Conformal Ballistic Pressure Measurement
May 2016
Bob Metz
Agenda

• History
• Measurement Location & Sensor Choice
• Comparison of Case Mouth, Drilled Midcase and Conformal
• How to use a Conformal Sensor
History

Why Measure Gun Pressure?

• Verify peak pressure for ammunition quality control
• Peak pressure relates to:
  – Safety
  – Proper gun operation
  – Velocity
  – Quality
• When developing new firearms to understand its characteristics and behavior
History

Controlling Organizations

• PCB is specified in
  – Sporting Arms & Ammunition Manufacturers Institute (SAAMI) by the standards of ANSI Z299.1, ANSI Z299.2, ANSI Z299.3 and ANSI Z299.4
  – Permanent International Commission for Firearms Testing (C.I.P)

• PCB Models
  – Shot shell 118A07 & 165B02
  – Case Mouth 109C, 119B
  – Conformal 117B
History
Crusher Installed in Test Barrel

• Hole drilled in case
  – Precise alignment required

• Gas vents through hole
  – Expands gas check into piston hole, forming a seal

• Resulting pressure acts on Crusher removed & measured

• Convert deformation into ‘copper units of pressure’

• 1972 Conformal Patent
Measurement Locations

- Test barrel mounting location Vs. Sensor Model:
Modern Pressure Measurement
Sensor Locations

- Mid-case located at approx. mid-point of length of case
- Conformal location determined by SAAMI or C.I.P.
- Case mouth location
- Port location at approx. 38.1 cm (15 in.) from bolt face
Ballistic Pressure Sensors

• Conformal sensors
  – 2400 & 4140 bar (35 & 60 k psi)
  – Each sensor matches case curvature

• New Series for shot shell testing
  – 1040 & 2070 bar (15 & 30 k psi)
  – Flat diaphragm for plastic or paper case

• Case Mouth Series 109 & 119
  – 5520 & 6900 bar (80 &100 k psi)
  – Ceramic coated integral diaphragms
  – Case mouth, drilled case ballistics
Small Arms Pressure Test
Method Background

Method 1 – Drilled Case
Method 2 – Case Mouth
Method 3 - Conformal Sensor
  • Pressure sensor touches the brass case
  • Diaphragm of sensor is machined to conform to curve of the brass case
Drilled Mid-case or Case Mouth

- **Flush mount**
  - *NOT possible due to curvature of the barrel* or rifling

- **Recess mount must be used**
  - Sensor diaphragm is not flush to sensing surface
  - Considerations – reduced frequency response
  - Protects against heat or particle damage
Problem with Drilled Case

Drilled case gives a low pressure value by 10-20%.

- Leakage through the hole in the drilled case & chamber wall before expansion against the chamber wall
- Volume of the channel up to the transducer
- Filter value selection (22 kHz) another 5-10%
- Burn speed of powder affects the pressure
Problem with Drilled Case

Recess mounting causes passage resonance

- \( F_{\text{max}} = \frac{C}{4(L+.4d)} \)
  
  Where:  
  - \( C \) = Speed of sound in media  
  - \( L \) = Linear length of passage  
  - \( d \) = Diameter of passage

- **Ex. 1**
  
  0.1 x 0.060 inch passage, using speed of sound in air of 13,500 in./sec
  
  \[
  F_{\text{max}} = \frac{C}{4(L+.4d)} = \frac{13,500}{4(0.1+.4\times0.060)} = 32,500 \text{ Hz}
  \]

- **Damping is proportional to**, \( \sqrt[3]{\frac{L}{d^3}} \)
  
  - More damping with a smaller hole  
  - Affects rise time

<table>
<thead>
<tr>
<th>Ex.</th>
<th>C</th>
<th>L (in)</th>
<th>d (in)</th>
<th>F-max (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13,500</td>
<td>0.100</td>
<td>0.060</td>
<td>27,217</td>
</tr>
<tr>
<td>2</td>
<td>13,500</td>
<td>0.100</td>
<td>0.098</td>
<td>24,246</td>
</tr>
<tr>
<td>3</td>
<td>13,500</td>
<td>0.100</td>
<td>0.125</td>
<td>22,500</td>
</tr>
</tbody>
</table>
Problem with Case Mouth*

- Method very sensitive to the choice of filter
  - Because pressure acts as shock wave and impacts the diaphragm at the moment the projectile leaves the case
- Therefore, important that the transducer and the filter are well balanced to avoid overshoot
- Damping effect of filter can influence rise time
- Another disadvantage
  - Fast burning powder
  - $P_{\text{max}}$ is reached before projectile leaves the case
  - This means that the pressure is measured after the real peak

*Pressure Measurement for 9 mm Luger Ammunition, Nexplo Bofors, Johansson, S.E., November 1, 2000
Problem with Case Mouth

• Overshoot not repeatable and requires a filter compared to Case Mouth

• Measure **after** peak pressure has happened ($\Delta t$)

• For fast burning powders
  – Pressure could be over the safe limit
  – Case mouth pressure may not indicate that

![Diagram of Conformal and Case Mouth with time delay indicated by $\Delta t$.]
Problem with Case Mouth

• 45 Cal test data
  – Scope zero is 2000 psi
  – Conformal offset 7100 psi

• Example of overshoot

<table>
<thead>
<tr>
<th>Shot</th>
<th>Conf (psi)</th>
<th>Time to Pk (μsec)</th>
<th>CM (psi)</th>
<th>Time to Pk (μsec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lot 8-4</td>
<td>21636</td>
<td>257</td>
<td>19286</td>
<td>321</td>
</tr>
</tbody>
</table>

\[ \Delta = 64 \mu\text{sec} \]
Sensor Diaphragms

Integral Machined Diaphragms

- Rigid structure withstands high pressure (to 100 k psi) repetitive cycling for extended sensor life
- Thickness 0.254 to 0.457 mm (0.010 to 0.018 in)
  - Allows for machining conformal curvature
Small Arms Pressure Test
Case Mouth 109C, 119B

PCB® uses live guns to validate each serial number
• Shot shell Series 165 in 12 gauge with HS Precision test barrel
• Case mouth Series 109C, 119B in Modified .223
117B Conformal Method

Conformal Sensor Installation in Test Barrel
- Centerfire or Rimfire
Curvature Facts

- PCB® obtained a patent for this design in July 1975. (Patent #3886792)

- Curvature machined corresponds to the chamber diameter at a specific distance from boltface.

- 117B’s are not caliber specific. If two calibers have the same curvature, the same 117B can be used.

- Curvature is generally a straight cut.
  - Occasionally a taper will need to be machined onto the diaphragm curvature (>0.020”/inch).
  - Align yellow dot to muzell
Conformal Sensor Installation

Typical Conformal Sensor Installation in Test Barrel
Conformal Sensor Installation

- Mounting port preparation centerline location must be maintained
  - Protruding sharp edge of diaphragm will cut brass
  - This edge also affects sensor output
- Installation of sensor into mounting port
  - Recess of 0.05 mm (0.002 in) maximum is permitted
  - Greater recess may rupture brass
    - Prevents case from extraction
  - Flush co-planer mounting is accomplished by installing spacers
Conformal Sensor Installation

Case should have a small, complete circle

Good

Bad
Conformal Brass Calibration

- Series 117B requires a special brass calibration. Series 090B conformal calibration adaptors serve this purpose.
- Customer must send in new brass cases for PCB® to perform the calibration.

![Diagram showing Series 117B sensor, Series 090B adaptor, and Brass case]
PCB® Conformal Pressure Calibration System

- K9905D High Pressure Calibrator
- Static pressure range to 6900 bar (100,000 psi)
- Self-contained hydraulic system
- Precision strain gage reference and digital readout
Series 090B Calibration Adaptor Assembly & Use

Calibration adaptor simulates chamber for each caliber
Oil Calibration Certificate

- Oil calibration will establish linearity
- Will not establish an accurate sensitivity required for use as conformal gage
Calibration Cert with Offset

- Calibration using cartridge case shows that slope of the sensors output does not go through zero
- This is the offset pressure
- Offset varies per caliber and follows specific SAAMI guidelines
Shot Shell Sensors
for
Tangential Measurement
Series 165 Shot Shell Sensor

Typical Sensor Installation in 12 Gage Shot Gun Universal Receiver
New 118A07 Shot Shell Sensor

Replaces obsolete 165A02, 167A11, 165M05

• Removal of internal thread
  – All welded design
  – Improved accuracy and repeatability, $\leq 0.5\%$

• Test data verified with AVL 5QP2000t drilled case at Banco Nazionale di Prova, Italia
# 118A07 Shot Shell Sensor

Tested in PCB Test Barrel

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>S/N 1910 Max Pressure (V)</th>
<th>S/N 1909 Max Pressure (V)</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.21</td>
<td>1.21</td>
<td>-0.31%</td>
</tr>
<tr>
<td>2</td>
<td>1.20</td>
<td>1.19</td>
<td>-0.40%</td>
</tr>
<tr>
<td>3</td>
<td>1.20</td>
<td>1.20</td>
<td>0.01%</td>
</tr>
<tr>
<td>4</td>
<td>1.19</td>
<td>1.19</td>
<td>-0.07%</td>
</tr>
<tr>
<td>5</td>
<td>1.28</td>
<td>1.28</td>
<td>-0.02%</td>
</tr>
</tbody>
</table>

Average: -0.03%
Minimum: -0.07%
Maximum: 0.01%
Standard Deviation: 0.04%
Range: 0.07%
118A07 Shot Shell Sensor

Tested by Banco Nazionale di Prova, Italia
Note: M165M02 SN1909 was development unit – new model is 118A07

<table>
<thead>
<tr>
<th>Comparison between PCB M165M02 SN 253 and PCB M165M02 SN 1909</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCB M165M02 SN 253</td>
</tr>
<tr>
<td>703 bar</td>
</tr>
<tr>
<td>17 mm</td>
</tr>
<tr>
<td>No drilled case</td>
</tr>
<tr>
<td>Sensitivity 3.16 pC/bar</td>
</tr>
<tr>
<td>Mounting torque 12 Nm</td>
</tr>
</tbody>
</table>

![Graph showing data comparison](image)

May 2015

PCB PIEZOTRONICS, INC. CONFIDENTIAL
Summary

Conformal

• **Case Mouth**
  – Solves time to peak problem with fast burning powder
  – Eliminates gas passage resonance
  – Reduces requirement for filtering

• **Midcase**
  – No need for case drilling or alignment
  – No gas leakage around case before expansion

Shot Shell

• New design improves linearity ≤ 0.5%
• Improved repeatability