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A PCB PIEZOTRONICS DIV.

Conformal Ballistic Pressure Measurement

May 2016

Bob Metz

Agenda

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

History

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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

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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

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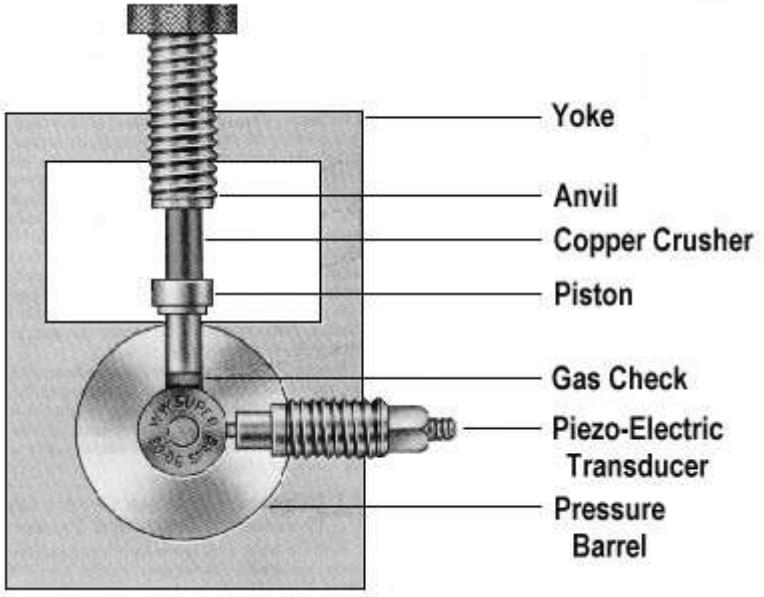
- Hole drilled in case
  - Precise alignment required
- Gas vents through hole
  - Expands gas check into piston hole, forming a seal
- Resulting pressure acts on Crusher removed & measured
- Convert deformation into ‘copper units of pressure’
- 1972 Conformal Patent



Measurement Locations

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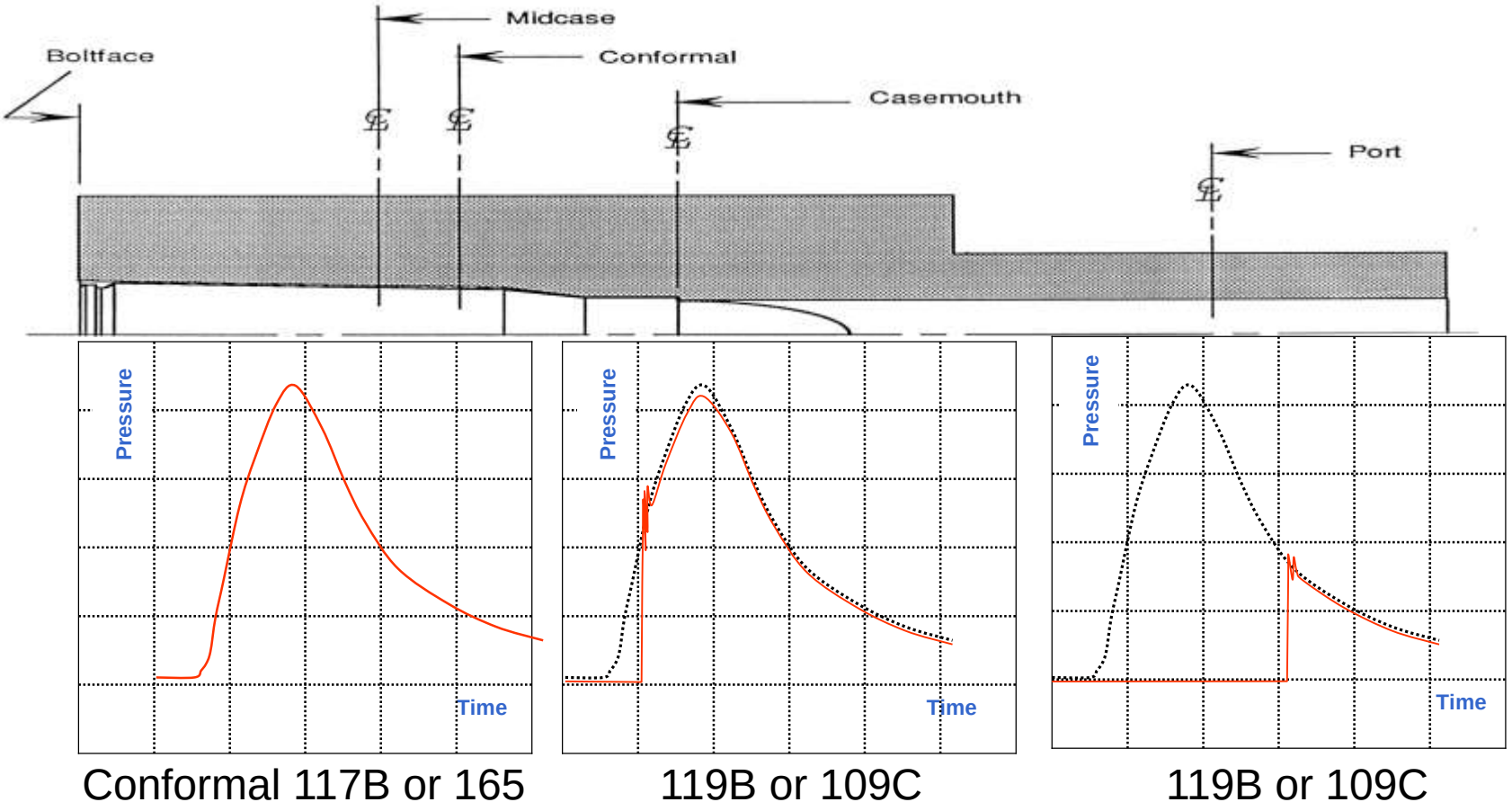
- Test barrel mounting location Vs. Sensor Model:



Conformal 117B or 165 | 119B or 109C | 119B or 109C

Modern Pressure Measurement Sensor Locations

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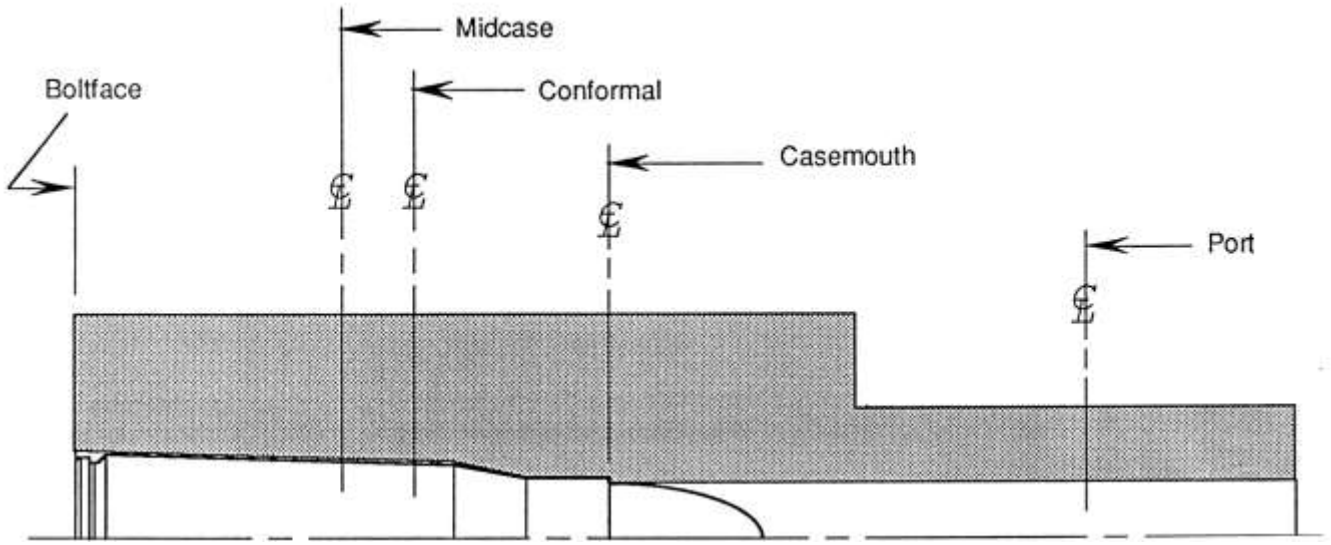
- Mid-case located at approx. mid-point of length of case
- Conformal location determined by SAAMI or C.I.P.
- Case mouth location
- Port location at approx. 38.1 cm (15 in.) from bolt face



Ballistic Pressure Sensors

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- 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

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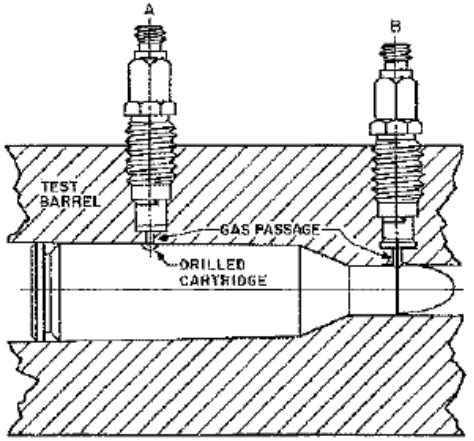
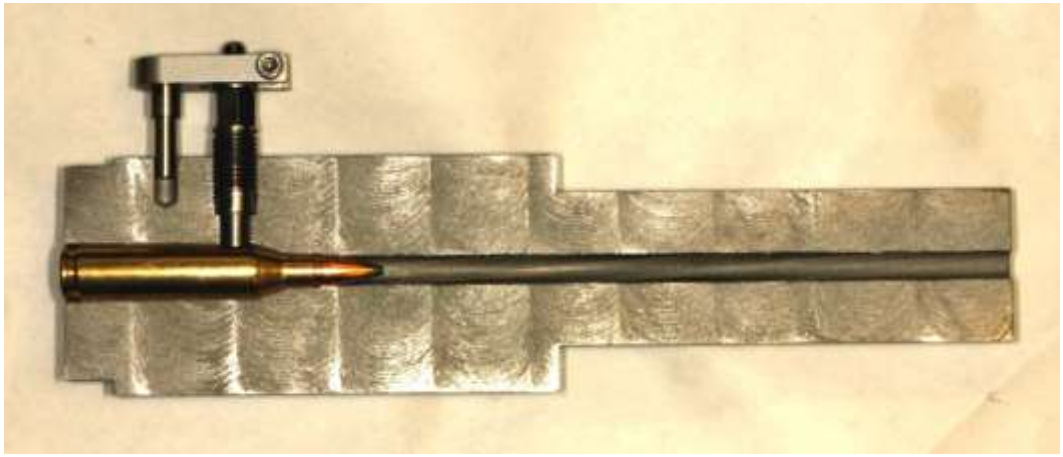
Method 1 – Drilled Case

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

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- 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

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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 k Hz) another 5-10%
- Burn speed of powder affects the pressure

Problem with Drilled Case

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Recess mounting causes passage resonance

- $F_{max} = C / 4(L+.4d)$

  Where: C = Speed of sound in media

  L = Linear length of passage

  d = Diameter of passage

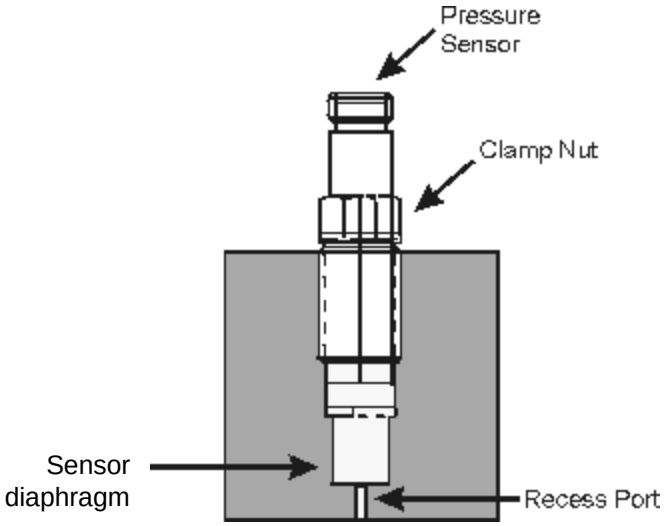
- Ex. 1

  0.1 x 0.060 inch passage, using speed of sound in air of 13,500 in./sec

  $F_{max} = C / 4(L+.4d) = 13,500 / [(4*(0.1+.4*0.060)\ ] = 32,500$ Hz

Ex.	C	L (in)	d (in)	F-max (Hz)
1	13,500	0.100	0.060	27,217
2	13,500	0.100	0.098	24,246
3	13,500	0.100	0.125	22,500

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



Problem with Case Mouth*

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- 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
  - Pmax 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

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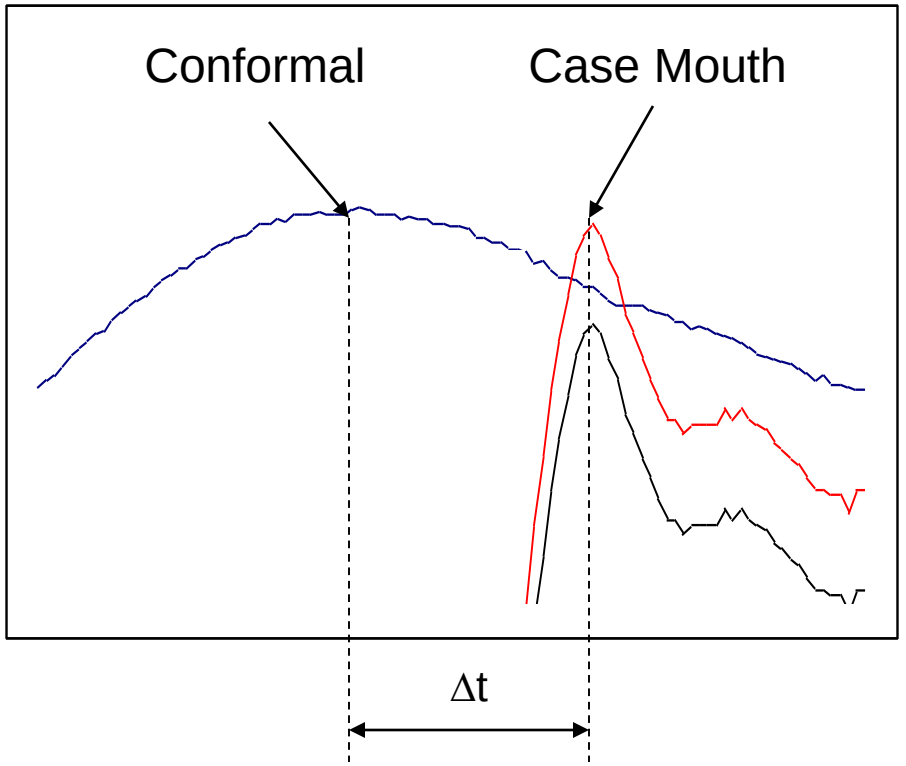
- Overshoot not repeatable and requires a filter compared to Case Mouth
- Measure **after** peak pressure has happened (Δt)
- For fast burning powders
  - Pressure could be over the safe limit
  - Case mouth pressure may not indicate that



Time delay due to Case Mouth location

Problem with Case Mouth

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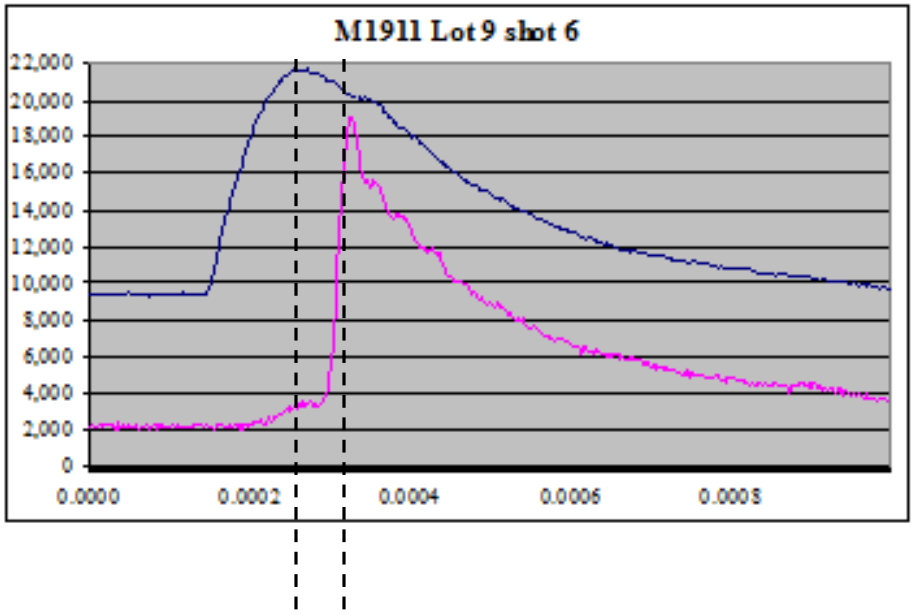
- 45 Cal test data
  - Scope zero is 2000 psi
  - Conformal offset 7100 psi
- Example of overshoot

Shot	Conf (psi)	Time to Pk (µsec)	CM (psi)	Time to Pk (µsec)
Lot 8-4	21636	257	19286	321



Δ = 64 µsec

Sensor Diaphragms

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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

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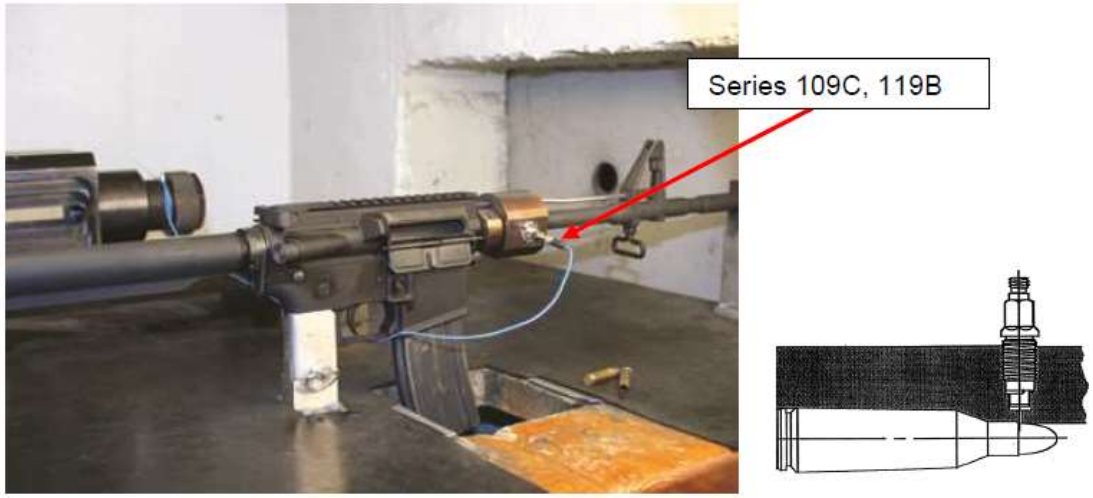
PCB® uses live guns to validate each serial number

- Shot shell Series 165 in 12 gauge with HS Precision test barrel
- Case mouth Series 109C, 119B in Modified .223



117B Conformal Method

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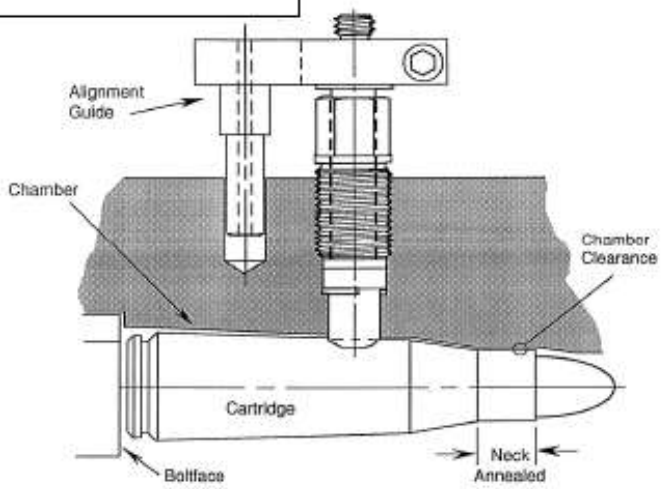

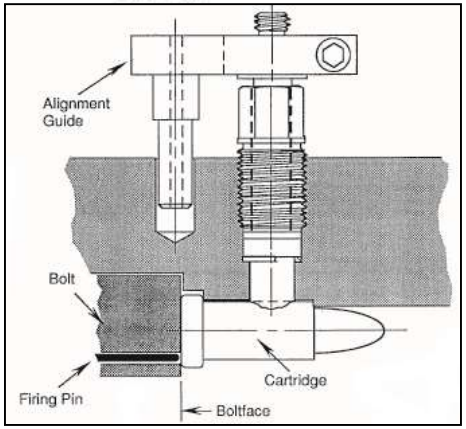

Conformal Sensor Installation in Test Barrel

- Centerfire or Rimfire

Curvature Facts

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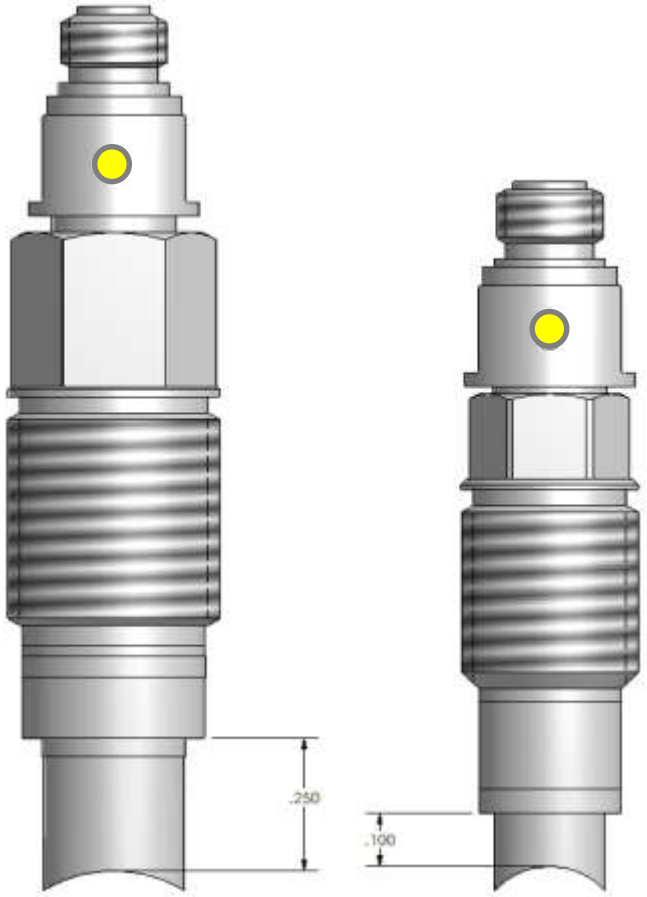

- PCB® obtained a patent for this design in July 1975. (Patent #3886792)
- Curvature machined corresponds to the chamber diameter at a specific distance from boltface.
- 117B's are not caliber specific. If two calibers have the same curvature, the same 117B can be used.
- Curvature is generally a straight cut.
  - Occasionally a taper will need to be machined onto the diaphragm curvature (>.020"/inch).
  - Align yellow dot to muzell

Conformal Sensor Installation

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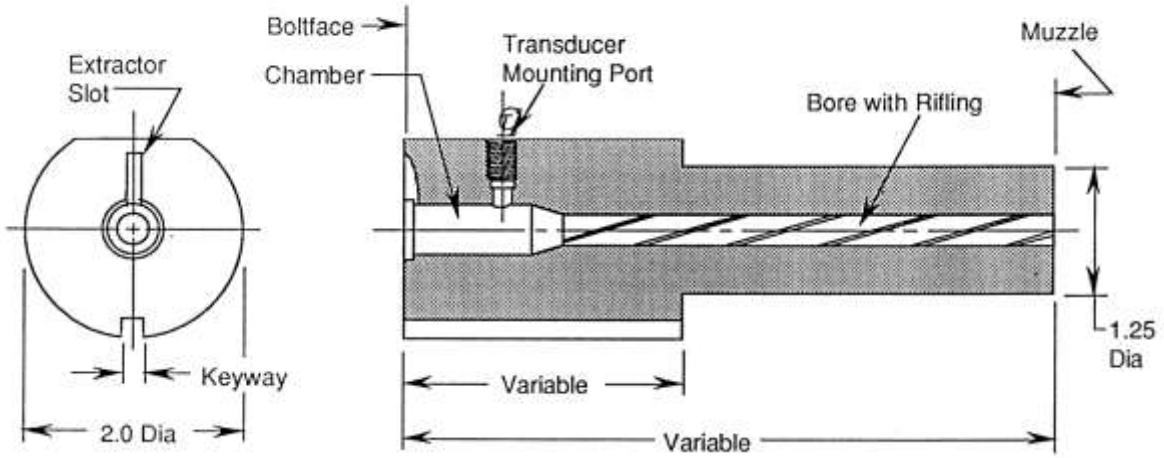
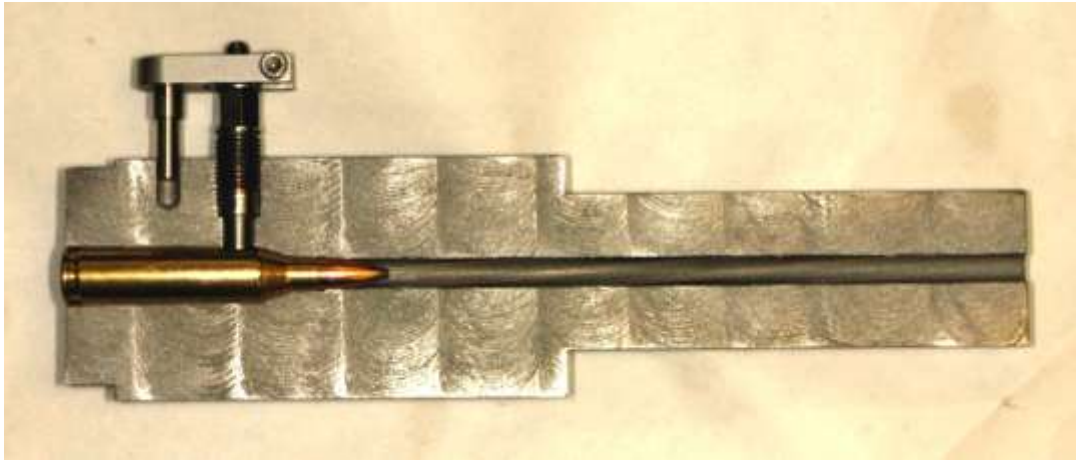


Typical Conformal Sensor Installation in Test Barrel



Conformal Sensor Installation

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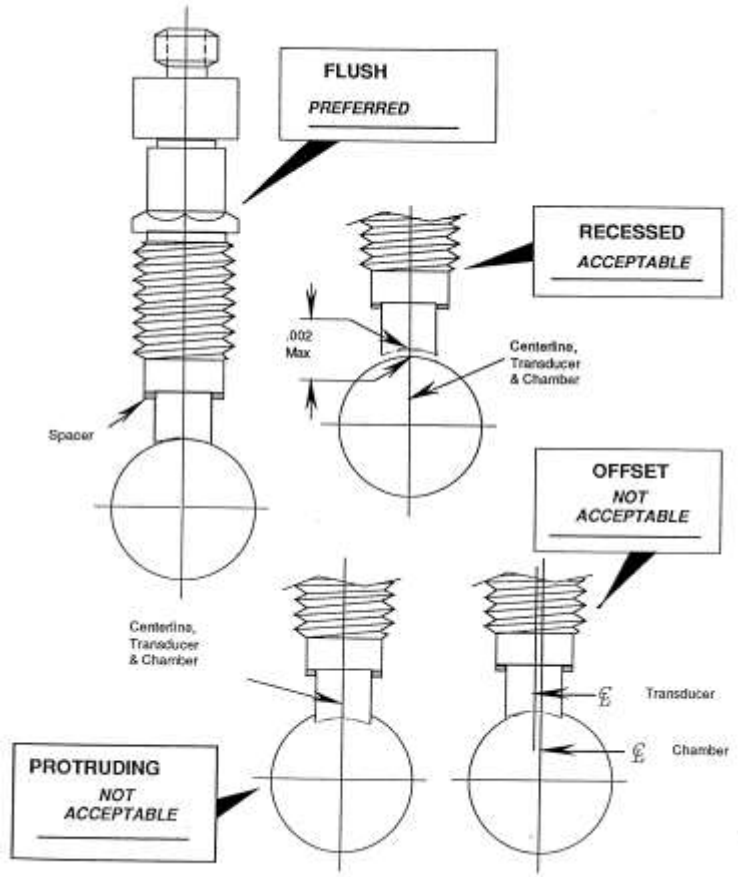
- Mounting port preparation centerline location must be maintained
  - Protruding sharp edge of diaphragm will cut brass
  - This edge also affects sensor output
- Installation of sensor into mounting port
  - Recess of 0.05 mm (0.002 in) maximum is permitted
  - Greater recess may rupture brass
   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



Conformal Sensor Installation

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Case should have a small, complete circle

Good

Bad

Conformal Brass Calibration

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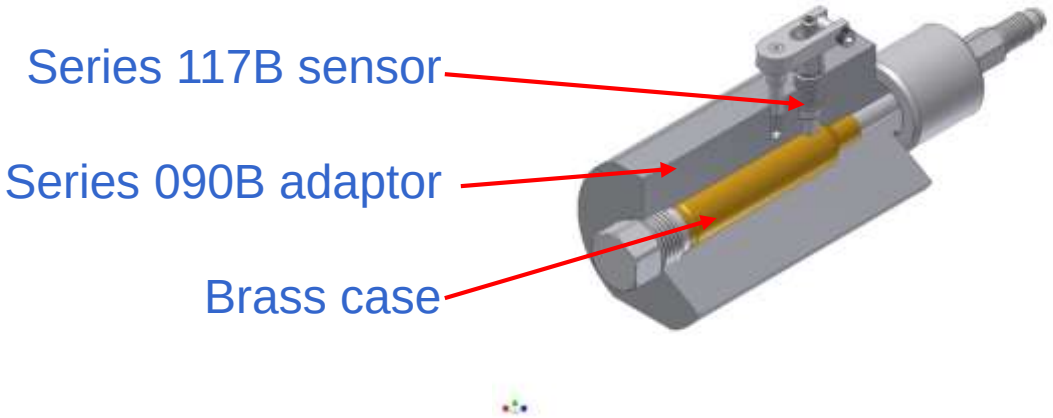
- Series 117B requires a special brass calibration. Series 090B conformal calibration adaptors serve this purpose.
- Customer must send in new brass cases for PCB® to perform the calibration.



PCB® Conformal Pressure Calibration System

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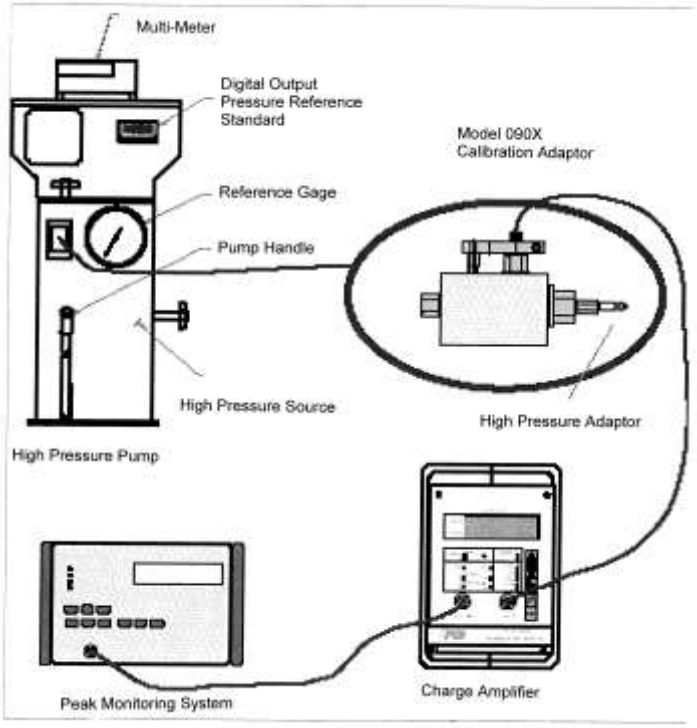
- K9905D High Pressure Calibrator
- Static pressure range to 6900 bar (100,000 psi)
- Self-contained hydraulic system
- Precision strain gage reference and digital readout



Series 090B Calibration Adaptor Assembly & Use

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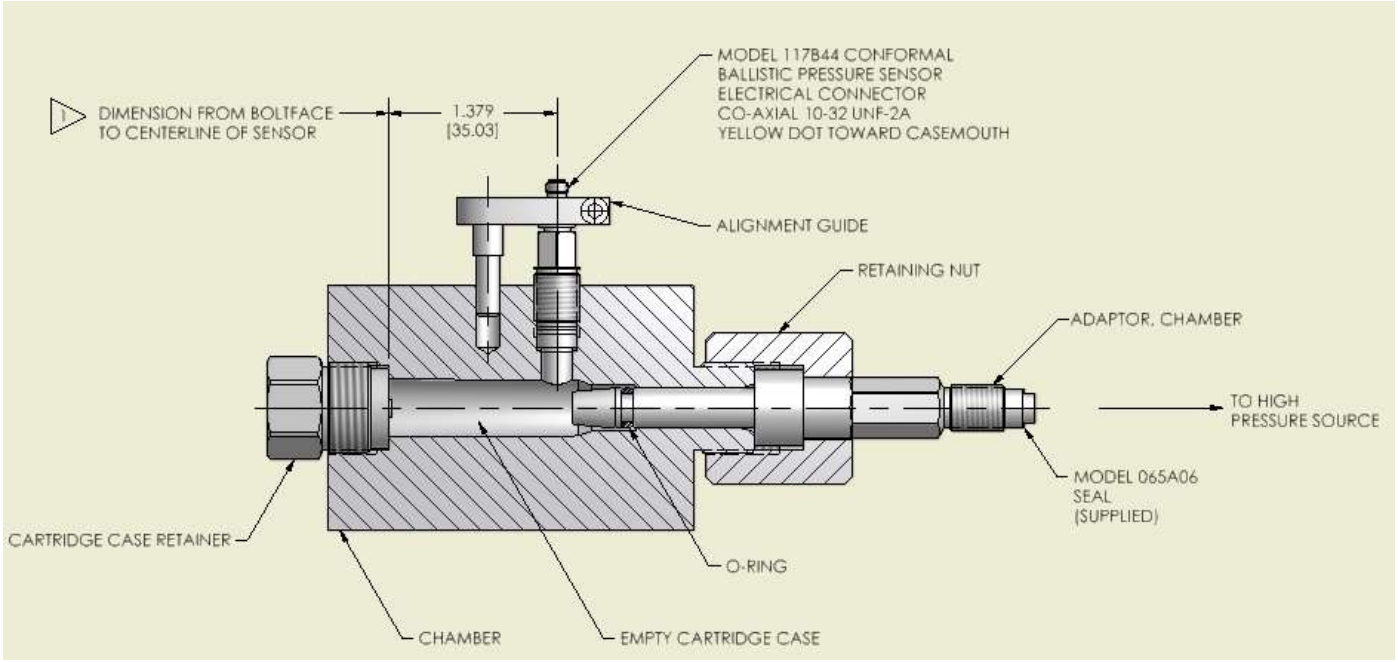
Calibration adaptor simulates chamber for each caliber



Oil Calibration Certificate

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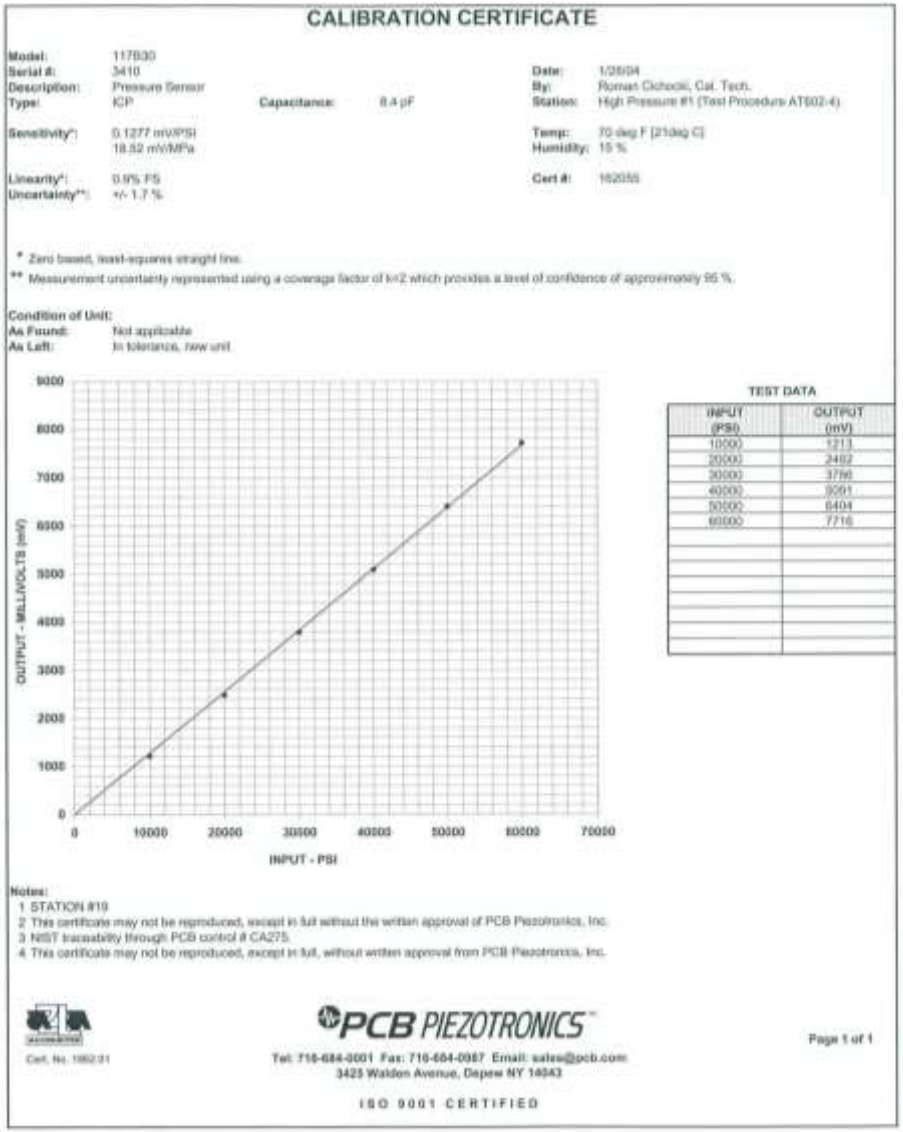

CALIBRATION CERTIFICATE

Model: 117B30
Serial #: 3410
Description: Pressure Sensor
Type: ICP
Capacitance: 8.4 pF

Date: 1/26/04
By: Roman Cichocki, Cal. Tech.
Station: High Pressure #1 (Test Procedure AT602-4)

Sensitivity*: 0.1277 mV/PSI
18.32 mV/MPa

Temp: 70 deg F (21deg C)
Humidity: 15 %

Linearity*: 0.9% FS
Uncertainty**: +/- 1.7 %

Cert #: 162055

* Zero based, least-squares straight line.
** Measurement uncertainty represented using a coverage factor of k=2 which provides a level of confidence of approximately 95 %.

Condition of Unit:
As Found: Not applicable
As Left: In tolerance, new unit

TEST DATA

INPUT (PSI)	OUTPUT (mV)
10000	1213
20000	2402
30000	3766
40000	5091
50000	6404
60000	7716

OUTPUT - MILLIVOLTS (mV)
INPUT - PSI

Notes:
1. STATION #19
2. This certificate may not be reproduced, except in full without the written approval of PCB Piezotronics, Inc.
3. NIST traceability through PCB control # CA275.
4. This certificate may not be reproduced, except in full, without written approval from PCB Piezotronics, Inc.

Cert. No. 162131

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

Calibration Cert with Offset

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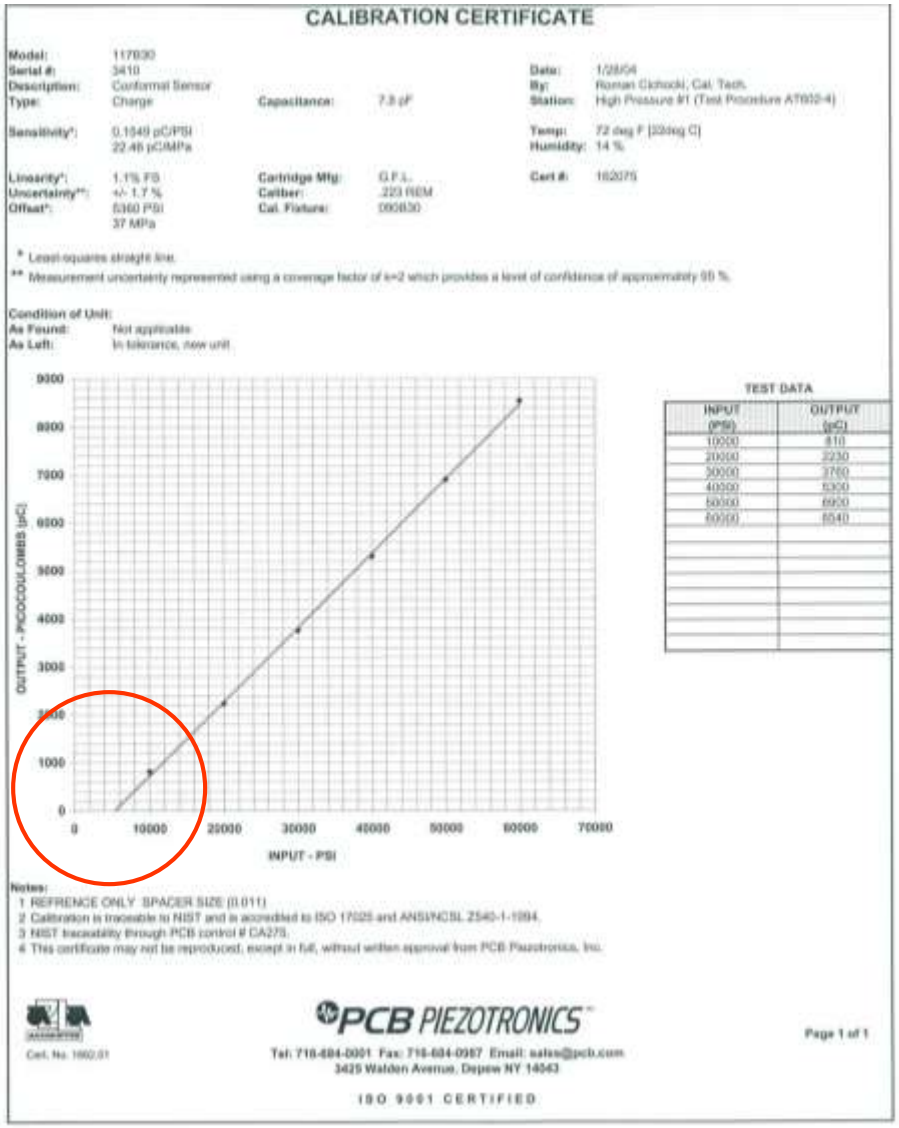

CALIBRATION CERTIFICATE

Model: 117B30
Serial #: 3410
Description: Conformal Sensor
Type: Charge
Capacitance: 7.9 pF
Date: 1/28/04
By: Roman Cichocki, Cal. Tech.
Station: High Pressure #1 (Test Procedure AT602-4)
Sensitivity*: 0.1549 pC/PSI
22.46 pC/MPa
Temp: 72 deg F [22deg C]
Humidity: 14 %
Linearity*: 1.1% FS
Uncertainty**: +/- 1.7 %
Offset*: 5360 PSI
37 MPa
Cartridge Mfg: G.F.L.
Caliber: .223 REM
Cal. Fixture: 080830
Cert #: 162075

* Least-squares straight line.
** Measurement uncertainty represented using a coverage factor of k=2 which provides a level of confidence of approximately 95 %.

Condition of Unit:
As Found: Not applicable
As Left: In tolerance, new unit

TEST DATA

INPUT (PSI)	OUTPUT (pC)
10000	810
20000	2230
30000	3760
40000	5300
50000	6900
60000	8540

OUTPUT - PICOCOULOMBS (pC)
INPUT - PSI

Notes:
1 REFRENCE ONLY SPACER SIZE (0.011)
2 Calibration is traceable to NIST and is accredited to ISO 17025 and ANSI/NCSL Z540-1-1994.
3 NIST traceability through PCB control # CA275.
4 This certificate may not be reproduced, except in full, without written approval from PCB Piezotronics, Inc.

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- 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

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Shot Shell Sensors
for
Tangential Measurement

Series 165 Shot Shell Sensor

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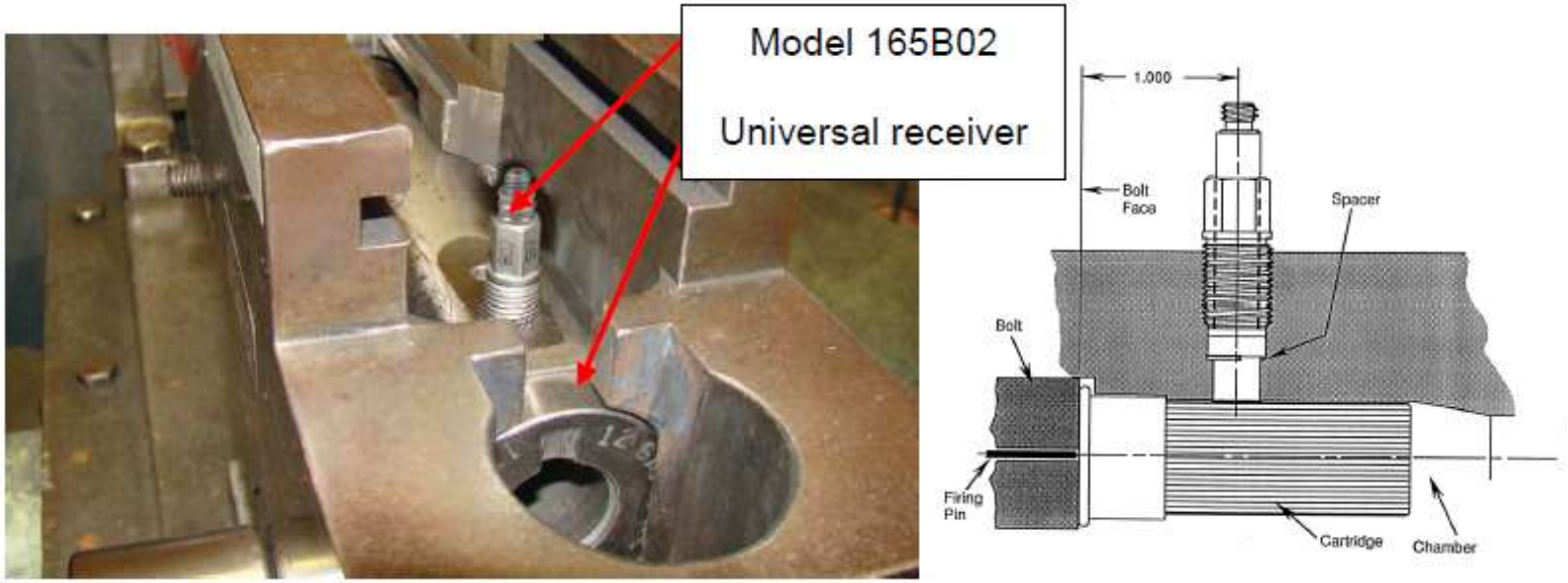

Typical Sensor Installation in 12 Gage Shot Gun Universal Receiver

New 118A07 Shot Shell Sensor

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Replaces obsolete 165A02, 167A11, 165M05

- Removal of internal thread
  - All welded design
  - Improved accuracy and repeatability, ≤ 0.5%
- Test data verified with AVL 5QP2000t drilled case at Banco Nazionale di Prova, Italia

118A07 Shot Shell Sensor

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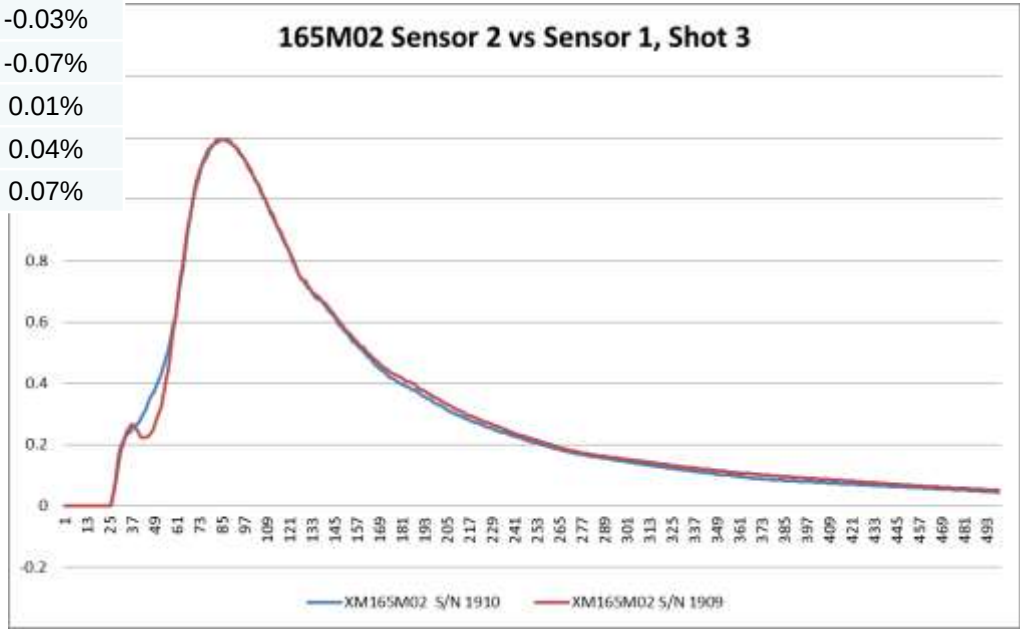
Tested in PCB Test Barrel

118A07 Redesign Shotgun Test			
Shot Number	S/N 1910 Max Pressure (V)	S/N 1909 Max Pressure (V)	% Difference
1	1.21	1.21	-0.31%
2	1.20	1.19	-0.40%
3	1.20	1.20	0.01%
4	1.19	1.19	-0.07%
5	1.28	1.28	-0.02%
		Average	-0.03%
		Minimum	-0.07%
		Maximum	0.01%
		Standard Deviation	0.04%
		Range	0.07%



118A07 Shot Shell Sensor

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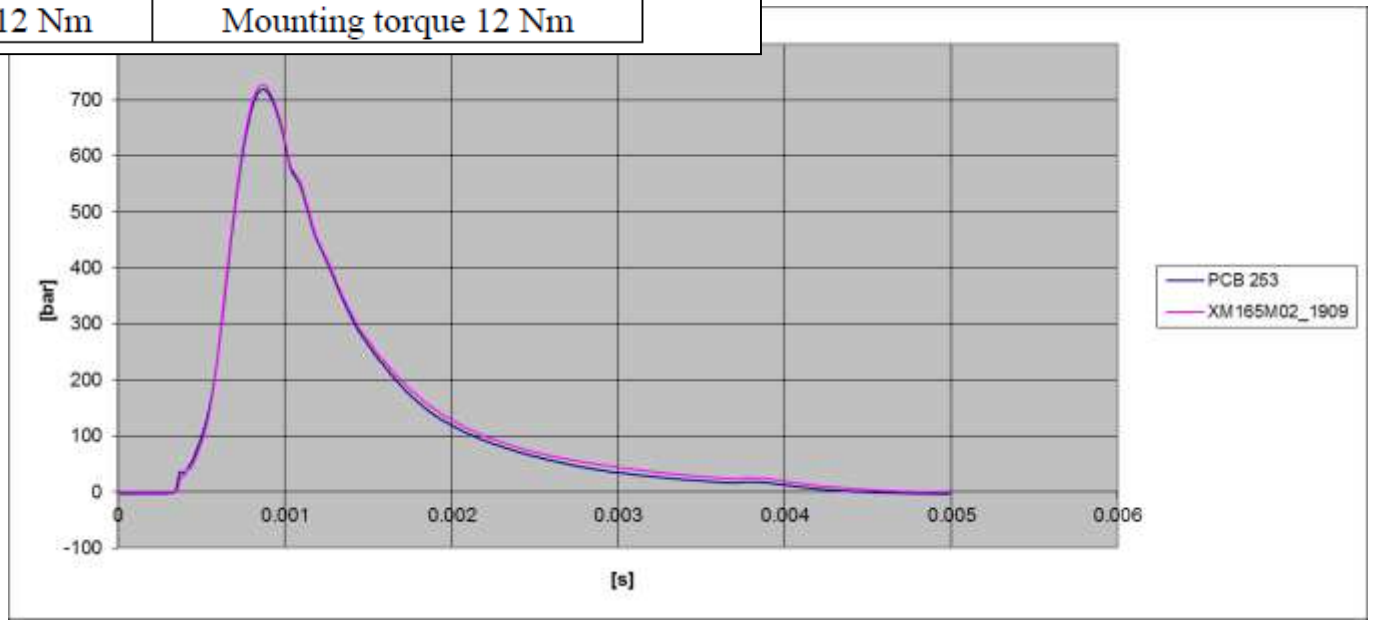
Tested by Banco Nazionale di Prova, Italia

Note: M165M02 SN1909 was development unit –new model is 118A07

Comparison between PCB M165M02 SN 253 and PCB M165M02 SN 1909

PCB M165M02 SN 253	PCB XM165M02 SN 1909
703 bar	706 bar
17 mm	17 mm
No drilled case	No drilled case
Sensitivity 3.16 pC/bar	Sensitivity 4.17 pC/bar
Mounting torque 12 Nm	Mounting torque 12 Nm



Summary

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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 $\leq$ 0.5%
- Improved repeatability