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Introduction to Air Blast Measurements - Part V

Alternate Technologies?

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Introduction to Air Blast Measurements - Part V: Alternate Technologies?

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If the guidance provided in Parts I-IV is followed, a valid signal representing the air-blast environment will be delivered for subsequent signal conditioning (e.g., digitizing and recording) and analysis. A final question to be addressed is whether there is an alternate technology to piezoelectric ICP® pressure transducers that should be considered for measuring the air-blast environment. The answer is yes; the alternate technology is MEMS (**M**icro **E**lectro **M**echanical **S**ystems)-based transducers.

Like ICP®, silicon-based MEMS (piezoresistive) transducers are often used for air-blast pressure measurements. One reason is that mechanical strain is typically a desired response measurement when structures are loaded by an air blast. Therefore, strain-gage signal conditioning, i.e., differential amplifiers and power supplies, are usually already in place at the test facility, and these same signal conditioning devices can be applied directly to MEMS pressure transducers. This interoperability, not to mention the ease with which MEMS sensors can be statically calibrated, certainly encourages their utilization.

This section attempts to objectively compare strengths and weaknesses of MEMS and ICP®-type pressure transducers focused *only* on their applicability to the air-blast environment. The analysis considers erroneous responses to the undesired stimuli that accompany air blasts, which as previously noted, include as a minimum: thermal transients; light; acceleration/strain; and ionization products of the explosion. In addition, the transducer performance parameters of dynamic range, ruggedness/survivability, frequency response, and self-check are examined. We will deal with these issues one at a time in what this author considers their order of importance.

Thermal transients

Reference 8 discusses challenges encountered due to thermal-transient sensitivity of MEMS pressure transducers. Heat transfer by conduction, convection, and radiation results in the individual strain-elements of the pressure transducer's diaphragm encountering spatially distributed temperatures. These temperatures change with time and are different than that of their supporting structure. In addition, thermally induced distortion (e.g., bending) of the diaphragm can occur. The results of these combined effects are both a zero-shift and a change in sensitivity of the transducer. Figure 14 shows a pressure-time record acquired from a MEMS transducer in a contained explosive environment. This measurement was affected by thermal-transient stimuli.

Methods to mitigate thermal-transient response (as described in reference 8) include (1) a protective or shadowing screen over the diaphragm, (2) opaque grease in front of the diaphragm, and (3) the addition of an opaque material that adheres to the diaphragm such as black tape or RTV. Metallic coatings can also be added to the front of the diaphragm. All of these "fixes" degrade the frequency response (discussed below) of the transducer to some extent as a byproduct of delaying the thermal transient.

References 9 and 10 describe recent advances using MEMS "silicon-on-insulator" (SOI) pressure transducer technology. This technology enables steady-state operation at temperatures to greater than 1000 °F (538 °C), while also enhancing transducer performance in thermal-transient environments.

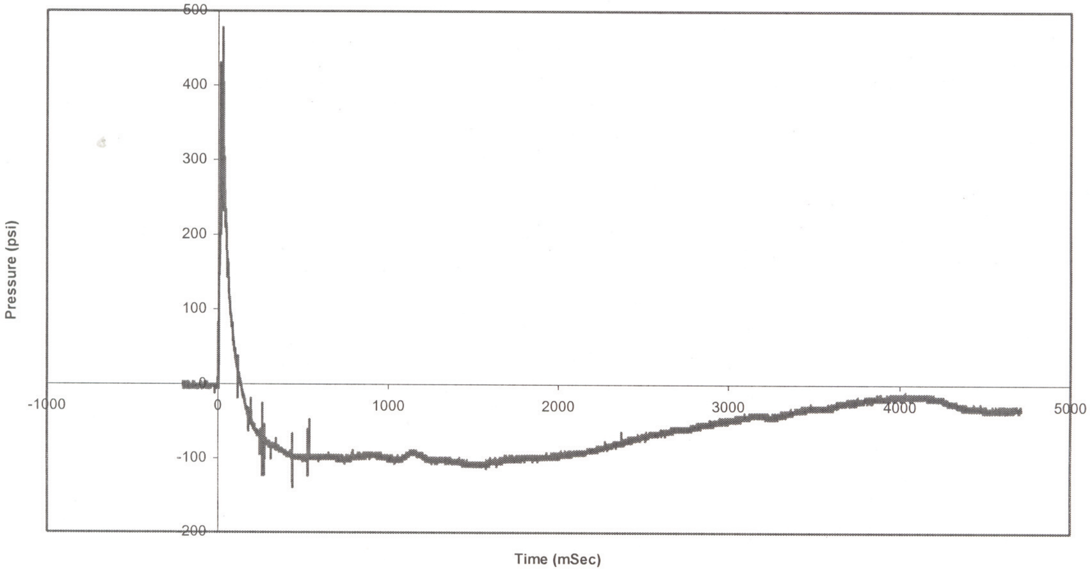

Figure 14: Erroneous Blast Pressure Data (Notice the negative 100 psig reading!)

The initial effect of transient temperature on quartz ICP® pressure transducers is to cause internal component dimensional changes (see Fig. 5 of TN-12), which ultimately result in a partial release of the preload within the stack of quartz plates. The release of this preload results in an error in the pressure transducer output and a false indication of a negative pressure after the pressure event is over. An RTV coating is usually placed on the diaphragm of the transducer to provide a barrier to thermal transients. Coatings, placed on either MEMS or ICP® transducers, typically delay the thermal transient for no more than a few 10's of milliseconds.

Light

Reference 8 also discusses light-sensitivity of silicon transducers. This is of interest because light intensity increases with proximity to the air blast. Silicon-diaphragm pressure transducers absorb short-wavelength electromagnetic radiation in the range between 3,000 to 10,000 A, most of which is in the visible spectrum. The temporary results are photoconduction as well as a photo diode effect in the junction isolation between the gages and the bulk material. Reference 8 concludes, "flash sensitivities of silicon diaphragms vary widely from unit to unit, and it is rather easy to obtain a full-scale output from a flash of light."

Again, since the publication of Reference 8, more recent SOI technology[9,10], used by select manufacturers, has greatly minimized transducer response attributable to light. By comparison, quartz ICP® technology has no sensitivity to light.

Frequency response

MEMS pressure transducers typically possess a maximum resonant frequency of 100 to 200 kHz at pressures under 100 psi extending to a 1 MHz resonance at 1,000 psi. Quartz ICP® transducers possess resonant frequencies of 300 to 400 KHz over this same pressure range. Frequency tailoring (mentioned previously in this article) extends the useable frequency response of quartz ICP® transducers. In addition, they do not require screens and are not influenced by the addition of coatings or RTVs to their diaphragms. MEMS transducers, in ranges less than 100 psi, typically find their frequency response degraded by the addition of thermal protective coatings to their diaphragms. This occurs due to the low density of silicon and the thinner diaphragms necessitated at the lower pressure-ranges. All quartz ICP® pressure transducers are extremely rigid, so as to be virtually unaffected by coatings.

Acceleration (strain)

As noted earlier, blast loading of the housing of a structure in which a pressure transducer is mounted creates motion of the structure and, additionally, induces mechanical strain into it. The lower profile of the MEMS silicon diaphragm assembly (< 0.015" thick), along with the low modulus/density ratio of silicon (approximately 1/3 that of steel), minimizes the acceleration response of MEMS pressure transducers. In addition, some MEMS SOI technology, analogous to ICP® technology, incorporates a second transducer for acceleration compensation. When acceleration compensation is provided, the acceleration sensitivity of ICP® transducers is also very small; however, the larger, more complex structure of their sensing element (Fig. 5) makes them more sensitive to strain coupling.

Ruggedness (survivability)

MEMS pressure transducers are specified with ranges to 30,000 psi, and, historically, with stated over-range capabilities of two or three times full-scale, without damage. Currently, select MEMS transducers[9] are being fabricated with mechanical over-range stops to increase this capability. Quartz transducers may be specified with over-range capability, in some instances, of 200 times full-scale.

Dynamic range

MEMS pressure transducers typically provide an output signal of 100 to 200 millivolts without amplification. The basic piezoelectric sensing element in ICP® transducers typically has a dynamic range of 100 to 120 dB. Quartz ICP® pressure transducers can readily provide a 5-volt full-scale output without amplification. Measuring a 100-psi blast-pressure wave with a 500-psi MEMS pressure transducer that has a 100 mV full-scale output would result in 20 mV of signal before amplification. The comparable measurement with a 500-psi ICP® transducer could result in 1000 mV of signal before amplification. This typical 50:1 signal ratio greatly reduces the number of ranges of ICP® transducers that have to be inventoried at a test facility.

Self-check

End-to-end checks of the integrity on the measurement system can be performed both with MEMS and ICP® transducers. With MEMS transducers one can shunt calibrate the system by paralleling a resistor across one arm of the bridge to produce a known voltage change. Calibration is somewhat of a misnomer, since the values of the transducer's bridge resistors have some dependency on ambient temperature. Nevertheless, the signal indicates continuity and provides some measure of gain through the circuit, which is important information when long runs of cables are involved. The equivalent check for the ICP® transducer is the monitoring of the bias voltage associated with the MOSFET inside the transducer. This bias voltage serves as a continuity check.

Ionization products

The MEMS and ICP® transducers can both be mounted with the transducer housing either grounded or ungrounded to a mounting plate. Both devices have low-impedance outputs, and various cable shielding options can be provided. Any relative advantage between the two technologies would have to be associated with the dynamic range of the ICP® transducer, which was credited above under "dynamic range".

Transducer cost has not been considered in the preceding discussion. The cost of lost test data is often priceless. If multiple channels of acceptable strain-gage signal conditioning are in place, the MEMS transducer is the most economical solution. If these existing and available channels are not in place, per channel costs favor the ICP® solution.

Table I recaps the preceding comparison. A (+) indicates the best or highest performance and a (X) lesser but still highly competitive performance. It should again be noted that the MEMS SOI pressure-transducer technology is currently emerging, and is only available from select manufacturers. The more significant observations include the ICP® sensors' greater tolerance to thermal-transient protection barriers (e.g., RTVs), as well as their much greater dynamic range, compared to the lower acceleration or strain response associated with MEMS SOI sensors. In many air-blast environments both MEMS and ICP® pressure transducers currently operate successfully. However, focusing only on this air-blast application, the ICP® pressure transducers are seen to have some advantage.

Evaluation Parameter	ICP®	SOI	Silicon p-n
Thermal transients	+		
Light	+	X	
Frequency Response	+	+	+
Acceleration (strain)	X	+	X
Ruggedness (survivability)	+	+	
Dynamic range	+		
Self-check	+	+	+
Ionization Products	+	+	+

(+) is best or highest performance
(X) is lesser but still highly competitive performance

Table I: Technical Comparison of ICP® vs. MEMS Transducers for the Air-Blast Application

Conclusion (Parts I – V)

After briefly describing the air-blast environment, some of the historical challenges associated with its measurement were presented. Problems associated with interfacing a pressure transducer to the air-blast environment were next described, and analysis procedures were provided to calculate the effects of any transducer mounting compromises. Tools for validation of data were then discussed, and methods to minimize any documented environment-induced noise, if present, were provided. The frequency limitations attributable to long cables runs used in air-blast testing were then described, and some computational tools were identified. Last, a comparison of different transducer technologies was performed.

Measurement of air-blast phenomena is a challenging task for the test engineer or technician. Hopefully this work will provide comprehensive guidance where a lack of it now exists.

8. Whittier, Robert M., Reducing Transient Thermal Sensitivity of Silicon Diaphragm Pressure Transducers, Eleventh Transducer Workshop, Seattle, WA, available Secretariat Range Commander's Council, White Sands Missile Range, NM, pp. 292-301, June 2-4, 1981.

9. Kurtz, A. D., Ainsworth, R. W., Thorpe, S. J., Ned, A., Further Work on Acceleration Insensitive Semiconductor Pressure Sensors for High Bandwidth Measurements on Rotating Turbine Blades, NASA 2003 Propulsion Measurement Sensor Development Workshop, Huntsville, Alabama, May 13-15, 2003.

10. Kurtz, A. D., Ned, A. A., Epstein, A. H., Improved Ruggedized SOI Transducers Operational Above 600 °C, Twenty-First Transducer Workshop, Lexington Park, MD, June 22-23, 2004.

A number of additional reference sources were consulted for this work. A few of the more valuable are noted below:

- Hilten, John S., Vezzetti, Carol F., Mayo-Wells, J. Franklin, and Lederer, Paul S., Experimental Investigation of Means for Reducing the Response of Pressure Transducers to Thermal Transients, NBS Technical Note 961, National Bureau of Standards, Washington, DC, January 1978.

- Hilten, John S., Vezzetti, Carol F., Mayo-Wells, J. Franklin, and Lederer, Paul S., A Test Method for Determining the Effect of Thermal Transients on Pressure-Transducer Response, NBS Technical Note 905, National Bureau of Standards, Washington, DC, January 1976.

- Sachs, Donald C., Cole, Eldine, Air Blast Measurement Technology, Report Defense Nuclear Agency #DNA 4115F, work performed by Kaman Sciences Corp. (K-76-38U(R), Colorado Springs, CO, September 1976.

- A Guide for the Dynamic Calibration of Pressure Transducers, ISA-37.16.01-2002, Nov. 21, 2002.

Please refer to PCB *Tech Notes* TN-12, TN-13, TN-18 *and* TN-21 *for full text of Parts* I, II, III, *and* IV *of the "Introduction to Air Blast Measurements" Series*

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