Method of Using Thin Metallic Foils to Minimize Thermal Transients and Photoelectric effects in Pressure Measurements[1]

Joel P. Booth Robert W. Milton Mark W. Kirkham
U.S. Army Aviation and Missile Command; Research, Development, & Engineering Center
AMSRD-AMR-SG-RF
Redstone Arsenal, AL. 35898-5000
(256) 976-2424
Joel.booth@rdec.redstone.army.mil

Abstract— This paper will discuss the development of a method to reduce ~~the~~ transient effects on piezoelectric pressure transducers used in the measurement of blast overpressure produced by non-conventional explosives. This method was developed during testing of high-energy and non-conventional explosives at the Aviation and Missile Research, Development and Engineering Center (AMRDEC) on the Redstone Arsenal in Huntsville, Alabama. There are two major contributors that negatively affect the quality of data gathered in the measurement of blast overpressures using piezoelectric pressure transducers. These undesirable effects are thermal and photoelectric transients generated in the explosive blast. These transients were found to obscure the data generated by causing a non-positive amplitude shift in the pressure-time curves when trying to measure the performance of non-conventional explosives. This paper will explore the phenomenon in detail, utilizing graphical data derived from laboratory experiments to explain the problem and to illustrate how the use of this method may improve blast measurements

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II. Introduction and Background

While testing Thermobaric formulations, a problem has been encountered with using current pressure transducers. Most current pressure transducers were developed for the testing of conventional high-energy explosives. Conventional high-energy explosives create a very large peak pressure spike with very little thermal output over a short time duration. The typical high-energy explosive reaction has a duration on the order of a few milliseconds. The environment of a Thermobaric reaction (TBX) is very different from the environment of a traditional high energy explosive such as TNT. Figure 1 shows a typical Thermobaric Explosion. The environment of a TBX is characterized by a multistage event that produces a lower peak pressure, longer duration impulse, and a higher thermal output. The TBX can have durations on the order of tens of milliseconds with some formulations extending up to a few seconds. The TBX is also associated with a combustion sustained shock front that acts differently than normal explosive events. Thermobaric explosives are generally oxygen deficient. For a proper reaction, additional oxygen from the air is required. This means that only part of the energy is released during the initial detonation phase. In this phase there is a mixing of high levels of fuel rich particles in the surrounding atmosphere. This leads to an afterburning effect that is similar a fuel-air explosion [1]. The thermal transients and photoelectric effects produced by these reactions are the leading causes for the problems encountered in measurements of the reaction. The following picture depicts the typical TBX and its measurement environment.

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Figure 1. Typical Thermobaric Explosion

Most high response rate transducers that are in use for explosive measurements are piezoelectric or piezoresistive. Piezoelectric transducers use quartz crystals. An applied force excites the crystal producing a voltage relative to the amount and rate of the application. The crystals are contained in a metallic housing - usually steel. The thermal expansion coefficient of steel is 11×10^{-6}/°C. The thermal expansion coefficient of quartz is $.7 \times 10^{-6}$/°C [2]. This creates a situation where the housing is displaced 15 times more than the crystal causing either compression or strain or both depending on the construction of the transducer. This external force has an adverse effect on the measurements obtained from the transducer. Several of these transducers also use P-N junctions to isolate some of the electrical components from the silicon substructure. P-N junctions are semiconductors that have opposite doping types to form an insulator under certain conditions. These P-N junctions can be affected by photoelectric radiation. The radiation causes the creation of hole-electron pairs, which will affect the function of the transducer [3]. Piezoresistive transducers have their own problems as well. They are not as robust as the piezoelectric, and the manufacturing processes involved with obtaining the necessary response rate are very difficult. In addition, piezoresistive sensors use P-N junctions to isolate the Wheatstone bridge from the rest of the transducer. These junctions are very susceptible to photoelectric radiation. Another consideration is that the P-N junctions will not operate properly over 350°F [4].

III. Quantum Mechanics

The physics behind the photoelectric effect are as follows. Quantum mechanics tells us that electrons in any material can be knocked out or displaced from the material by light. This photoelectric effect is present in many commonplace devices like televisions and night vision viewers. To clarify, the light must be of the proper wavelength or frequency to impart enough energy to the electron so it is capable of overcoming the work function of the material. The work function is a physical property of materials and states the minimum energy needed for the electrons to be displaced. There also exists a cut-off frequency for each material that is the point at which no matter how intense the light, no electrons will be displaced. The following is the work function equation, where h is plank's constant, f is the frequency, K_{max} is the maximum kinetic energy imparted to the electron, and ϕ is the work function of the material [5].

$$hf = K_{\max} + \phi \tag{1}$$

Table 1 lists for certain different materials the work function value in electron volts (eV), the cutoff frequency of the material and where that cutoff frequency is located in the spectrum. Note that most commonplace metallics will block the visible spectrum and do not begin to release electrons until hit with ultraviolet emissions [6].

Table 1. Work Functions of Certain Materials

Element	Symbol	Work function (eV)	Cutoff frequency	Visible	Ultraviolet
Silver	Ag	4.74	1.14E+15		X
Aluminum	AL	4.41	1.07E+15		X
Gold	Au	5.47	1.32E+15		X
Cobalt	Co	5	1.21E+15		X
Iron	Fe	4.81	1.16E+15		X
Germanium	Ge	5	1.21E+15		X
Iridium	Ir	5.76	1.39E+15		X
Nickel	Ni	5.35	1.29E+15		X
Lead	Pb	5.6	1.35E+15		X
Platinum	Pt	5.7	1.38E+15		X
Selenium	Se	5.9	1.43E+15		X

IV. Findings and Proposed solution

Following a series of in-depth testing, it was found that certain processes could improve the performance of the transducer in this environment. It is recommended that the transducer be slightly recessed in the measurement adapter, and that a very thin layer of composite metal foil be applied to the surface of the adapter. This orients the transducer in such a way that it creates a cavity between the input stage of the transducer and the foil. The chamber is then filled with an incompressible fluid or other transfer medium. The thin composite foil must be composed of an outer layer of high-density reflective metal (gold) deposited upon a base layer of metal, which has a high coefficient of thermal conductivity (aluminum). The outer layer of high density metal serves as an initial protection from the explosive's emissions by reflection. The inner layer of the foil, a thermally conductive material, the emission effects to the surface of the adapter.

It is believed that the composite foil accomplishes the following:

1. The high density, reflective metal foil protects the sensor surface from radiant energy by acting as a mirror and reflects the emissions of the Thermobaric reaction.

2. The high density, reflective metal foil protects the sensor surface from the direct energy of the explosive fireball by acting as a heat shield.

3. The metal film serves as a physical particulate barrier by preventing soot and other particulates from condensing on the sensor surface.

4. The metal film is extremely thin, and does not lead to signal attenuation.
5. The thermally conductive foil protects the sensor by dissipating and conducting any heat that passes through the first layer. The energy is dissipated to the surface of the adapter, and is not conducted to the face of the transducer.

Figures 2 and 3 show the response of a piezoelectric transducer to a broadband light source. The first trace (blue line) is without the thin film composite metallic shielding and the second (pink line) is with the shielding. The shield reduced the transient effect by up to ten times as compared with the unshielded transducer. As shown below, the unshielded transducer gives – 27 volts at the peak of the down swing equating to –550 psi absolute (See figure below). This reading is out of range for this gauge since it is only calibrated to – 400 psi. This is currently believed to be a combined effect of the thermal transients and photoelectric effect.

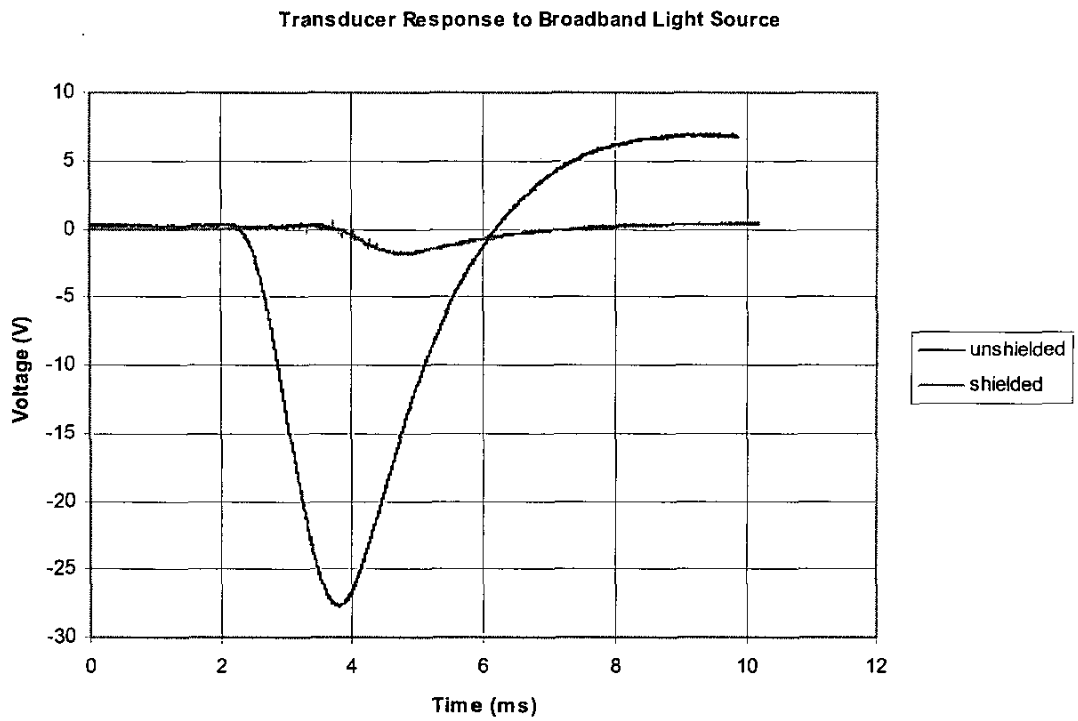

Figure 2. Transducer Response in Voltage

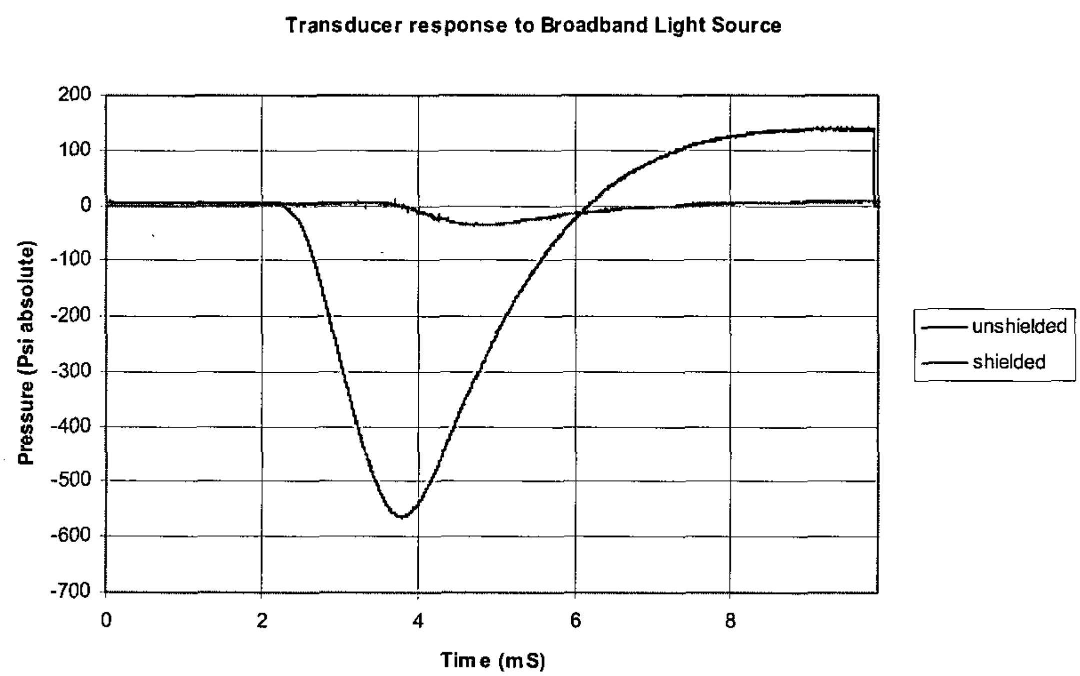

Figure 3. Transducer Response in Psi(Absolute)

Figure 4 is a cross-sectional view of the proposed configuration and orientation of the transducer, foil and adapter. This diagram shows the two different layers and their positioning as well as the incompressible fluid placed under the foil to aide in the conveyance of the pressure wave to the diaphragm of the transducer. There is also a section view to aide in understanding. This sketch is based on our application and could easily be adapted to any type transducer or configuration.

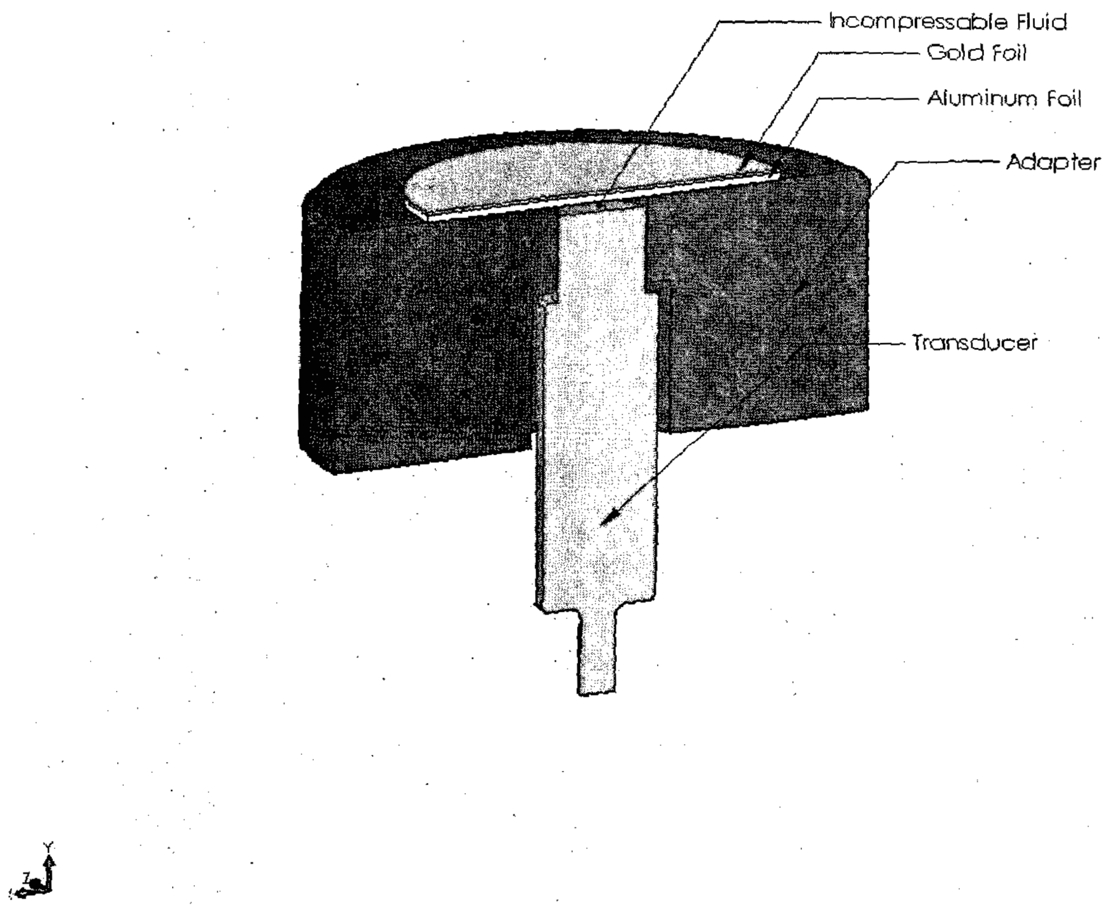

Figure 4 Cross-sectional view of Proposed Solution

V. Conclusion

It is the current belief that the use of composite metallic foils could greatly improve the measurements of blast overpressure in a Thermobaric environment. This would be more of an aide - not necessarily a final solution. These results can out of an ongoing research project at the AMRDEC. At the present time, AMRDEC is directing several efforts to design and manufacture a transducer that will survive the reaction and collect data that is unaffected by the transients produced. There is a Small Business Innovative Research (SBIR) topic that is nearing award for the design and manufacture of transducer that will mean the requirements of the TBX. More than likely, the first cut at solving this problem will be using transducers that are piezoelectric or piezoresistive. However we are also currently investigating fiber optic options as well.

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Biography

Joel P. Booth is a research engineer with the Applied Sensors, Guidance and Electronics Directorate of the U.S. Army Aviation and Missile Command; Redstone Arsenal. He graduated with a B.S. in Electrical engineering from the University of Alabama in Huntsville.

Robert Milton, Attended Louisiana College and University Of Alabama In Huntsville with honors in mechanical engineering. Worked in Propulsion for 20 years. Received 28 civilian government awards for excellence including the achievement medal for civilian service. Nominated for federal engineer of the year for 1992.

Areas of past experience: rocket exhaust plume signature characterization, Insensitive Munitions testing, explosives, bullet, and fragment impact testing and analysis, turbojet, turboprop, and ducted rocket testing.

Mark Kirkham is Physicist for the US Army Research, Development, and Engineering Command, Propulsion and Structures Directorate, Propulsion Technology Function. He holds a B.S. in Physics/Instrumentation from Athens State University in Athens, Al. Mark has 20 years of experience in the areas of Research, Development, Design and Testing of solid rocket propulsion systems.