PROJECTILE-BORNE INSTRUMENTATION FOR CHARACTERIZATION OF IN-BORE ENVIRONMENTS

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ABSTRACT

The U.S. Army Research Laboratory has recently developed a projectile-borne instrumentation system for characterization of in-bore environments. In conjunction with Applied Ordnance Technology (AOT) an instrumented pusher assembly (IPA) was developed to capture in-bore data as a projectile accelerated down the gun tube. For in-bore data measurements, flight worthiness of the projectile was not a concern, therefore, a cylinder was pressed on the front of the IPA to simulate the mass of a projectile to realistically represent the environment in the gun tube. In-bore data was measured for 40 ms and stored on the IPA and upon exiting the gun tube the cylinder separated from the IPA exposing an antenna and the data was telemetered to a ground station for analysis. Instrumentation included a tri-axial accelerometer for measurement of setback and balloting loads, three pressure gages for measurements of the propellant load on the projectile, a low g accelerometer as a first movement indicator and a magnetometer to determine when the projectile exited the gun tube.

Measurements of in-bore phenomena are invaluable for the interior ballistician to validate theoretical calculations of new propellant formulations, projectiles, or gun tubes. The IPA was tested in an experimental 5.2” (132mm) gun, however, it can be adapted to small and large calibre guns for characterization of the in-bore environment or it can be tailored to also characterize the in-flight environment.

ACKNOWLEDGEMENTS

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INTRODUCION

In an effort to more clearly understand the in-bore environment of a large calibre gun the U.S. Army Research Laboratory in conjunction with Applied Ordnance Technology[1] (AOT) developed an Instrumented Pusher Assembly (IPA) for characterization of the in-bore phenomena within a gun tube. The tried and true method of measuring in-bore pressures is with the use of pressure gage ports in the gun tube. This method provides the ballistician with valuable data, however, it has its drawbacks. For instance, a finite number of pressure gages are used in various locations along the gun tube. When the pressures are measured they have to be combined and/or analyzed individually to determine the actual loads acting on the projectile. The IPA incorporates pressure gages in the base of the projectile and as it moves down the gun tube it is constantly measuring the loads on the projectile giving the ballistician a continuous data set of the load on the projectile. In addition the actual loads acting on the projectile are determined as opposed to loads on the wall of the gun tube.

The other advantage of the IPA is it can be used in a fielded gun system with no modification to the gun tube required. If pressure gage ports are drilled and tapped in a gun tube it becomes a test asset and it no longer has any value as a fielded system. With the IPA the in-bore environment of a fielded system can be measured and the system can be returned to the field.

In addition to the pressure measurements the IPA incorporated a high-g, tri-axial accelerometer to measure set-back and balloting loads, a low g accelerometer as a first movement indicator and a magnetometer to determine when the projectile exited the barrel. The IPA used a delay repeat encoder to capture data, after triggering via a g-switch data is captured for 40ms and then the data is transmitted via an s-band transmitter. The encoder is programmed to continually repeat the transmission of the 40ms of data for the duration of the flight.

A low-g accelerometer was utilized to determine first movement of the projectile and a magnetometer measured the earth's magnetic field to give an indication of when the IPA exited the gun tube. These data were used for calculations of the muzzle velocity and total in-bore travel for a validation of the data obtained.

INSTRUMENTED PUSHER ASSEMBLY (IPA)

The IPA is a self contained unit with batteries, sensors, supporting electronics and antenna, there are no external requirements for data capture. A ground station is required to record the data stream during the test. Figure 1 is an illustration of the IPA.

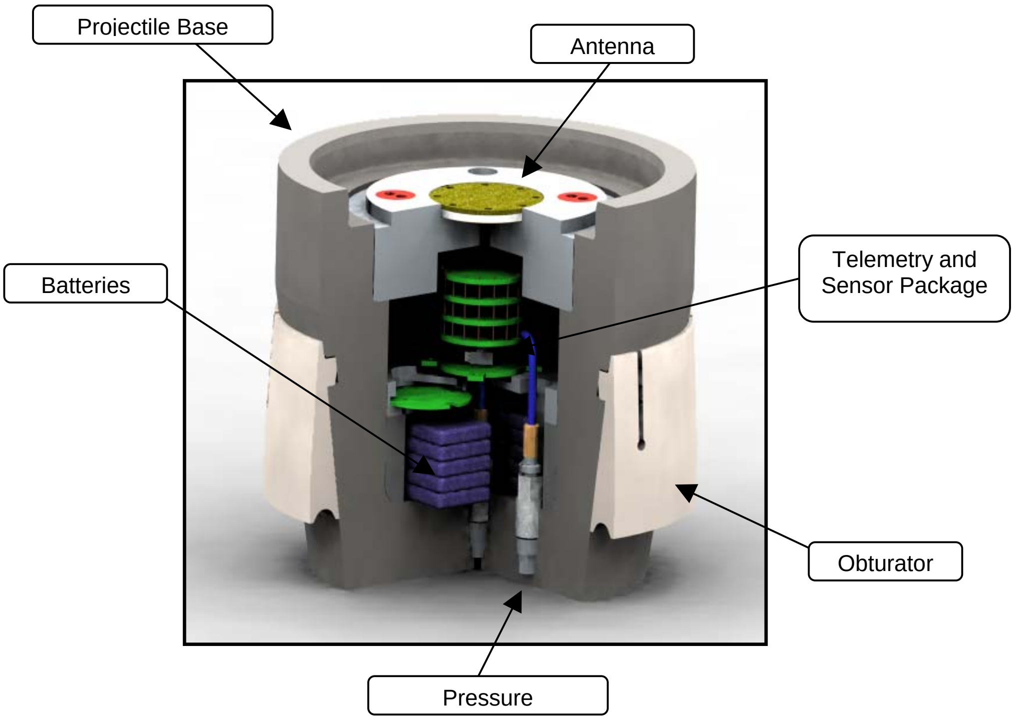

Figure 1 Instrumented Pusher Assembly

The telemetry and sensor package consisted of five custom printed circuit boards (PCB's) and one commercially available board. The five custom boards were an eight channel encoder, an instrumentation sensor suite, a tri-axial accelerometer board, a piezoelectric pressure transducer conditioning board, and a voltage regulator board.

The commercially available board was a 250 mW s-band transmitter available from M/A COM. Commercially available rechargeable lithium ion polymer batteries purchased from Kokam were used to power the system.

Instrumentation Sensor Suite (ISS)

The ISS board is a custom designed PCB developed at ARL for measurements of various projectile dynamics depending on the specific application [2]. The ISS contains a tri-axial magnetometer, an axial accelerometer, a dual axis accelerometer, an accelerometer ring and a temperature sensor. These sensors can be tailored for the specific application and test. For the IPA the sensors utilized were a low-g accelerometer as a first movement indicator and one axis of the magnetometer to determine muzzle exit time.

PCM Encoder

A PCM encoder was used to encode the various sensor inputs and put them in a single data stream for transmission to the ground station. The encoder was developed at ARL and the bit rate and function is programmable for each application [3]. For the IPA the encoder recorded eight analog channels at 833,000 samples per second with 12 bit resolution for 40 ms.

Pressure Gages and Conditioning Board

Commercially available PCB Piezotronics pressure transducers were used to measure the pressure on the base of the IPA. PCB Piezotronics supplies a signal conditioning unit for the pressure gages however, for obvious reasons, this was not a practical approach for the IPA. A custom designed signal conditioning board was designed that would supply a 20V constant current signal for the transducer excitation. Three pressure gages were used in the IPA, one was on the IPA axis,, one was offset 1" and the third was offset an inch however, it was a blind gage sealed from the environment, to detect artificial measurements due to acceleration.

Tri-Axial Accelerometer and Conditioning Board

Under contract with PEO-STRI with ARL as the technical lead Endevco Corporation developed a miniaturized, surface mount version of their commercially available 7270 accelerometer. Under the same effort the new accelerometer (Model 70) was mounted on a cube to create the model 73 tri-axial accelerometer [4]. The model 73 accelerometer was utilized to measure the setback and balloting accelerations the IPA experienced. A custom PCB was developed at ARL to provide the signal conditioning for the tri-axial accelerometer.

Voltage Regulator Board

The voltage regulator board was a simple circuit created with commercially available components for the regulation of voltage from the batteries to the various components within the IPA.

Transmitter and Antenna

The transmitter utilized was a commercially available 250 mW transmitter purchased from M/A COM. The antenna was a patch antenna developed by the U.S. Navy. A plastic cover plate was placed over the antenna to provide protection during handling and assembly.

RESULTS

During the development of their Advanced Modular Gun (AMG) AOT performed a test series and fired nineteen test projectiles at NSWC Dahlgren's Terminal Range. Of the nineteen projectiles two contained IPA's to collect in-bore data. Both IPA tests were successful and the measured chamber pressure obtained by the test range for the two tests was 98 ksi (675.7 MPa) and 101 ksi (696.4 MPa) respectively. The two tests were identical except the first one used a cardboard case to contain the propellant and the second test used a combustible cartridge case [5]. Both IPA's successfully transmitted the sensor data to a ground station for data analysis. Flight time of the projectile allowed the delay repeat encoder to send approximately eleven repeats of the data prior to impact of the projectile. Figure 1 is the raw data from one of the pressure gases showing the multiple repeats of data from the encoder. Several locations on the graph have minor data dropouts, the advantage of the delay repeat encoder is it allows for the reconstruction of data if there is a section that has a dropout of data, it can be taken from a different repeat with the time stamp to create a clean record, figure 1 is the data as recorded. The time scale on the graph is the time of flight, not data acquisition time. Data was recorded at 833,000 samples per second however, each repeat cycle is eleven times longer than the record cycle to match the RF transmission rate.

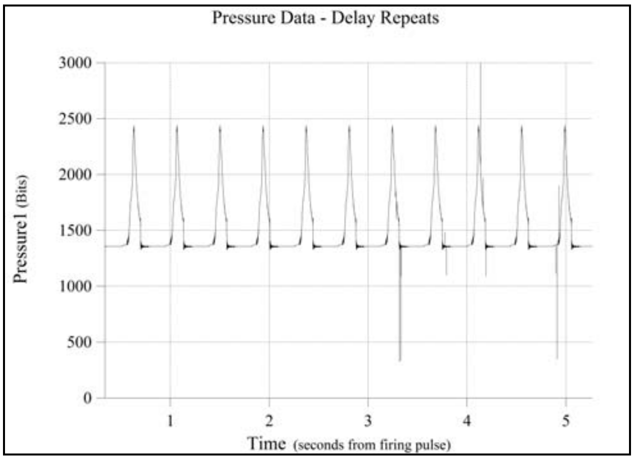

Figure 2 Raw Pressure Data Showing Repeats

Two pressure gages measured base pressure on the IPA and the blind gage showed negligible effects due to the acceleration. Accelerations were calculated from the two pressure gages, the mass of the projectile, and the surface area of the IPA using the basic formula's below.

$$F=ma \rightarrow a=F/m \quad (1)$$

$$F=PA \quad (2)$$

Substituting (2) into (1)

$$a=PA/m$$

Figure 2 shows the accelerations calculated from the pressure data compared to the measured acceleration data obtained from the Endevco accelerometer, the graph shows good correlation between the sensors

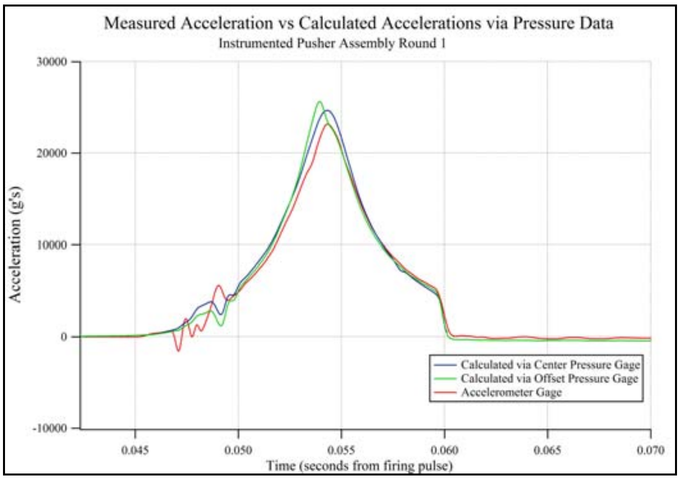

Figure 3 Measured Acceleration vs Calculated Acceleration

Using the muzzle exit time determined from the magnetometer and a single integration of the acceleration curve the velocity curve and muzzle velocity of the IPA was determined and is shown in figure 3. The calculated muzzle velocity was 1246 m/s whereas the measured velocity with radar was 1203 m/s which is within three and a half percent [5]. Figure 4 shows the double integration of the acceleration curve and the calculated gun tube length. Based on the exit time from the magnetometer the length of travel of the IPA was 6.59m and the actual length of travel was 6.70m [6].

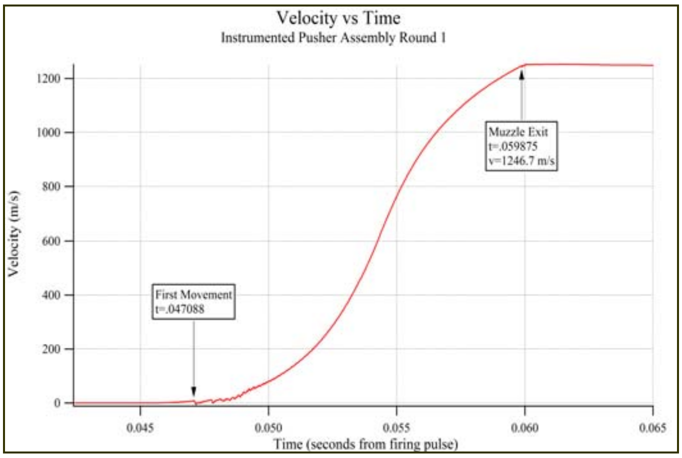

Figure 4 Single Integraton of Acceleration Data

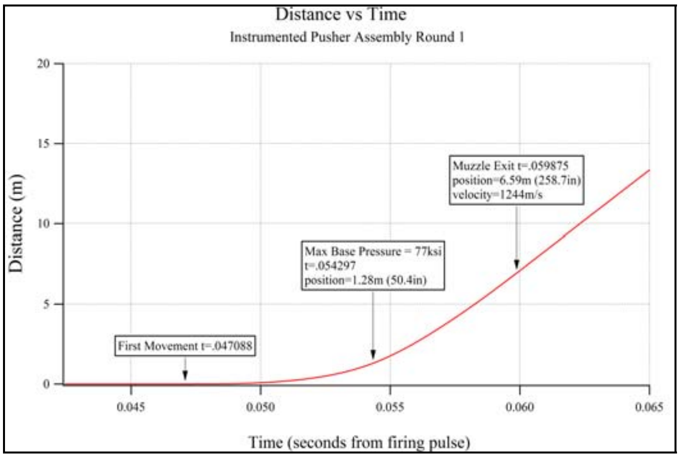

Figure 5 Double Integration of Acceleration Data

CONCLUSION

Two IPA's successfully obtained in-bore pressure and acceleration data for AOT's Advanced Modular Gun being developed under a Navy contract. The IPA's recorded and stored 40 ms of data and continually transmitted the PCM data stream to a ground station for data analysis. Eight channels of data (three pressure, three high-g acceleration, one low-g acceleration, and one magnetometer) were recorded. Calculated acceleration from the pressure gages compared well to the measure accelerometer data. Single and double integration of the acceleration data to obtain muzzle velocity and IPA travel compared well to radar data and measured travel.

The IPA performed and functioned as designed. In-bore data was collected that can be used by the interior ballistician to refine projectile design and propellant formulations.

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[1] At the time of development of the IPA AOT was an independently owned company. They have since be purchased by Science and Applications International Corporation (SAIC), SAIC news release, 28 Aug 06
[2] Davis, B. S., Inertial Sensor Suite, HSTSS/JAMI Symposium Proceedings, Denver, CO 27-29 Aug 2002
[3] Muller, P., ARL Encoder Development, HSTSS/JAMI Symposium Proceedings, Denver, CO 27-29 Aug 2002
[4] P. Peregino, E. Bukowski, Development and Evaluation of a Surface-Mount High-G Accelerometer, ARL-TR-3331, Sept 04
[5] Applied Ordnance Technology Inc. Test Report Barrel Joint Test Advanced Modular Gun, Navy Contract No. N00178-04-D-1025, Feb 2006
[6] Brian Schmidt, AOT, email conversation, 5 Jan 06