



# Ballistic Pressure Sensors Reference Guide





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This compilation is intended as a reference guide to the characteristics and behavior of firearms and ammunition, and as an introduction to the various types of ballistics measurements that are made.

Dimensions shown on figures are in inches

## BALLISTICS TERMINOLOGY

**ANNEALED:** Description of metal heated after work hardening to prevent it from being too brittle.

**BARREL TIME:** Time between the impact of the firing pin on the primer and when the bullet exits the muzzle.

**BELT:** Area of cartridge case with an increased or reinforced diameter ahead of extractor groove.

**BORE:** The inside of the barrel of a gun, the inside diameter of the barrel before rifling is cut.

**BRASS:** Term often applied to empty cartridge cases; an alloy of copper and zinc.

**BREECH:** The area of a firearm at the rear of the bore that receives the cartridge case.

**BULLET:** The missile only. Becomes a projectile when in flight.

**CALIBER:** Approximate bore or groove diameter expressed (in English) in decimals of an inch, otherwise in the metric system (millimeters). Example: 38 caliber = 0.38 inches diameter.

**CARTRIDGE:** A complete, assembled unit of ammunition: Includes case, propellant powder, primer, and bullet.

**CASE:** The paper, metal or plastic container which holds all the other components of a round of ammunition; sometimes called "hull" or "shell".

**CENTER FIRE:** Refers to centrally located primer in base of metal cartridges.

**CHAMBER:** That part of the bore, at the breech, formed to accept and support the cartridge.

**FLASH HOLE:** The hole leading from the primer pocket into the body of the cartridge case.

**GAUGE:** Commonly refers to the size of a shot shell (the smaller the number, the larger the shell).

**GROOVES:** Spiral cuts or impressions in the bore of a gun that causes a bullet to spin as it moves through the barrel.

**IGNITION:** The setting on fire of the propellant powder charge, by the primer.



**LANDS:** The spiral raised portion of a bore remaining after the grooves have been cut or formed.

**MAGNUM:** A load, or cartridge having greater power. Usually a longer case, or a caliber with exceptionally larger powder capacity.

**MUZZLE:** The front end of a barrel; the point at which a projectile leaves the barrel.

**NECK:** The portion of a cartridge case that grips the bullet.

**NECK DOWN:** To reduce the diameter of the neck.

**POWDER:** The propellant materials used in most firearms.

**PRESSURE:** The pressure exerted by a burning charge of powder in the chamber of a gun.

**PRIMER:** A small metal cup in a centerfire cartridge containing a detonating mixture, which is used to ignite the propellant powder. It is seated in the primer pocket.

**PRIMER POCKET:** The cavity in the base of the cartridge case made to receive and support the primer.

**PROOF AMMUNITION:** Ammunition made with very accurate controls on the powder quantity and quality for determining pressure.

**REFERENCE AMMUNITION:** Ammunition used to determine a close statistical group of pressure ratings.

**RIFLING:** Parallel spiral grooves cut into the bore to make the bullet spin and stabilize in flight. Made up of grooves and lands.

**RIM:** The projecting edge at the base of most cartridge cases upon which the extractor pulls.

**RIMFIRE:** Refers to a cartridge that features the primer in its rim. Usually found in .22 caliber rounds.

**ROUND:** A military term meaning one complete cartridge.

**SAAMI:** Small Arms and Ammunition Manufacturers Institute; the organization that standardizes case and chamber specifications in the USA.

**SHOT:** The lead alloy or steel spheres, which are used for the projectiles in smoothbore guns (shotguns).

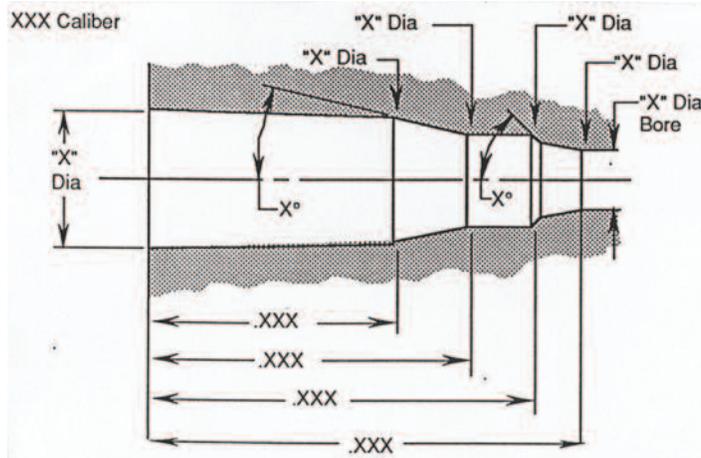
**SHOULDER:** The sharply sloping or rounded part of a cartridge case. Joins the neck to the body.

**VELOCITY:** The speed at which a projectile travels. Measured in feet per second at a given range

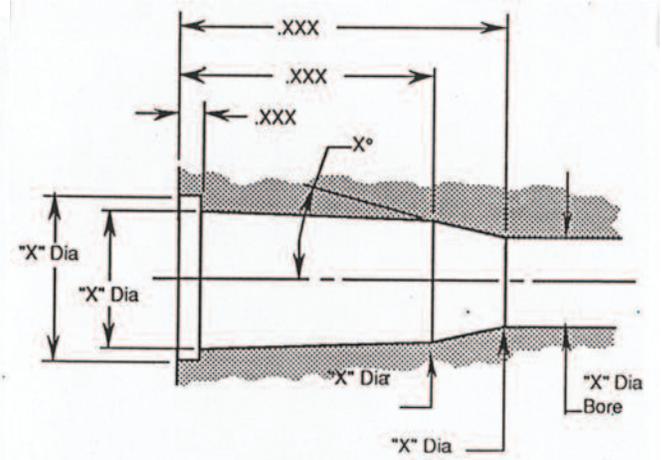


## INTRODUCTION

In order to better understand the characteristics or behavior of firearms and ammunition, various types of ballistics measurements are often made. To make these measurements, test fixtures are instrumented with various types of sensors, such as piezoelectric pressure sensors. The following information may be helpful in trying to understand the basics of making ballistics measurements.



**Figure 1 - Chamber Drawing**



**Figure 2 - Chamber Drawing**

Figures 1 and 2 show dimensions of gun chambers, with tolerances to maintain control for each caliber. These are uniformly used by manufacturers to maintain safe material conditions, and to ensure that all guns manufactured will accept and fire ammunition from any producer.

## TYPES OF BALLISTIC PRESSURE MEASUREMENTS

### COPPER CRUSHER

The copper crusher is a mechanical procedure in which a test barrel is modified to contain a small piston installed over a drilled cartridge case.

Figure 3 on page 4 shows a cross-section of a typical copper crusher installed onto a pressure barrel. In this pressure measurement system, a small hole is drilled through one wall of the case in line with the piston hole, generally at mid-case location. The gas check, piston, and copper crusher are installed and retained with the thumb screw. When fired, the gases vent out through the drilled hole and expand the gas check into the piston hole, forming a seal. The resulting pressure acting on the piston forces the copper crusher into a permanent deformation. The crusher is removed and carefully measured. Tables supplied by the crusher manufacturers are used to convert the deformation into a relative value, called copper units of pressure (commonly referred to as "cups.")

This procedure has to be manually performed for each firing. Lead crushers have also been used. Some customers have used PCB quartz force sensors in place of the crusher, to directly measure force of the piston.

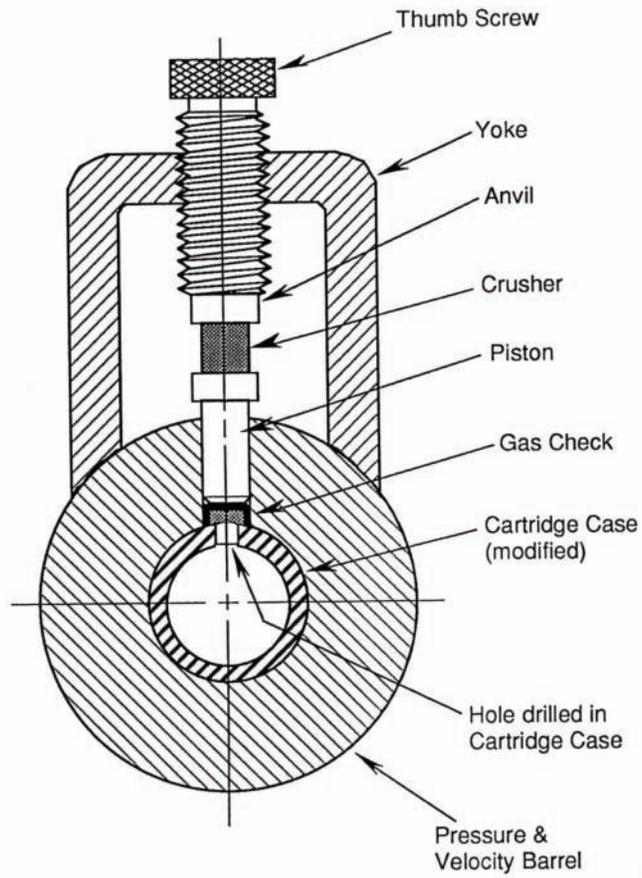


Figure 3- Copper Crusher

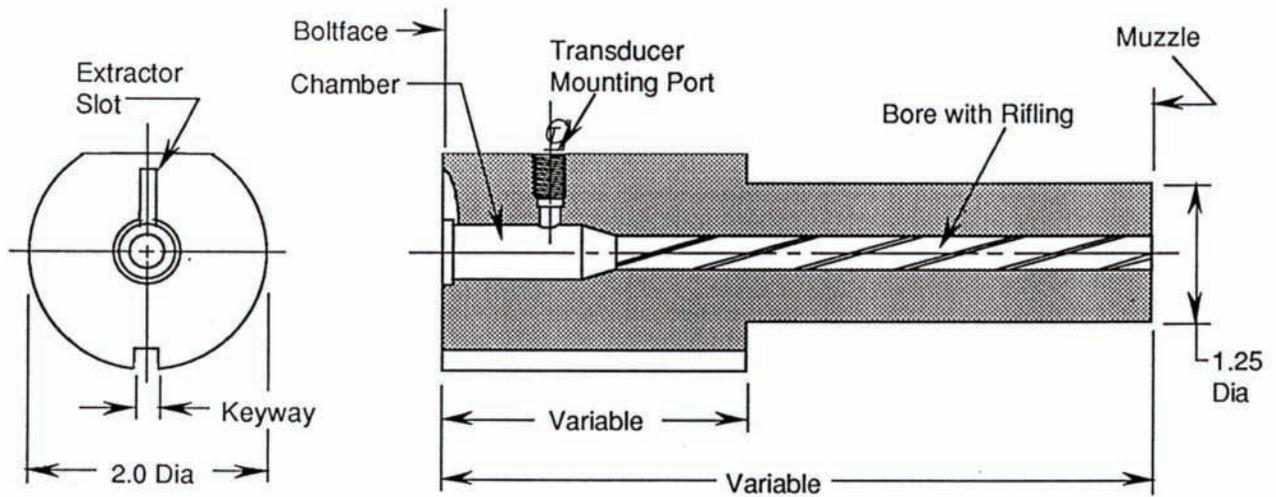


Figure 4 - Universal Receiver Pressure and Velocity Test Barrel



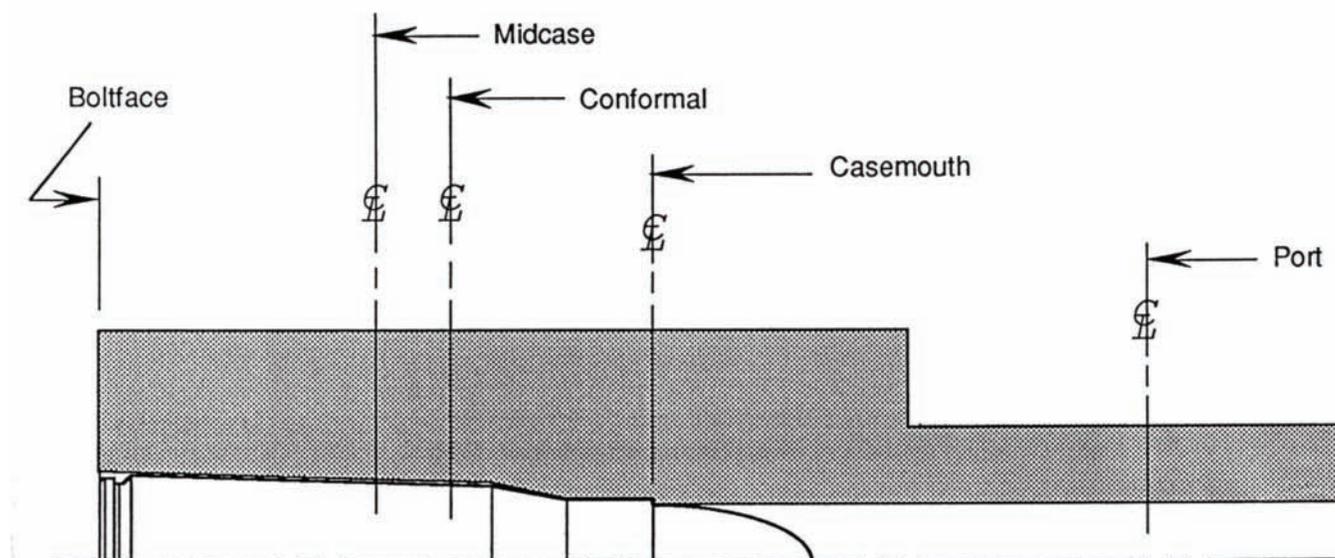
Figure 4 describes a typical pressure and velocity test barrel made to fit into a universal receiver. The keyway is used to align the test barrel in the universal receiver, and the extractor slot is used to remove the cartridge case.

The **VELOCITY** part of the test barrel description deals with external ballistics (outside of the barrel). It is the measurement of projectile speed and direction beyond the muzzle.

The **PRESSURE** part of the description deals with interior ballistics (inside of the barrel). Measurements of pressure inside of chamber, cartridge case, and bore can be made by various methods, including copper crusher (older method) or piezoelectric sensor(s).

In addition to these specially made barrels, standard rifle, pistol, and shotgun barrels are also sometimes instrumented for pressure measurements.

### BALLISTIC SENSOR MEASUREMENT LOCATIONS



**Figure 5- Pressure Measurement Sensor Locations**

Figure 5 shows various locations at which pressure measurements are typically made on small arms ammunition (all sensor locations are dimensioned from the bolt face surface). The following describes these locations, the typical PCB sensors used for measurements at the locations, and the pressures typically associated with the measurements.

#### **MID-CASE:**

- Located at approximately mid-point of length of case
- PCB Models 109C11, 119B, 119B11
- Approximate pressure: rifle 60K psi, pistol or revolver 40K psi
- For measurements at this location, the copper crusher technique is also used (*see Figure 3*)



**CONFORMAL:**

- Location - determined by SAAMI- PCB Series 117Bx
- Approximate pressure: rifle 60K psi, pistol or revolver 40K psi

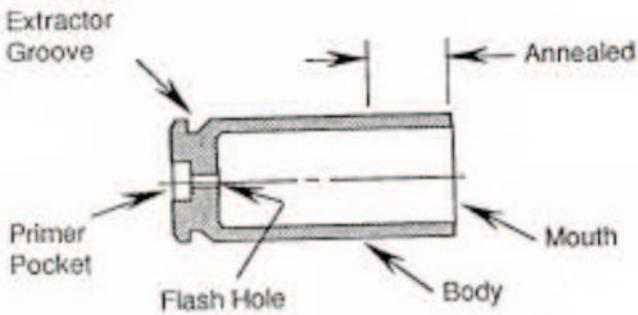
**CASE MOUTH:**

- Location at mouth of case
- PCB Models 109C11, 119B, 119B11
- Approximate pressure: rifle 60K psi, pistol or revolver 40K psi

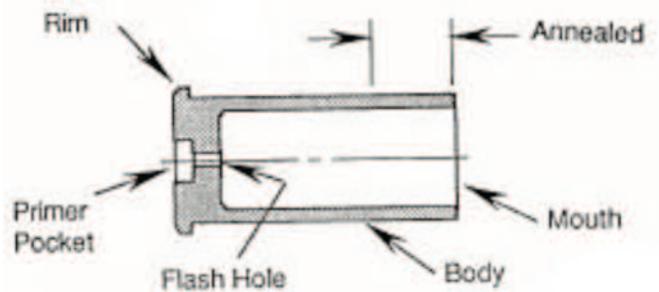
**PORT:**

- Location at approximately 15 inches from bolt face- for use on semi-automatic or full automatic guns
- PCB Models 109C11, 119B, 119B11
- Approximate pressure: rifle 15K psi, pistol 15K psi

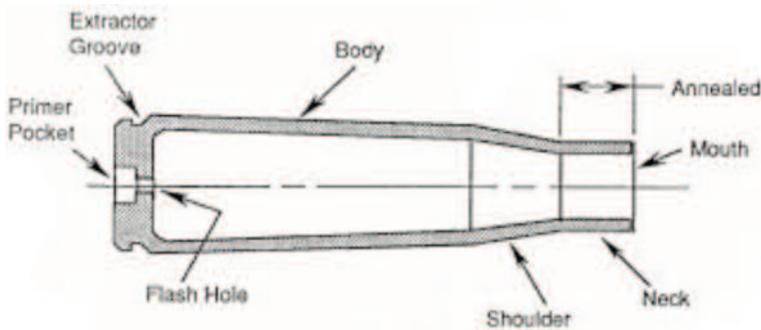
**CASE TYPES**



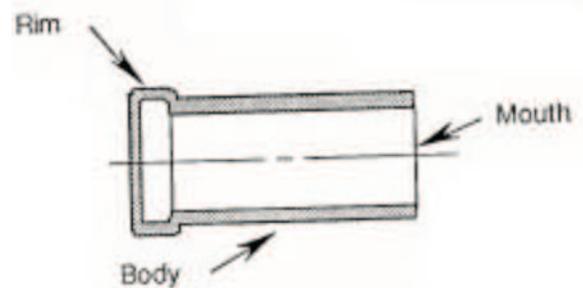
**Figure 6- Centerfire Pistol Case**



**Figure 7 - Centerfire Revolver Case**

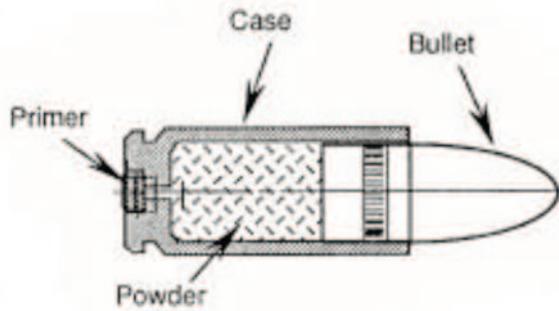


**Figure 8- Centerfire Rifle Case**

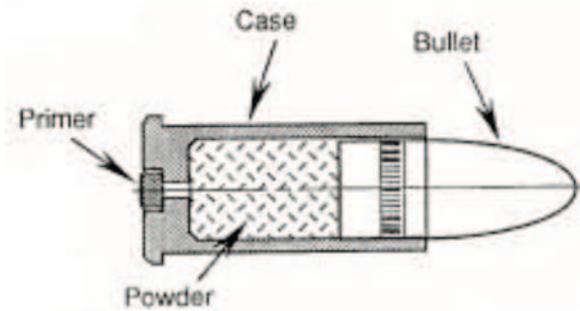


**Figure 9- Rimfire Case**

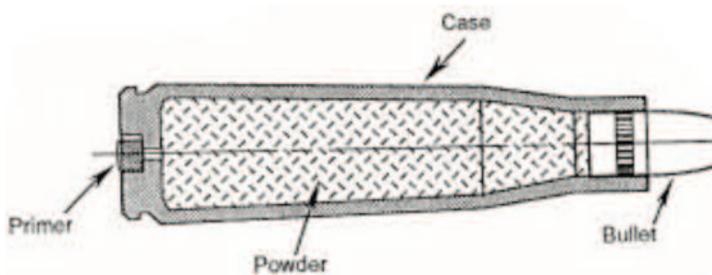
Case nomenclature for revolver, pistol, rifle, and rimfire in *Figures 6 – 9* are almost identical except for external configuration and size, which determines caliber.



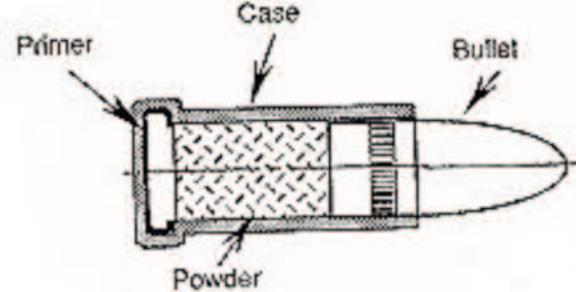
**Figure 10- Centerfire Pistol Cartridge**



**Figure 11- Centerfire Revolver Cartridge**



**Figure 12- Centerfire Rifle Cartridge**



**Figure 13- Rimfire Cartridge**

As seen in *Figures 10 - 13*, cartridge nomenclature is similar to case nomenclature. Some fired cartridges may have their cases reloaded with new primer, powder, and bullet. The reloaded cartridge is then resized. Rimfire cartridges (usually .22 caliber) are generally not reloadable.

Note that metal of reloaded cartridge cases is generally harder because of the work hardening caused by the expansion of the brass when fired. Calibration of PCB Series 117Bx Conformal Pressure Sensors is always performed with unfired brass.

## CASE MATERIALS

The following are examples of materials used in the manufacture of cases:

### BRASS:

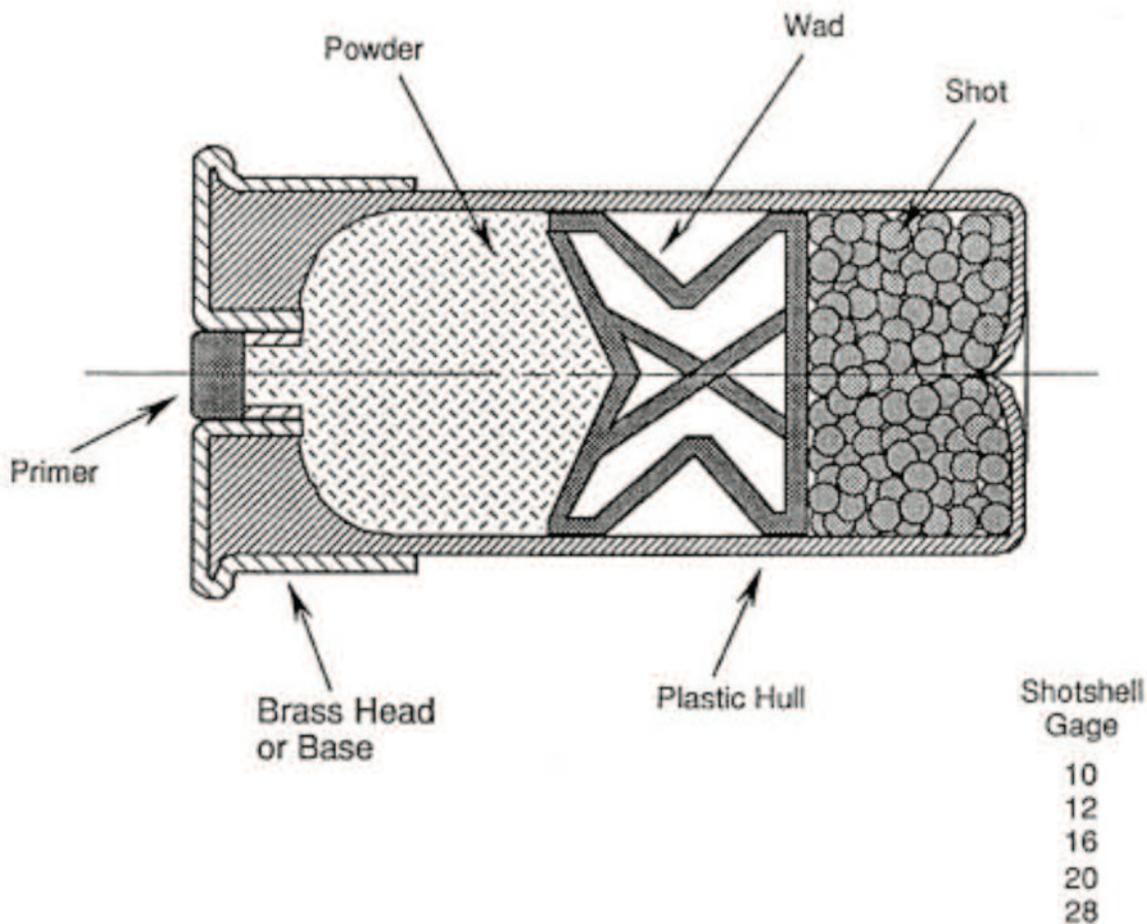
- Most common- approximately 97% of all cartridge cases
- May be reloaded many times

### ALUMINUM:

- Not common- approximately 2% of all cartridge cases.
- May NOT be reloaded
- Easier to fabricate than brass

**STEEL:**

- Not common- approximately 1% of all cartridge cases
- May not be reloaded
- Mainly for military use
- Extended shelf life; sealed primers.

**SHOT SHELL CARTRIDGES**

**Figure 14- Shot Shell Cartridge**

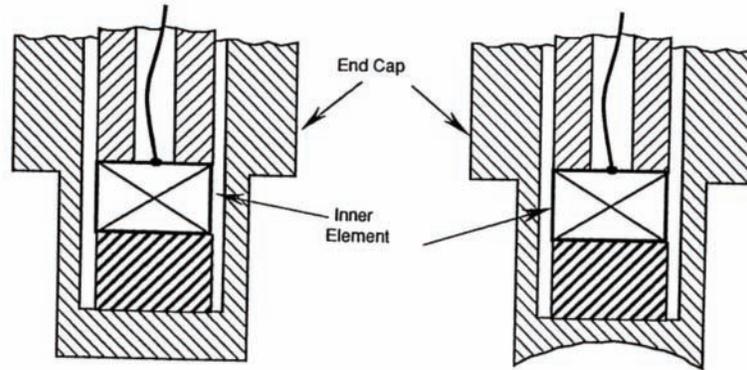
Shotgun cartridges, commonly referred to as shot shell, consist of a base, usually made from brass, containing a primer and a plastic hull. Older cardboard hulls are still in existence, and brass hulls are used in rare situations. The projectiles in shotgun cartridges are small lead alloy or steel balls, which are referred to as "shot."

Shot shell sizes are classified into sizes referred to as gauge. Twelve (12) gauge is the most common, followed by 20 gauge, 16 gauge, .410, 10 gauge, and 28 gauge. Note that .410 is technically not a gauge size. All shot shells are centerfire cartridges.



### SENSOR DIAPHRAGM DESIGNS

Various sensor diaphragms are used in the PCB® pressure sensor product line, depending on the ballistic design requirements. Some are illustrated in *Figures 15* through *17* below.



**Figure 15- Flat Integral Machined    Figure 16- Conformal Integral Machined**

#### **FLAT INTEGRAL, MACHINED DIAPHRAGM (see Figure 15):**

This type of diaphragm is machined into the sensor end cap. It offers a more rigid structure enabling it to withstand high-pressure (100K psi) repetitive cycling. Utilized when extended sensor life is desired. This thick (0.010 - 0.018 inch) diaphragm can be supplied with a flame sprayed ceramic coating which reduces thermal baseline undershoot and also protects the sensing surface against the erosive effects of the blast.

This diaphragm configuration is used on various PCB models, including Models 109C11, 109C12, 119B, 119B02, 119B11, 119B12, M165A01, and 165B02.

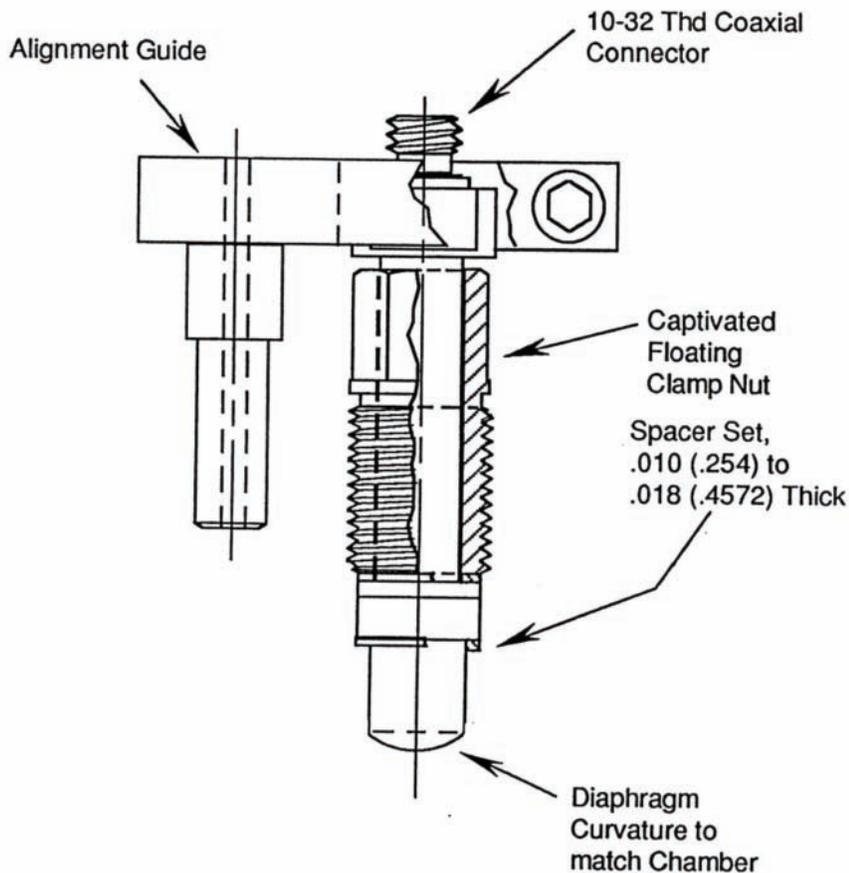
#### **CONFORMAL INTEGRAL, MACHINED DIAPHRAGM (see Figure 16):**

Identical characteristics as the Flat Integral type, except Conformal Integral does not require any ceramic coating, as it is not subjected to temperature and/or blast. This is the diaphragm configuration for PCB Series 117Bx Conformal Pressure Sensors.



## CONFORMAL BALLISTIC PRESSURE SENSORS

The conformal pressure sensor (see Figure 18), designed in cooperation with members of SAAMI (Small Arms and Ammunition Manufacturers Institute), 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. 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 17- Series 117Bx Conformal Ballistic Pressure Sensor**

The conformal sensor shown in *Figure 17* consists of an integral diaphragm with a specific curvature machined onto it. Diaphragm body diameter is made in two sizes: 0.194 inch, and 0.248 inch.

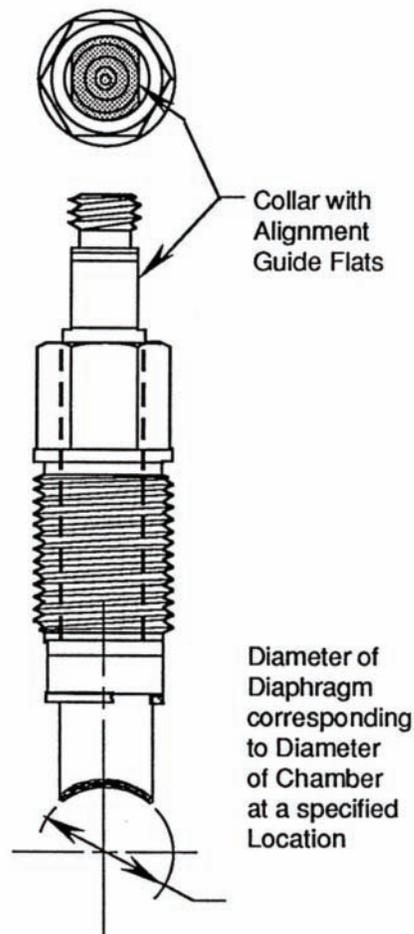
A captivated floating clamp nut rotates independently from the sensor body, allowing the sensor to be mounted while maintaining alignment of the curvature of the diaphragm to the chamber.



A removable alignment guide facilitates independent alignment of the curvature. The alignment pin has a small vent hole to allow close diameter installation.

A set of nine (9) spacers, with thickness from 0.010 to 0.018 inch (0.001 inch increments) compensates for variation in tolerances of the machined mounting hole depth. This spacer set facilitates the flush mounting of the diaphragm to within a tolerance of 0.001 inch.

*Figure 18* below shows the conformal sensor without the alignment guide.



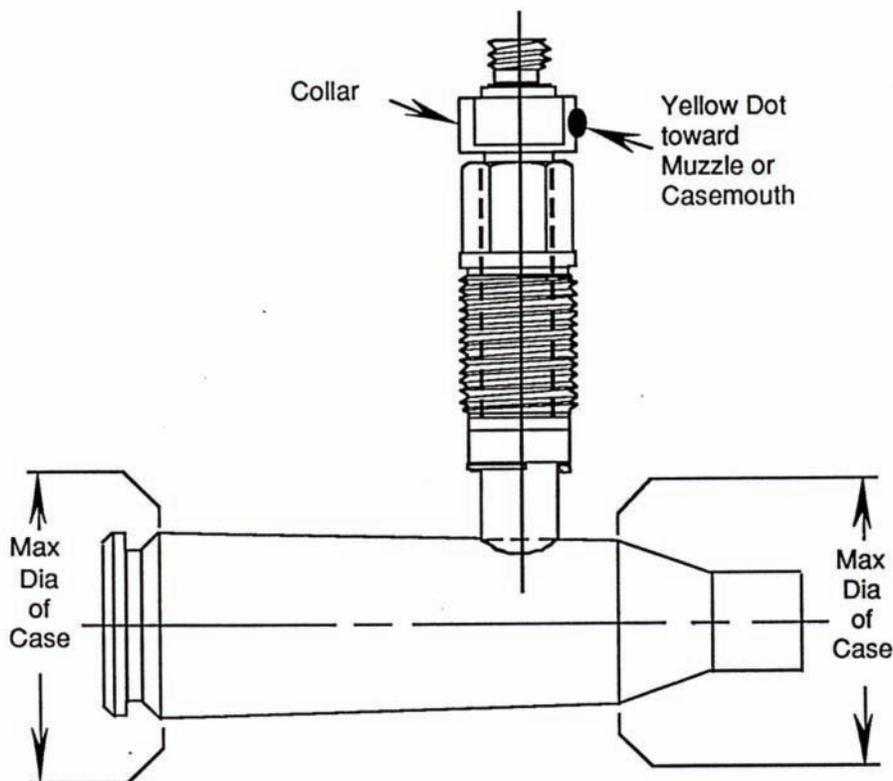
***Figure 18- Series 117Bx Conformal Sensor, Without Alignment Guide***



The curvature machined onto the diaphragm corresponds to the chamber diameter at a specific location forward of the bolt face. It is machined to correspond directly to the two flats machined onto the welded collar, at the connector end of the sensor.

Because the sensor location varies for different cartridges, the same PCB Model 117Bx conformal sensor is sometimes used for more than one caliber. For example, PCB Model 117B22 conformal sensor has a curvature of 0.494 inch diameter and may be used on 7mm Remington Mag., .264 Winchester Mag., 3.00 Winchester Mag., .338 Winchester Mag., 45-70 Government, and .458 Winchester Mag. calibers, at their respective locations.

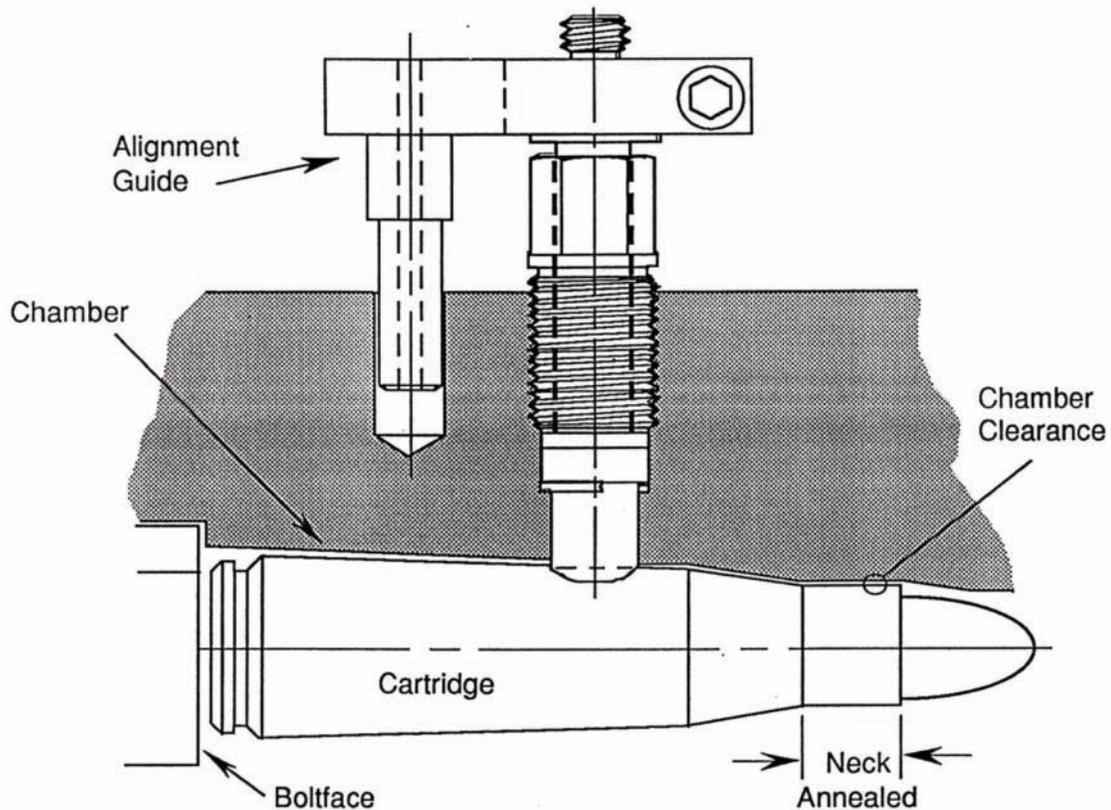
Please contact PCB for model numbers for various calibers.



**Figure 19- Centerfire Rifle Series 117Bx Conformal Sensor, Without Alignment Guide**

The curvature machined onto the diaphragm is generally a straight (90° to body) cut. For a particular caliber, the chamber may be machined with a severe taper on the diameter. This taper must also be machined onto the diaphragm curvature. *Figure 19* shows an example of the taper.

Any chamber that has a taper of 0.020 inch on diameter or greater has the taper machined onto the conformal sensor. To indicate the proper mounting direction, a yellow dot is placed onto the collar. This dot should always be located toward the muzzle or case mouth end. All sensors, including curvatures without tapers, have this yellow dot for maintaining consistency in mounting.



**Figure 20- Series 117Bx Conformal Sensor**

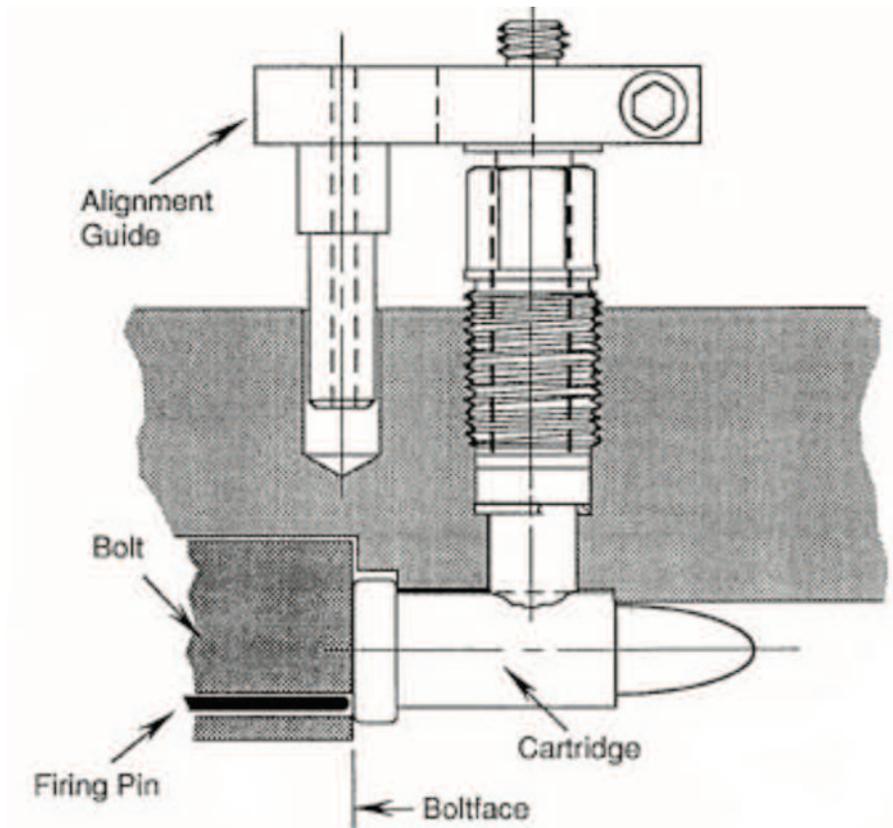
The cartridge case of an ammunition round is intentionally made smaller in diameter than the chamber to facilitate installation into all of the same caliber chambers, regardless of the manufacturer and/or tolerance size (*see Figure 20*).

The gas pressure generated by the burning powder builds up to a peak value (typically in 100 to 200 micro-seconds) and outward in all directions inside the case. This expands the case outwards tightly against the chamber. The softer (annealed) neck area expands easily, forming a pressure seal at the case mouth. The harder body area expands due to the internal pressure, and then springs back after the pressure is gone, allowing extraction of the fired case.

Note that the case itself does not have enough strength to hold this pressure. It will expand outward until constrained by the chamber around the circumference, and at the bolt face at the rear of the case. The cartridge case now forces itself onto the diaphragm of the sensor, creating a pressure input to the sensor.

Since the diaphragm of the sensor is insulated from the direct blast effects by the cartridge case itself, the sensor's life is greatly extended. There are also no thermal transients to affect the pressure sensor output.

Once properly installed, the sensor need not be removed, except for routine recalibration.



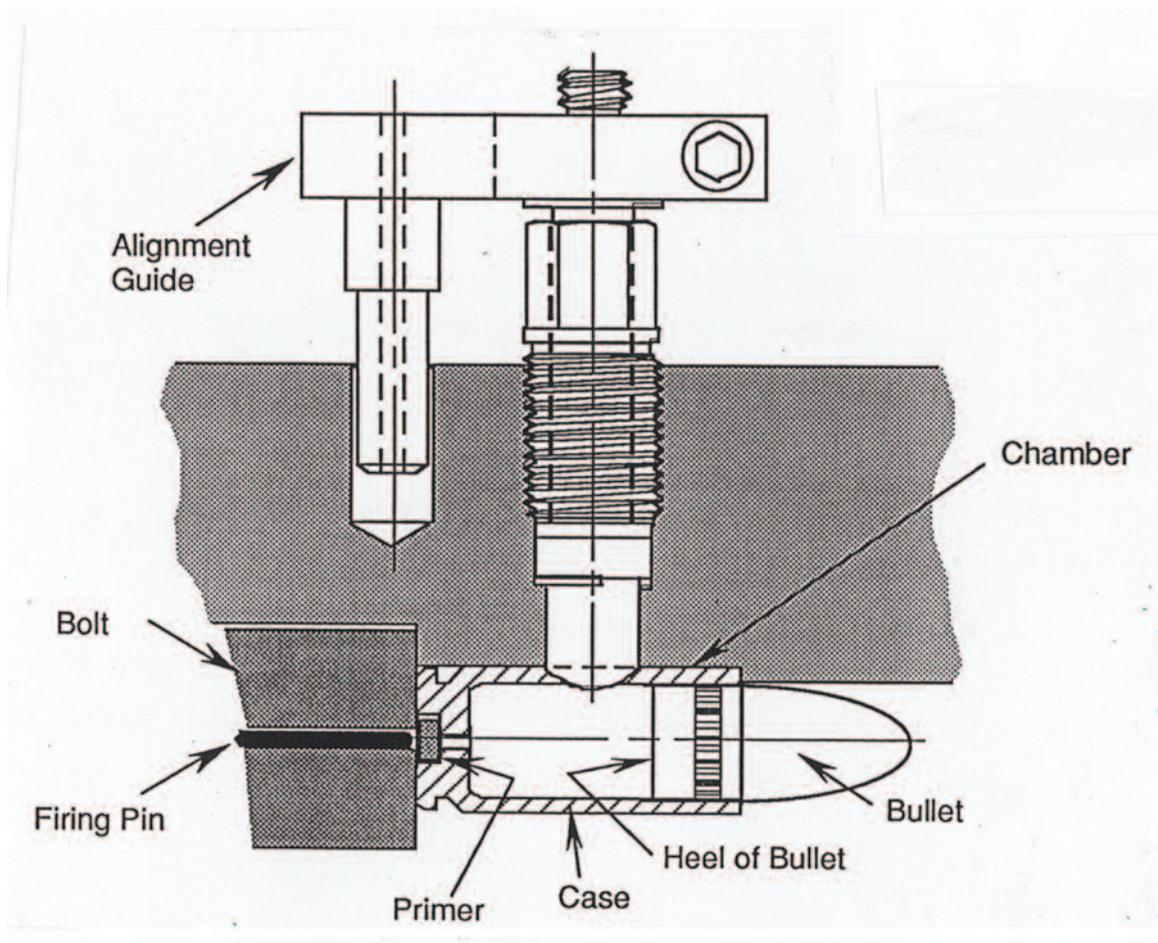
**Figure 21- Rimfire Series 117Bx Conformal Sensor, 0.194 inch dia. Diaphragm**

A small diaphragm diameter (0.194 inch) version of PCB Model 117Bx is used for cartridge cases having a curvature of 0.350 inch diameter or less. This sensor size is usually associated with .22 caliber ammunition.

The small diameter conformal is not used exclusively for rimfire. It may also be used on other smaller sized caliber centerfire ammunition.

Rimfire calibers are .22 short, .22 long rifle, .22 Winchester Rimfire, .22 Winchester Magnum Rimfire, and .22 long rifle shot.

Rimfire cartridges are fired by a firing pin striking the rim of the cartridge. These are relatively low-pressure cartridges, typically generating less than 15K psi.



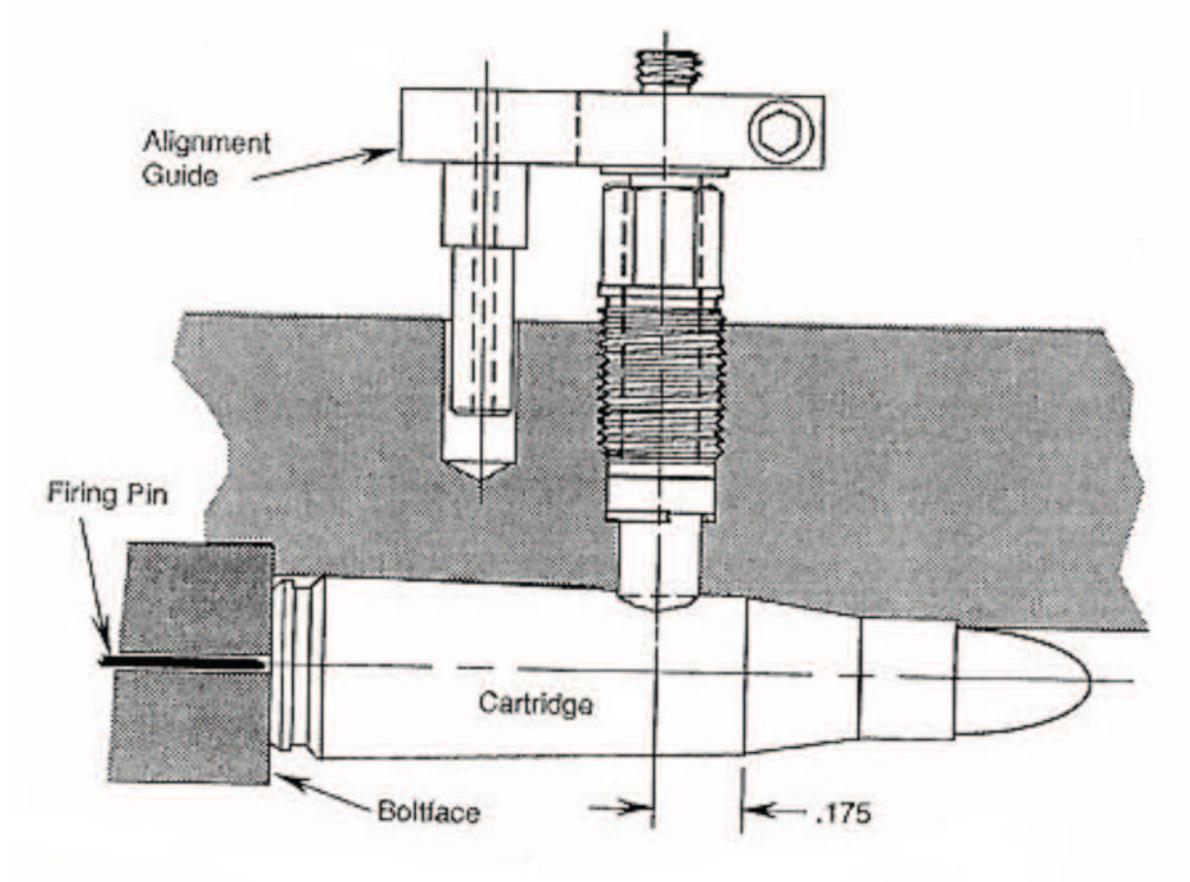
**Figure 22- Centerfire Pistol & Revolver Series 117Bx Conformal Sensor**

Centerfire pistol and revolver cartridges usually use the larger (0.248 inch) diameter diaphragm and may also (but rarely) use the smaller (0.198 inch) diameter diaphragm.

The conformal sensor is generally located slightly behind the heel of the bullet, as shown in *Figure 22*. Location is usually determined by SAAMI or dictated by the customer.

Pressures generated in these cartridges are usually 10K to 45K psi.

Centerfire cartridges are fired by a firing pin striking the centrally located primer.



**Figure 23- Centerfire Rifle Series 117Bx Conformal Sensor, 0.248 inch dia. Diaphragm**

Centerfire rifle cartridges almost always use the larger (0.248 inch) diameter diaphragm, and may also (but rarely) use the smaller (0.198 inch) diameter diaphragm.

The conformal sensors (on the necked-down cartridges) are located 0.175 inch from shoulder and sidewall junction. This is usually determined by SAAMI or dictated by the customer.

Pressures generated in these cartridges are generally 20k to 60k psi.

Centerfire cartridges are fired by a firing pin striking the centrally located primer.

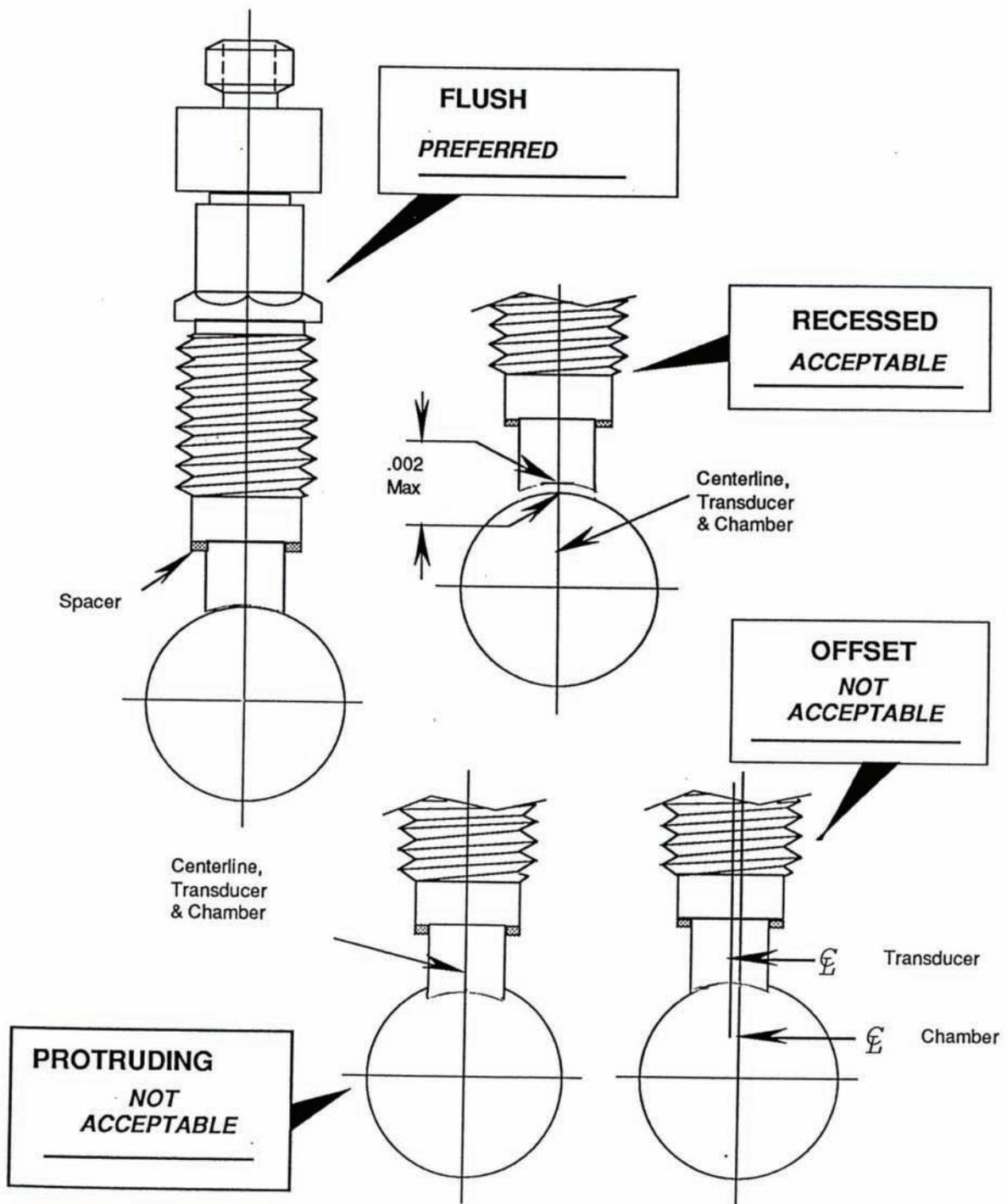


Figure 24- Conformal Sensor Mounting

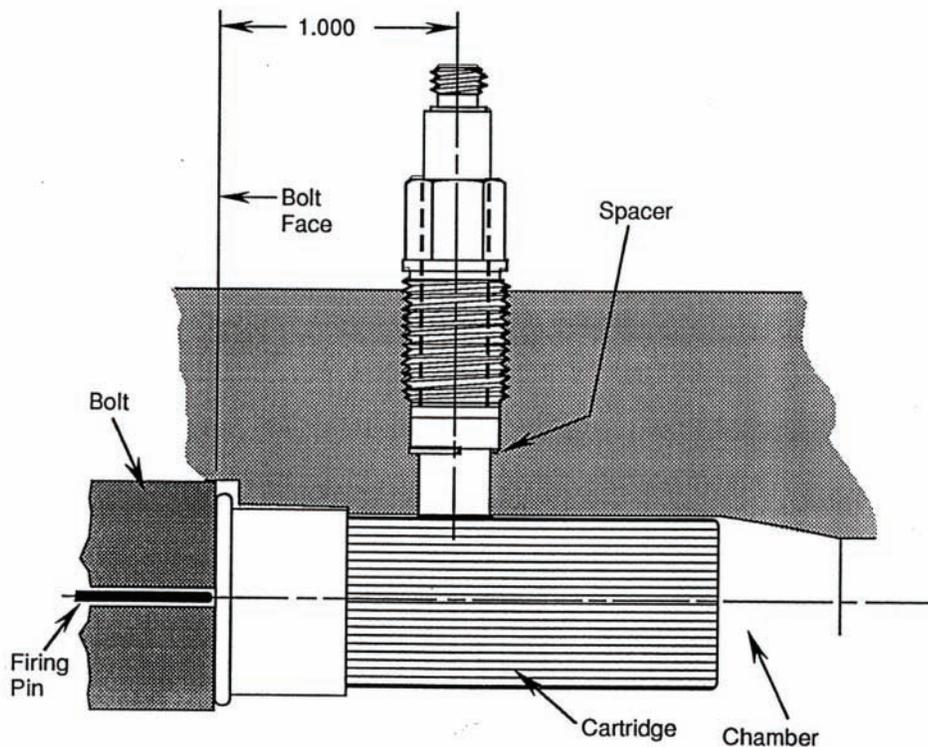


Preparation of the mounting port for a conformal sensor is very important. As illustrated in *Figure 24*, the centerline location from left to right must be maintained. Not only will the protruding sharp edge of a diaphragm cut into brass, but it will also affect the output of the sensor.

Installation depth of the sensor into a mounting port is equally important. A protruding sharp edge of a diaphragm will cut into brass, and will also affect the output of the sensor.

A recess of 0.002 inch maximum is permitted. Greater recess may rupture brass, and may prevent the case from being extracted from the chamber. A flush co-planar mounting is accomplished by selecting one or more of the spacer(s) supplied.

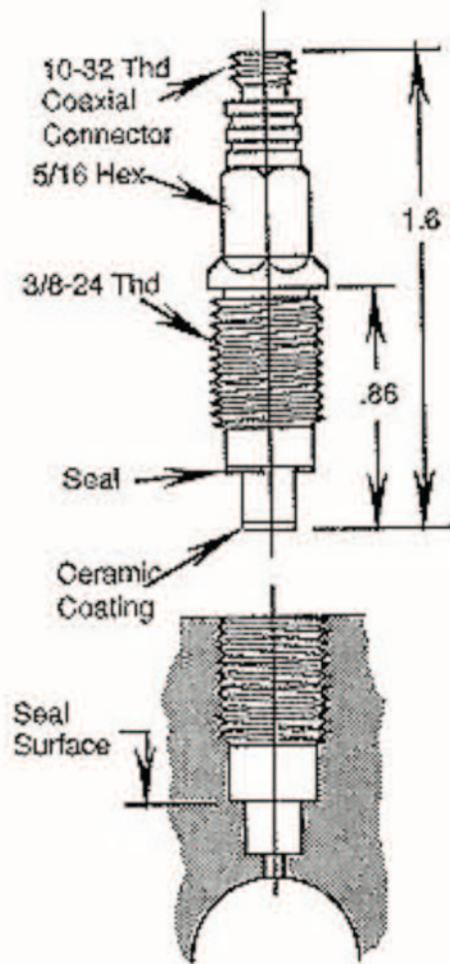
## OTHER BALLISTIC PRESSURE SENSOR CONFIGURATIONS



**Figure 25- Shot Shell "Mid-Case" Model 165B02 Sensor, 0.248 inch dia. Diaphragm**

Because of its flexibility, the shot shell plastic hull material does not necessitate the use of a conformal sensor. The sensor's is of flat, thin sheet metal diaphragm construction is flush mounted, using the spacer set supplied.

Pressure measurement occurs similar to the conformal method, in that the case expands outward due to internal pressure, sealing off the case mouth area and preventing hot gases from reaching the diaphragm. Thermal effects are eliminated, and the low pressures (approximately 15K psi) greatly extend sensor life.



**Figure 26- Shoulder Seal Ballistic Sensor Series 109, 119 with Ceramic Coated Diaphragm**

The integral diaphragm style sensor shown in *Figure 26* uses a shoulder seal made of stainless steel to seal at high-pressure (100k psi to 120k psi).

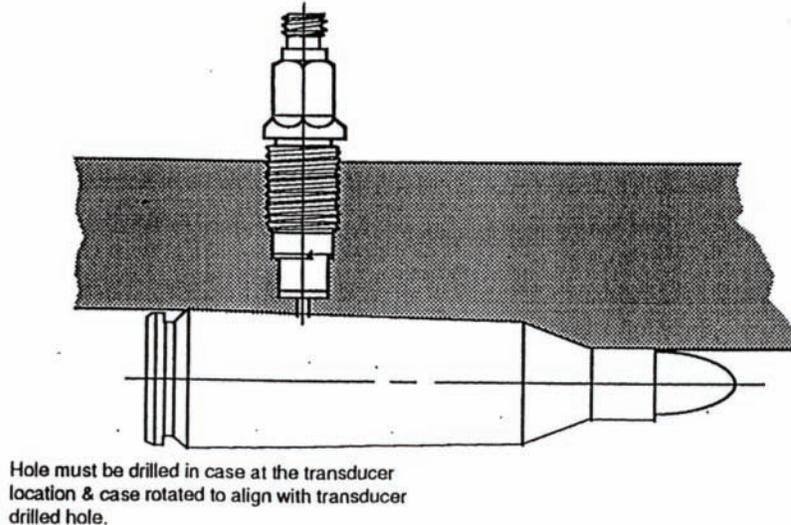
Mounting torque on this type of sensor is relatively high, 20-25 foot pounds. Consequently, precise mounting hole preparation is required. The use of a ceramic-coated diaphragm aids in thermal shock protection. The sensor should be removed periodically and the passage ports should be cleaned.



## OTHER BALLISTIC PRESSURE SENSOR MOUNTING TECHNIQUES

Using a sensor at the mid-case location has many drawbacks. First, the cartridge case (live round) must be drilled through one wall. Tape is placed over this opening to prevent powder from pouring out. When inserting into chamber, the drilled hole and sensor port must be aligned with each other.

Upon firing, hot gases are allowed to enter this passage and go directly onto the sensor diaphragm. This can result in thermal shock to the sensor and erosion of the diaphragm. Also, the passage has to be cleaned out periodically.

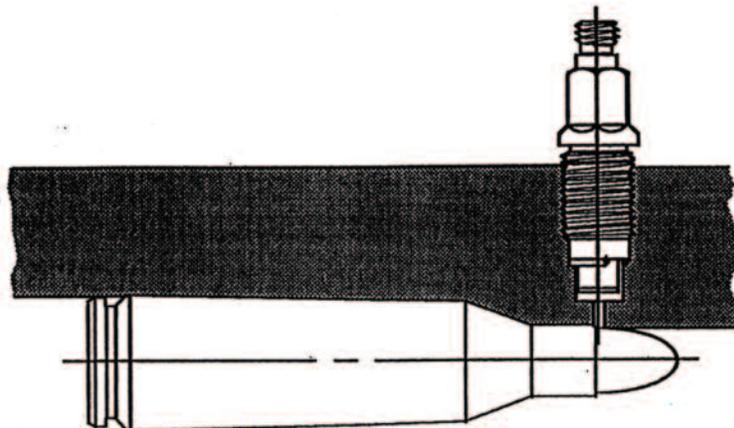


**Figure 27- Centerfire Rifle Mid-Case Sensor Series 109, 119 Shoulder Seal**

### CASE MOUTH SHOULDER SEAL (see Figures 28):

Using sensors at these locations presents challenges. However, one advantage over a mid-case location is that the sensor port does not have to be aligned with a drilled cartridge case. The same thermal and diaphragm erosion issues remain, and the passage has to be cleaned out periodically.

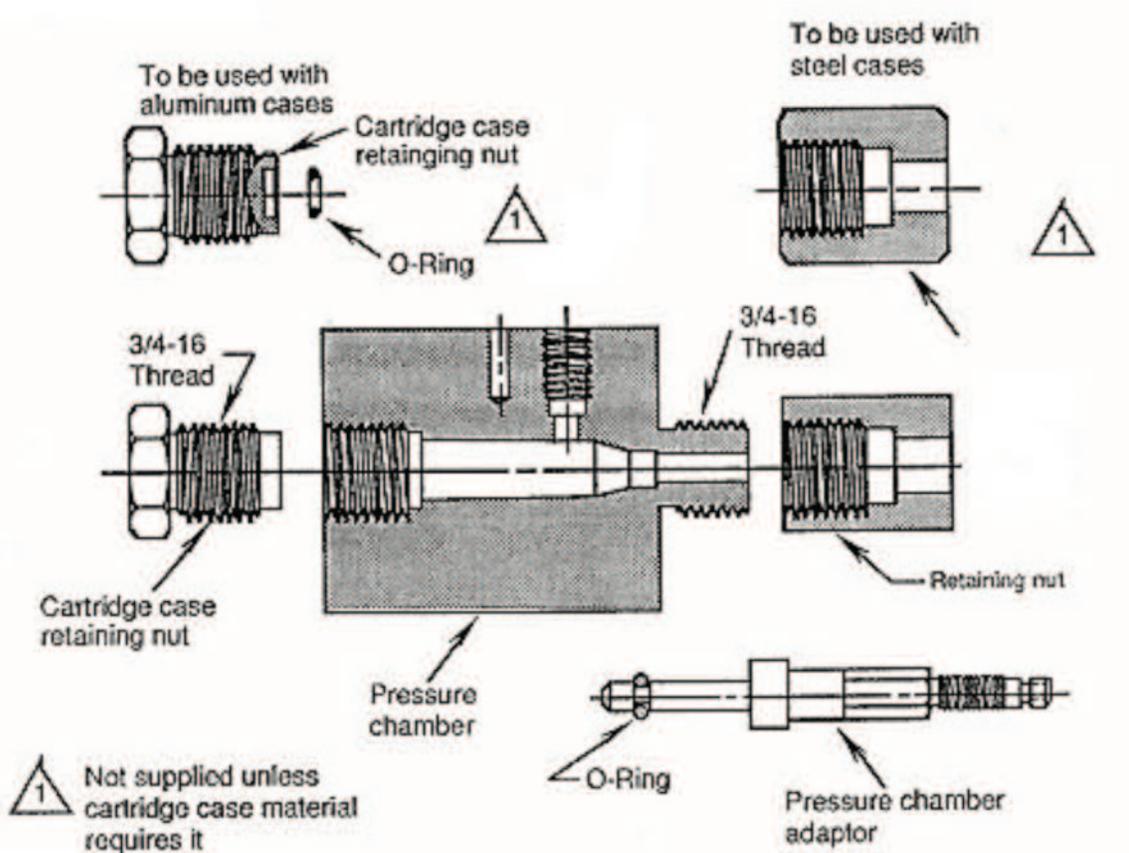
This type of mounting is used more often than the mid-case mounting method. PCB Series 109 and 119 sensors are typically used for measurements at these locations.



**Figure 28- Centerfire Rifle Case Mouth Sensor Series 109, 119 Shoulder Seal**



## CONFORMAL SENSOR CALIBRATION



**Figure 29- Conformal Calibration Adaptor Series 090Bx**

In order to accurately calibrate PCB Series 117Bx Conformal Sensors, it is necessary to use unfired cases with a primer in place. PCB's Model 090Bx Calibration Adaptor simulates the chamber, and is made for each specific caliber. The 090Bx adaptor consists of a pressure chamber, cartridge case retaining nut, pressure chamber adaptor, and an adaptor retaining nut (see Figure 29).

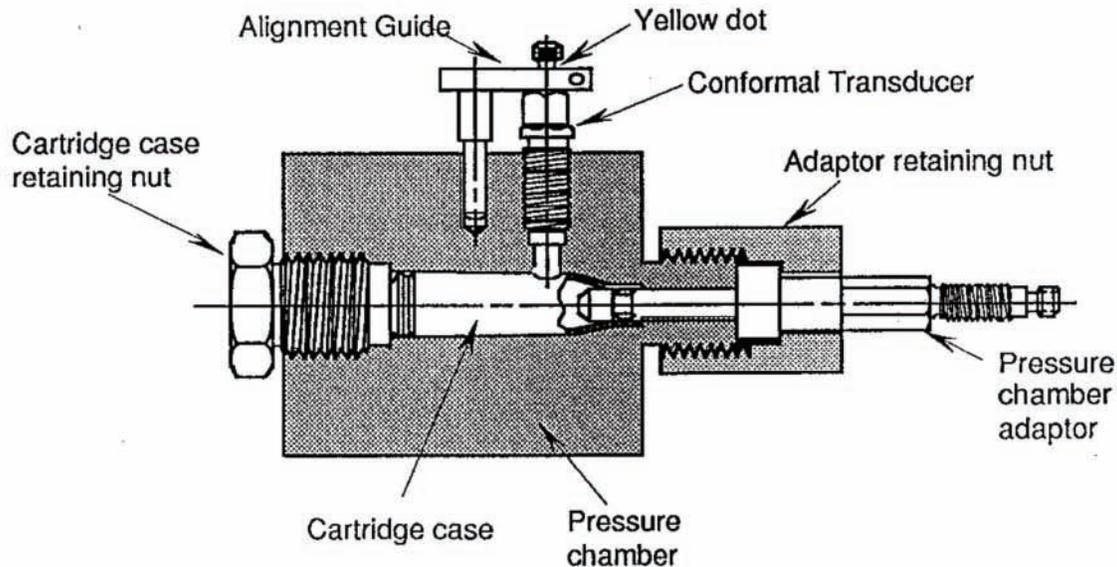
The PRESSURE CHAMBER has the specific caliber chamber configuration reamed into it, along with the sensor/alignment mounting hole(s). This is used to accept a cartridge case and to hold the calibration pressure with the conformal sensor.

The CARTRIDGE CASE RETAINING NUT has a 3/4-16 external thread and a hexagon head. This is used to hold the cartridge case in place while being pressurized. On occasion, it is necessary to use this type of retaining nut with an o-ring to facilitate sealing at the primer area. This is a necessity with cartridge cases made from aluminum alloy.

The PRESSURE CHAMBER ADAPTOR has a high-pressure input end configuration that is identical to the 3/8-24 external thread and 7/16 hex body found in Series 119 pressure sensors. This end is the same for all adaptors. The opposite end varies with each caliber, and is grooved for an o-ring that inserts directly into the cartridge case and seals the pressure inside the case.



The ADAPTOR RETAINING NUT has a 3/4-16 internal thread and a round knurled body. This is used to hold the pressure chamber adaptor into the cartridge case while being pressurized. When calibrating a sensor using steel cases, it is necessary to use the retaining nut with the hexagon body to facilitate assembly of the pressure chamber adaptor into the steel cartridge case.



**Figure 30- Series 090Bx Conformal Calibration Adaptor- Assembly and Use**

Series 117Bx Conformal Sensors are installed into the empty pressure chamber, using the spacer set supplied, so that the curvature of the sensor is flush with the chamber curvature.

The cartridge case requires the case mouth to be chamfered to allow easy entry of the o-ring on the pressure chamber adaptor. The use of a 90° countersink is recommended.

The cartridge case is inserted into the pressure chamber, and the cartridge case retaining nut is installed. The unthreaded portion “bottoms out” on the bolt face surface of the pressure chamber.

The o-ring on the pressure chamber adaptor is lubricated with silicone grease or hydraulic oil and inserted into pressure chamber opening.

The adaptor retaining nut is installed over the pressure chamber adaptor, and is hand-tightened.

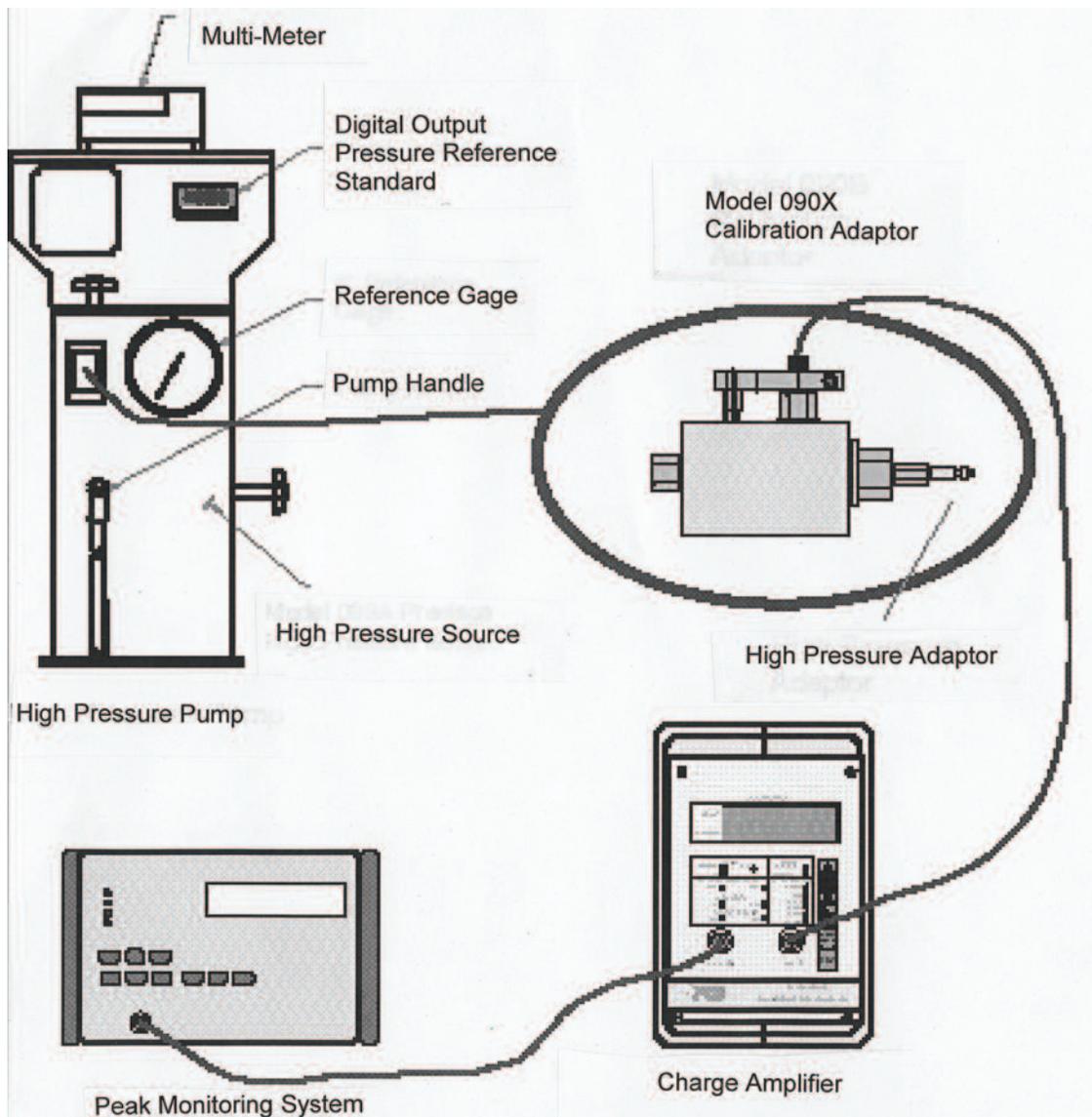


The calibration adaptor is then installed into a high-pressure port, and the following is performed:

- Pressure is applied slowly, starting at the lowest level
- Pressure is needed to expand the case until sensor output is recorded. This is the offset.
- Data is recorded at five pre-determined, incremental pressure levels, up to the maximum
- Pressure is released, and the cartridge case is discarded

A new chamfered cartridge case is installed

- Above steps are repeated for 10 cartridge cases
- Average of 10 rounds is taken at each pressure point



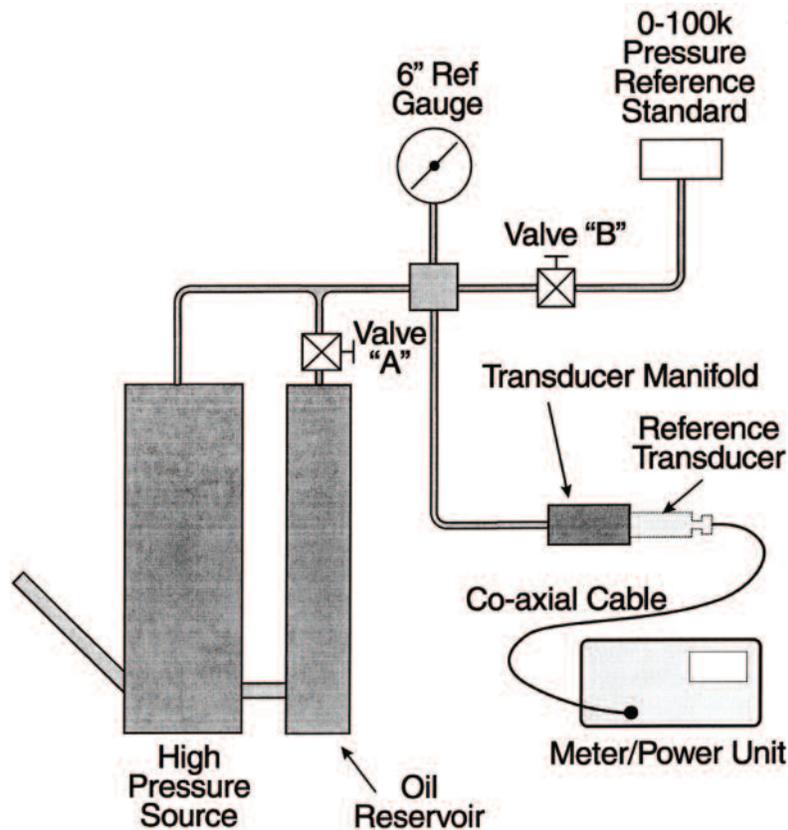
**Figure 31- Conformal Calibration System**



A typical high-pressure calibration system is shown in *Figure 31*.

Calibration of a PCB Series 117Bx Conformal Sensor is accomplished by mounting the sensor in the same manner as it is to be used in the gun. The high-pressure pump and appropriate adaptor used in calibration allows the calibration adaptor to be closely coupled to the pump, reducing volume and eliminating the need for high-pressure lines.

The calibration is performed by comparing the sensor charge output to the known static input pump pressure.



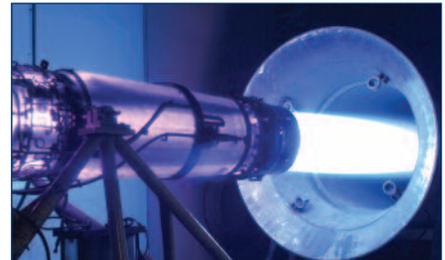
**Figure 32- Conformal Calibration System- High-Pressure Pump Detail**

An example of a calibration plot for a conformal sensor is shown in *Figure 33*. Calibration of a conformal sensor using the brass, aluminium, or steel cartridge cases shows that the slope of the sensor does not go through zero. This is due to the fact that a few thousand psi is required to expand outward the relaxed cartridge case to contact the chamber wall and Conformal Sensor. This pressure is referred to as the offset. The offset will vary per caliber, material thickness, and material hardness.

A conformal pressure sensor may also be oil calibrated (without using the calibration adaptor and cartridge case) if either, or both, are not available. An oil-only calibration will establish linearity, but will not establish the sensitivity accuracy required for use as a conformal pressure sensor (*see Figure 34*).







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