Dynamic Calibration Of Piezo-Electric Chamber Pressure Transducers

Art, Science, and Compromise

W. Scott Walton

Ballistic Technology Officer

US Army Aberdeen Test Center

Bottom Line Up Front

- For the last 40 years, the Army has been intensely concerned about eliminating small discrepancies in chamber pressure measurement
- ATC has changed its calibration technique for piezo-electric pressure transducers to a dynamic calibration process, which will cause indicated pressure levels to go down by 0.8%
- Lots of really smart people have trouble understanding why such small differences are so important
- Despite use of dynamic calibration, differences between Quartz (6213) and Tourmaline (E30MAZ) transducers continue to be observed.
- Better transducers are needed for chamber pressure measurement. **Existing transducers allow an unacceptably high probability of accepting bad lots or rejecting good lots of ammunition.**

Primary & Secondary Calibration Standards for 100,000 psi and above

Primary Standard

Controlled Clearance Dead Weight Tester (CCDWT) Piston Pressure Balance

Calibrated mass and piston used to calculate pressure. 0.02% uncertainty

Manganin Pressure Cell, **Secondary Standard** (0.1% uncertainty)

Strain Pressure Cell, **Secondary Standard** (0.1% to 0.4% uncertainty)

STATIC PRESSURE CAN BE GENERATED WITH VERY HIGH ACCURACY

Cross Float of 2 Dead Weight Pressure Balances

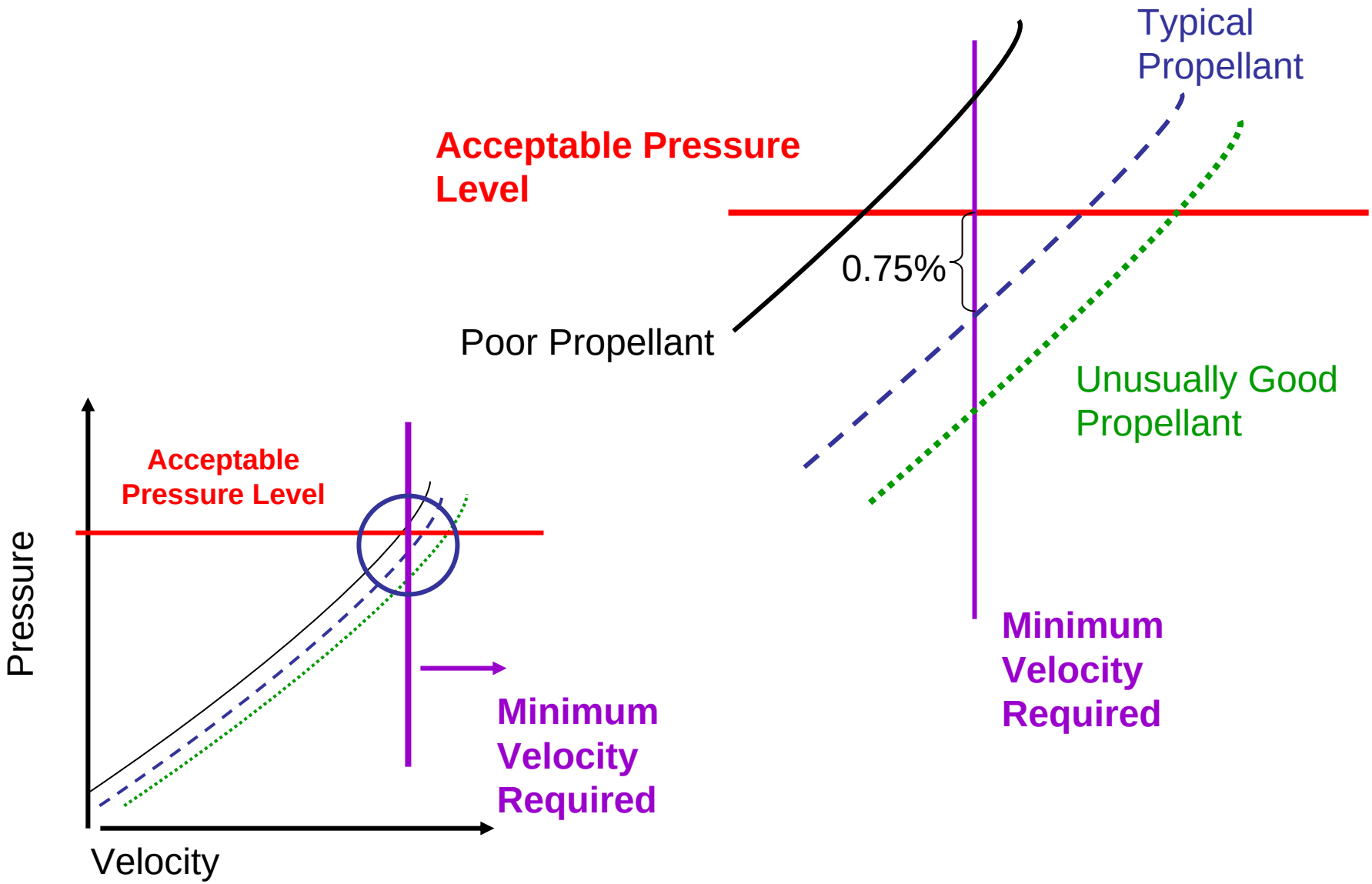
Harwood CCDWT	DH Model 45000 Bench Deadweight Tester	Difference
100,065	100,088	**-0.023%**
80,043	80,058	-0.019%
70,035	70,045	-0.014%
60,011	60,024	-0.022%
40,012	40,012	0.00%

Sensitivity = better than 20 grams on 1000 lb mass = 0.004%

Mechanical & Electrical Transducers (that must survive gun fire) are the ‘weakest link’ in the pressure measurement process

Chamber pressure measurement is the most demanding voltage measurement made in ballistic testing, yet existing techniques are still not good enough!

THERE IS ONLY 0.75% PRODUCTION LEEWAY BETWEEN THE PRESSURE NEEDED TO DEFEAT THE TARGET AND THE MAXIMUM ACCEPTABLE PRESSURE LEVEL WHEN MANUFACTURING THE MOST DEMANDING AMMUNITION

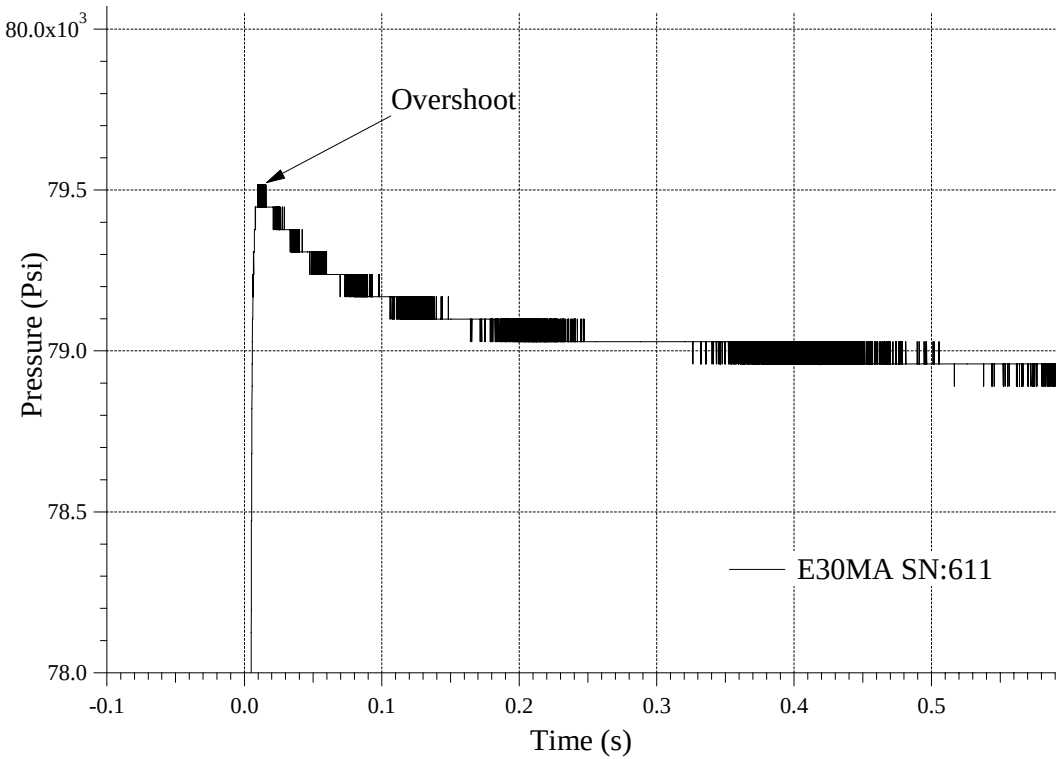


Background Timeline

- **Circa 1860, use of copper crusher gages began (static calibration used)**
- **Circa 1920, use of electronic chamber pressure transducers began**
- **Circa 1960, dynamic calibration of crusher gages began (25% improvement)**
- **1990 NATO crusher trials imply 1% difference between US (Tourmaline) and French (Quartz) measurements (Everyone celebrates excellent accuracy!)**
- **2002 NATO Crusher trials. A 1% bias noted (USA is devastated by accuracy problem!)**
- **2002 Tourmaline 'Cusp' observed**
- **2002 0% to 2% discrepancy between Quartz (NATO Kistler 6213B & USA E30MA) documented**
- **2004 Calibration of E30MA transducers investigated using Harwood Dynamic Calibrator (0.4% to 0.8% improvement)**
- **2006 Quick Release valve for DH calibrator perfected, new Dynamic Calibration procedure integrated into routine test process**
- **2006 0% to 2% discrepancy between Quartz (NATO Kistler 6213B) & Tourmaline (USA E30MAZ) continues to be observed**

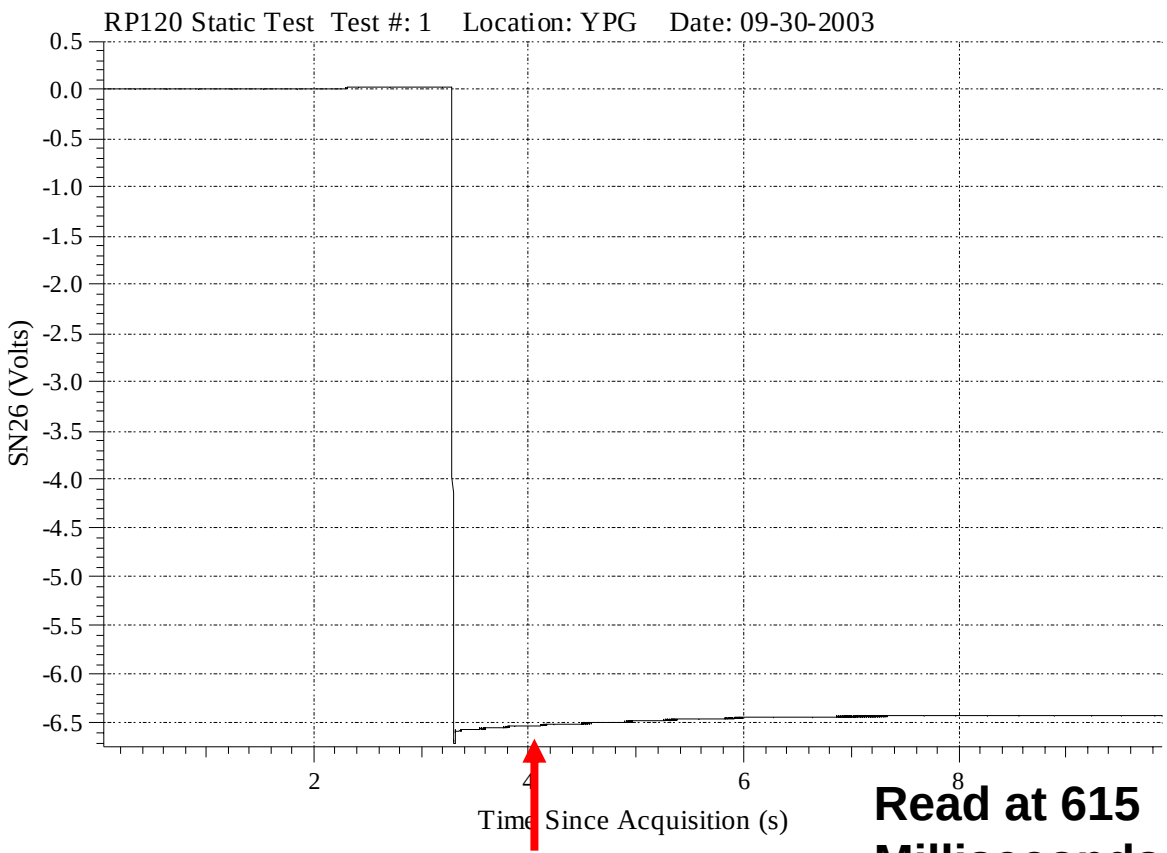
Tourmaline Cusp

Approx. 0.4% Overshoot



DH DeadWeight Piston Gage Calibrator

25 Millisecond Pressure Release

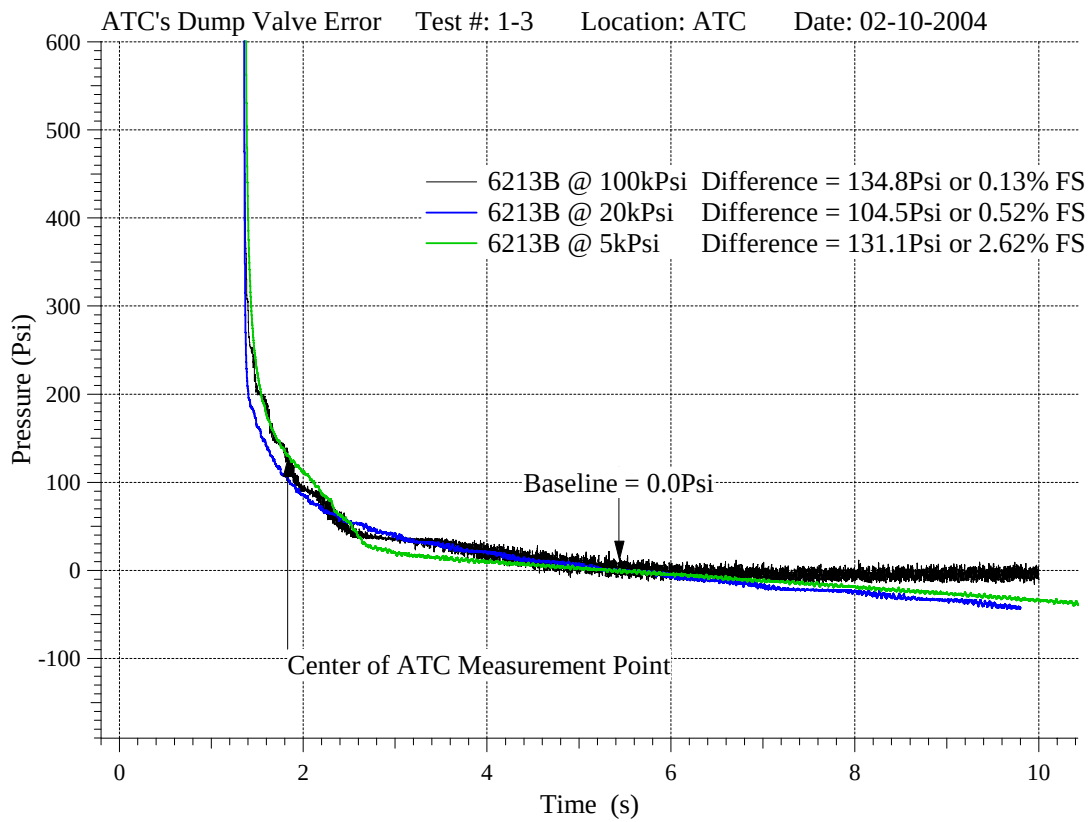


Read at 615 Milliseconds

0.04% uncertainty

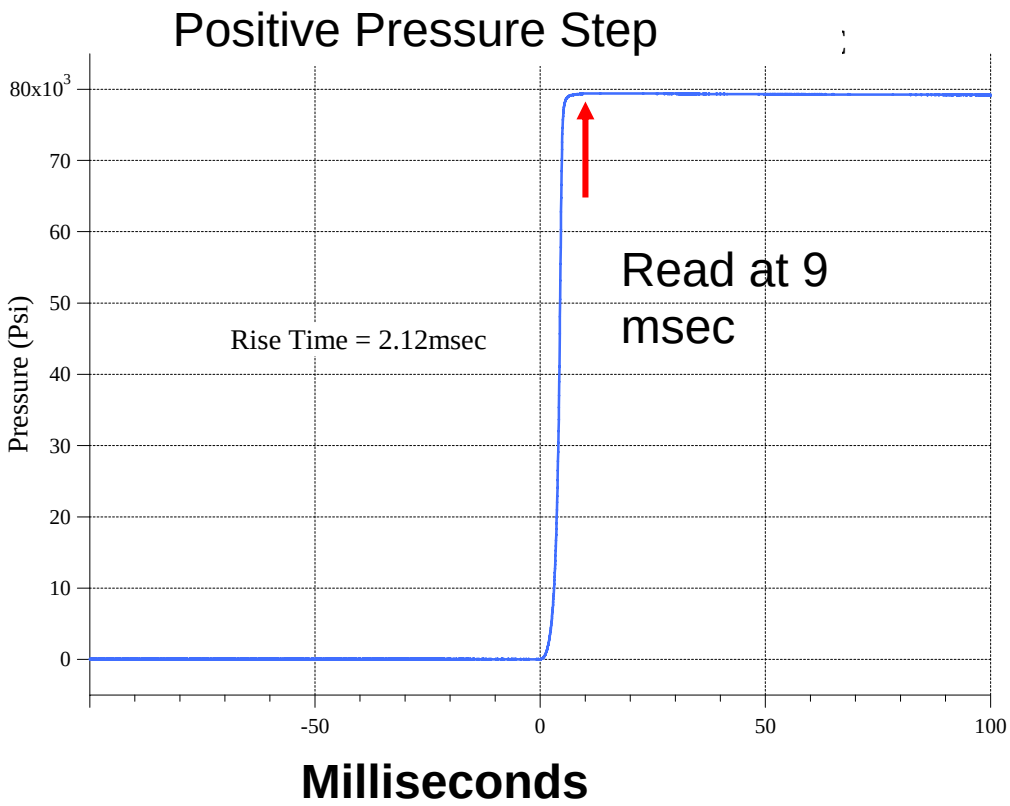
Error Caused by Valve Plumbing

Approx. 0.4% error at 100,000 psi



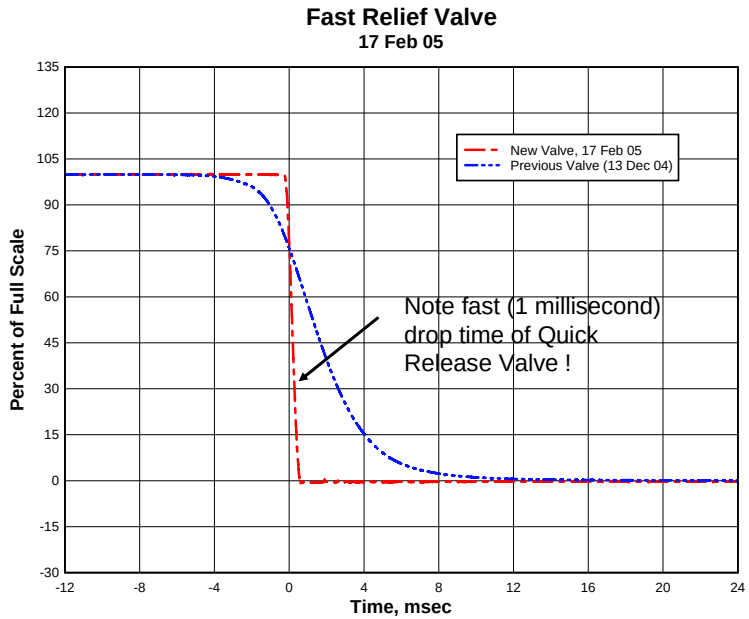
Dynamic Harwood Calibrator

Manganin Pressure Cell
Secondary Standard
uncertainty 0.10%

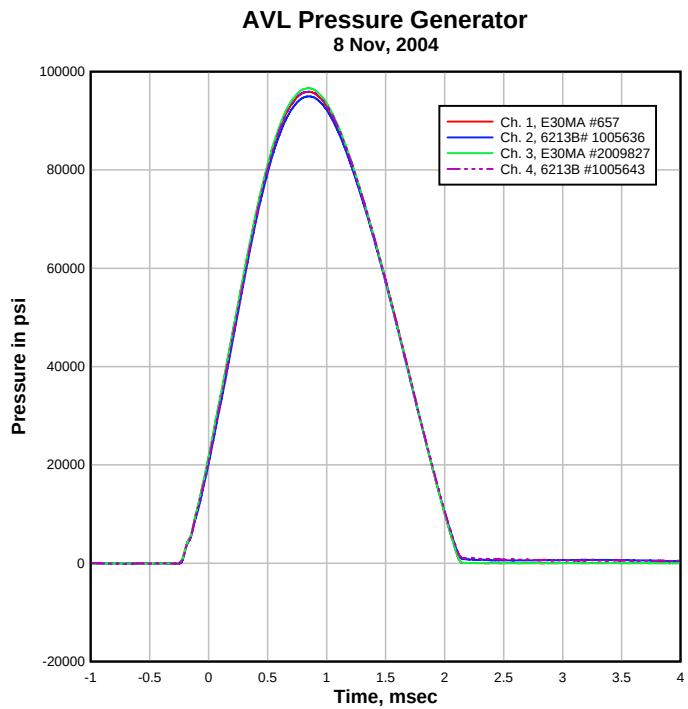


Quick Release Valve

Designed & Fabricated by Yuma Test Center to allow dynamic calibration with a dead weight piston gage (0.04% uncertainty)



AVL Dynamic Pressure Generator Used to Evaluate Pressure Transducer Performance in a Dynamic Environment



Relative readings only. **NOT a NIST Traceable calibration standard**

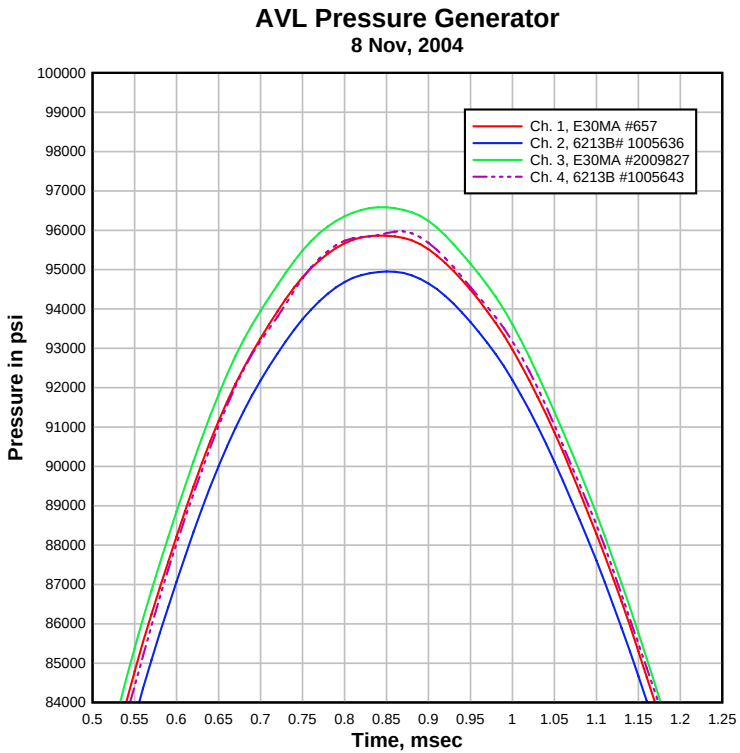
K-Fixture

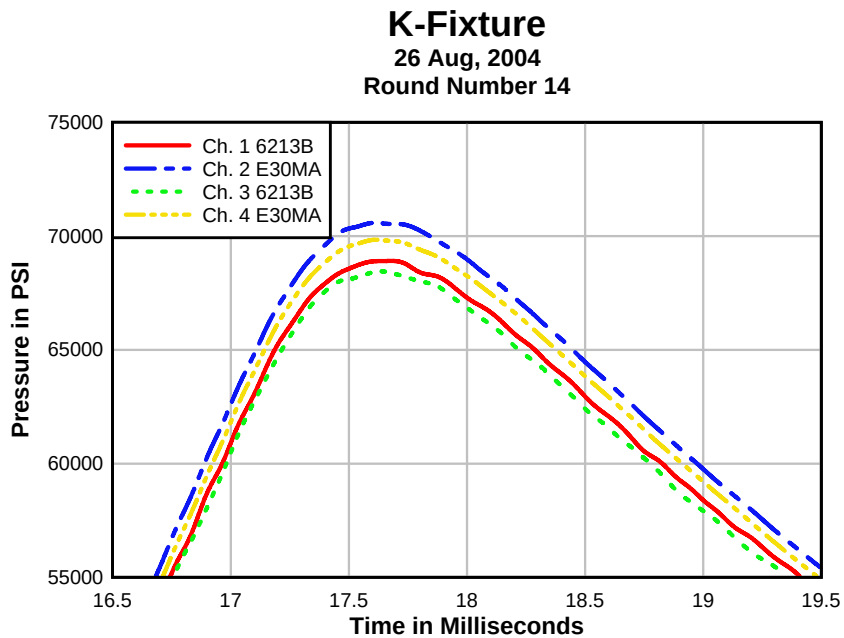
- Tests crushers & electrical transducers to 120,000 psi
- Uses standard 120mm breech & propellant, but 1/10th the cost of normal firing
- FY05 effort (Aug 05 test) confirmed operation up to 120 Kpsi
- FY06 – FY07 effort will reduce gas wash damage to inner parts and shorten ballistic cycle to improve agreement between mechanical copper crusher gages and piezo-electric transducers

Despite use of dynamic calibration, Differences Between Quartz (6213) and Tourmaline (E30MAZ) continue to be observed.

Latest testing (15 Feb 06) in AVL pressure generator continues to show a bias of 1.5% to 2.7% (Quartz High, Tourmaline Low), even though dynamic calibration technique was used to eliminate discrepancies caused by ‘tourmaline cusp’ effect.

This observation is consistent with Peter Stein’s warning not to ‘worship the Golden Calf’ of the calibration certificate, until you understand all other aspects of the measurement system. Clearly we still don’t understand something in this measurement system.





Existing Cannon Pressure Measurement Technology is Inadequate!

With existing transducers and the most demanding ammunition, the probability of either rejecting a good lot or accepting a bad lot can be 30% to 50% if reliable calibration rounds are not available!!!

- Desired Chamber Pressure Accuracy = Velocity Accuracy = 0.1%
- Current Accuracy is 1%(Best Case) to 2% (Worst Case)
- Desired Calibration Accuracy = 0.01% Using Quick Release Valve (Electronics = 0.001%)
- Current Capability is 0.04% pressure generation, with transducer response problems of 0% to 2%
- Desired Pressure levels up to 120,000 psi
- Current practice is 105 Kpsi
- E30MAZ Fielding for 120mm tank gun testing is now underway
- High Accuracy transducers are needed
- K-Fixture is available to test crushers & new transducer prototypes

Conclusions

- **USE OF DYNAMIC CALIBRATION TECHNIQUE IMPROVES ACCURACY OF FIELD TEST DATA BY 0.8%**
- **EVEN THOUGH 0.8% IS A SMALL AMOUNT, IT IS SIGNIFICANT IN THIS APPLICATION**
- **THE 6213B QUARTZ TRANSDUCER STILL DOES NOT AGREE WITH THE E30MAZ TOURMALINE TRANSDUCER, EVEN WHEN THE DYNAMIC CALIBRATION TECHNIQUE IS USED (NEED HELP FROM KISTLER & YPG ON THIS ISSUE)**
- **FURTHER WORK MIGHT INCLUDE COMPARISON OF 6213B AND E30MAZ ON PCB/BEN GRANATH DYNAMIC PRESSURE CALIBRATOR???**
- **MAJOR ISSUE IS REDUCING OCCASION-TO-OCCASION VARIATION**
- **A 0.1% ACCURACY TRANSDUCER IS NEEDED, THAT CAN BE CALIBRATED USING STATIC PRESSURE AT 120,000 PSI = 8300 BAR**
- **HIGH ACCURACY TRANSDUCER CANDIDATES:**
  - **PM ITTS/HSTSS/Qinetic??**
  - **PCB West??**
  - **?????**