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Conformal Sensor Measures Ammunition Pressure Through Cartridge Case

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The conformal ballistic pressure sensor was developed out of a need to standardize and improve measurement technology associated with quality testing of ammunition.

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The conformal sensor measures ammunition gun chamber pressure through an unmodified cartridge case (Figure 1). The device satisfies a very important transduction principle: it should be possible to install a sensor on a structure without altering the operation of the structure or affecting the measurement process. The sensor also has an operating lifetime orders of magnitude greater than conventional measurement sensors mounted at the case mouth or drilled case installations, as it does not have to feel the thermal shock of burning gas in order to record the pressure.

Figure 1
The conformal ballistic pressure sensor features a diaphragm whose curvature is built to conform to the specific caliber to be tested. A floating clamp nut is used to install the sensor while the alignment guide holds the curvature true to the chamber diameter.

An examination of the three conventional methods of testing ammunition [1] will illustrate the merits of the conformal pressure sensor technique.

Copper Crusher

Before the invention of piezoelectric pressure sensors, the copper crusher was used. It was a mechanical procedure in which a test barrel was modified to contain a small piston installed over a drilled cartridge case [1, 2]. A small copper cylinder was held against the piston by a retaining nut. When the gun is fired, the expanding gases force the piston against the copper cylinder, causing it to compress and permanently deform. The resulting disc is then removed from the barrel and measured with a micrometer. For small arms rifle ammunition, the typical deflection range is somewhere between 0.060 in. and 0.080 in.

Tables supplied by the manufacturer of the copper crushers are used to convert the deformation into relative values called "copper units of pressure," commonly referred to as CUPs. Although this measurement process is time consuming and has limited accuracy, it was a simple and reasonably reliable way to obtain ballistic data.

Quartz Sensors

Piezoelectric quartz ballistics pressure sensors have been used since the mid-1960s in both research and production testing for measurement of ammunition and gun barrel pressures. These sensors are installed at either a case mouth location or over a drilled cartridge and measure gas pressure directly from the burning powder (see Figure 2). One advantage of this method is that a single sensor can be moved from barrel to barrel to fit a machined recessed mounting port in a variety of calibers. However, both case mouth and drilled cartridge installations have inherent limitations, especially with the gas passages associated with recessed mounting.

Figure 2
Flat diaphragm quartz pressure sensors can he installed in the drilled case location (B). This installation has a gas passage that affects frequency response and rise time, therefore the measurement result. Location A is conformal.

To protect the quartz sensor from flash thermal effects, an ablative diaphragm coating must be applied and frequently replaced. Another disadvantage is that the recessed mounting port affects the operation of both the gun and the gas dynamics of the measurement process. With smaller caliber ammunition, such as .22, .38, and 9 mm, the sensor's recessed mounting port adds significantly to the volume inside the cartridge and always results in lower pressure readings [1]. Furthermore, the gas passage in front of the sensor may become restricted or plugged and require frequent cleaning.

Drilled cartridge location

The shell case must be drilled and the hole in the case taped to keep powder from falling out. During installation, the hole in the shell case must be carefully aligned with the gas passage leading to the sensor. Preparation is clearly a time-consuming process. When the gun is fired, there is always some gas leakage around the cartridge case. This leakage, combined with the added gas passage volume to the sensor, results in a lower-than-actual pressure reading [1, 2].

Case mouth location

With this method, the sensor does not actually detect the pressure until after the bullet leaves the shell case and passes by the gas passage to the sensor. The pressure measurement therefore takes place after the maximum pressure is reached inside the cartridge case [1]. Furthermore, copper or lead material from the bullet that is shaved off in the gas passage can restrict or clog the passage, affecting not only the measurand but also necessitating frequent passage cleaning.

Although ANSI and SAAMI (Sporting Arms and Ammunition Manufacturers Institute) document the conformal sensor as a performance standard for ammunition pressure measurements [2], NATO still uses the direct gas measurement method. Even with the associated measurement errors, the pressure sensor remains located at the case mouth or over a drilled cartridge.

Life Expectancy

One of the major problems with sensors used for direct gas measurement methods is their short life expectancy. Often, after only 1000 or 2000 rounds, the sensor must be replaced before the "lot" test measurements can be completed. Good measurement practice, for reasons of accuracy and consistency, suggests that it is desirable to start and finish a test lot with the same sensor. Thus, achieving long sensor life was one of the goals involved with the development of the conformal development of the conformal pressure sensor.

The Conformal Pressure Sensor

The conformal pressure sensor (see Figure 3), designed in cooperation with members of SAAMI, is intended for semi-permanent installation in a test barrel for rapid-fire production testing of ammunition. It incorporates a curved diaphragm machined to match a specific gun chamber diameter and taper at a predetermined location [2, 3, 4]. Installed in a test barrel, the diaphragm can be looked at as an integral piston that acts on the quartz sensing element due to the exploding gas pressure generated in the cartridge. It has no effect on the operation of the barrel or the measurement process.

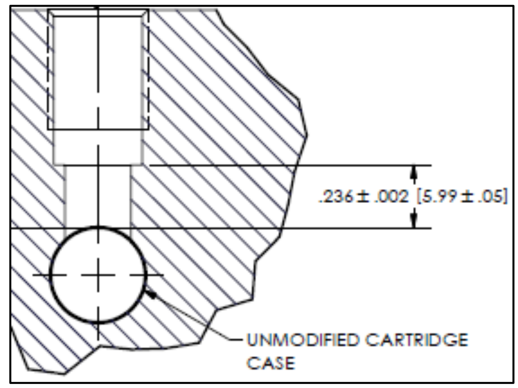


Figure 3

The conformal pressure sensor's diaphragm conforms to the shell case. Designed to match the diameter of the chamber, the device neither interferes with the operation of the test barrel nor alters the measurement process.

Installation

To determine the optimum site for sensor installation, the shell case for each caliber of ammunition has been tested and evaluated by members of SAAMI [2]. The ANSI/SAAMI Voluntary Industry Performance Standards for Pressure and Velocity Measurement on Pistol, Rifle, and Shotshell Ammunition also documents pressure/velocity test barrels that fit into universal receivers for test firing of sporting arms ammunition.

The sensor is installed into a test barrel with the aid of a fixture to maintain axial alignment (see Figure 4). A set of washers of variable thickness is supplied to help adjust sensor depth so that the diaphragm is mounted flush with the chamber walls. A bore scope is used to inspect the installation to ensure that the sensor curvature conforms to the chamber walls.

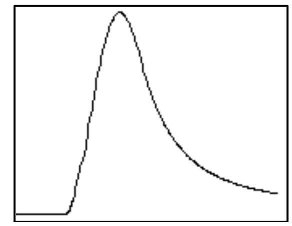
Figure 4

Installation of the conformal ballistic pressure sensor. Correct installation ensures sensor longevity in rapid-fire ammunition testing. Calibration adaptors simulate test barrels and determine SAAMI offset and sensitivity.

Operation

When the cartridge is fired, the shell case expands and comes into contact with the sensor diaphragm. A uniform ring-shaped pattern of the conformal diaphragm is embossed on the cartridge case. The pattern has a fine, even outline indicating where the shell case expanded during contact with the diaphragm. A raised pattern on the shell case indicates that the sensor diaphragm is not flush with the chamber walls. A gouge on the case indicates that the diaphragm is not properly aligned with the gun chamber wall and is cutting into the cartridge case.

Test measurements can be made as rapidly as the ammunition can be loaded and unloaded. There are no gas passages to clean or ablative diaphragm coatings to apply, and the sensors' longevity means they do not have to be replaced in the middle of a test lot. Feedback from the field indicates the conformal sensor, when correctly installed, outlasts the test barrel. A typical pressure-time conformal pressure measurement for .223 Remington ammunition is illustrated in Figure 5. Note the exceptionally clean, noise-free results.



223 Remington 55gr FMJ

SYSTEM 85 SHOT DATA

	----Muzzle----		----Pressure----			
Rnd	**Vel13**	**Prf**	**PeakA**	**TimeA**	**RiseA**	**AreaA**
1	3165	3	49555	420	143	27727

Figure 5

Typical pressure-time data for .223 Remington shows clean, noise-free data and a peak pressure of 49,555 psi. Courtesy of HPR Ammunition.

Calibration

Cartridge cases vary in thickness, material, and hardness for each caliber. Some case walls are straight and others are tapered. An adapter closely resembling the test barrel with cartridge and sensor installed is used to calibrate and determine the effect of the shell case on sensor sensitivity. For safety considerations, the cartridge primer is fired before the shell case is installed in the adapter. The calibration adapter allows the unfired shell case to be hydraulically pressurized against the conformal sensor and the output to be recorded. Application of known pressures establishes sensor sensitivity and linearity. The zero offset pressure required to expand the shell case and bring it into contact with the diaphragm is added to the measured peak pressure to determine the actual value. This is performed automatically by PCB's digital ballistic peak-holding meters.

The conformal sensor has a high-impedance charge output that couples into a charge amplifier with minimum operating controls. Sensitivity is normalized in the charge amplifier to 10,000 psi, (690 bar) per volt of output. High-impedance charge mode operation with a long discharge time constant is generally preferred in ballistic measurement systems to permit accurate static calibration.

Summary

Ballistic pressure testing with piezoelectric conformal pressure sensors offers semi-permanent installation in test barrels for rapid-fire production testing of ammunition. It provides direct payoffs to the manufacturer of ammunition; reduced testing time, as there is no grease or baffles to replace, and the ability to store electronic pressure data as a record of safely manufactured ammunition.

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