 Identifying the Surrounding Area

Many of the EEB facilities have various walls, roofs, and fixtures around the experimental area. When determining a potential area for probe installation, try to stay as far away from any hard surfaces as possible. Hard surfaces produce pressure reflections and a mach stem, which can contaminate data. Mach stem is a shock wave formed by the fusion of the incident and reflected shock waves from an explosion.⁶ Isolated placement is not always possible, thus the data may be contaminated by pressure phenomenon from nearby structures. The appearance of recorded waves being “clipped” or abruptly “cut-off” may be an indication of this type of contaminated data.

4.4 Probe Orientation

Each probe should be pointed directly to the center of the explosive event using a visible laser. The sensing element needs to be aligned in a vertical plane to the ground surface (Fig. 7). The element should also be elevated high enough off the ground surface to avoid a mach stem.³ Whether the probes are in a linear or circular array, it is critical that distances from the center of event are accurately measured and documented. Distance tolerances should be specified by the program manager in the experimental plan, but are typically within 1/8 inch of the specified required distance of the probe.



Fig. 7 Array of pencil probes mounted in a real experiment

4.5 Protection from Fragmentation

Most experiments conducted at the EEB facilities produce fragmentation, which will damage the pressure probes. A sacrificial pole is placed between the threat and probe (Fig. 8). The distance from probe tip to the sacrificial pole should be about five times the diameter of the pole. This allows the pressure wave to wrap around the pole and reconstitute before it reaches the sensing element on the probe but stop fragments that are in line to hit the probe. If you have multiple probes in a linear direction from the threat, you only have to protect the first probe.



Fig. 8 Sacrificial pole protecting the pencil probe

5. Pre-experiment System Verification

It is important to verify that the probe or probes are responding before the actual experiment by completing the steps as follows:

- 1) Press on the sensing element with your finger and confirm an amplified change in voltage from the resting baseline voltage is read by the data acquisition system (see Section 3.2).
- 2) Confirm the probe or probes are oriented correctly and secured to the fixture (see Section 4).
- 3) Confirm the data acquisition system triggers with the pre-shot trigger check.

These steps should be completed just prior to every experiment.

6. Troubleshooting Techniques

There are not many components to this probe system, so troubleshooting is fairly easy. Usually the pencil probe or the cabling are the components that cause the most trouble.

- 1) The first step is to check the indicator panel on the signal conditioner.
 - a) A red light indicates a short is present.
 - b) A yellow light indicates an open circuit.
 - c) A green light indicates there is no short or open circuit present. A green light and the gauge not responding could indicate an incorrect setting on the acquisition system or faulty cabling between the two systems.
- 2) For a red or yellow light in Step 1, the easiest check is to replace the existing probe with a known “good” probe and see if the fault ceases.
- 3) If the fault remains, take the known “good” probe and a new cable (confirmed working) and feed it into the same channel on the signal conditioner.
 - a) A green light generally indicates the original cable was in a shorted or open status as a “bad cable or connector”. Replace the cable and reconnect the original probe, then return to Step 1.
 - b) A red or yellow light could indicate a bad channel on the signal conditioner (see Step 4).
- 4) For a remaining fault, try a different channel on the signal conditioner and repeat the troubleshooting steps.

7. Summary

Pencil probes are important devices used in blast experiments to accurately measure the pressure at specified locations. The EEB follows several processes and techniques when implementing pencil probes in their blast experiments. It is important to follow the practices outlined in this report to obtain accurate measurements. These methods will ensure reliable and accurate data, which can then be compared with EEB’s historical data. It is hoped the processes and techniques described in this report provide a better understanding of pencil probes for current and future experimenters.

8. References

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List of Symbols, Abbreviations, and Acronyms

| | |
|------|---|
| ARL | Army Research Laboratory |
| BNC | Bayonet Neill–Concelman |
| CCDC | US Army Combat Capabilities Development Command |
| DC | direct current |
| EEB | Explosive Effects Branch |
| mV | millivolts |
| PCB | PicoCoulomB |
| psi | pounds per square inch |
| V | volts |

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