MINIATURE PENETRATOR (MINPEN) ACCELERATION RECORDER DEVELOPMENT AND TEST

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ABSTRACT

The Telemetry Technology Development Department at Sandia National Laboratories actively develops and tests acceleration recorders for penetrating weapons. This new acceleration recorder (MinPen) utilizes a microprocessor-based architecture for operational flexibility while maintaining electronics and packaging techniques developed over years of penetrator testing. MinPen has been demonstrated to function in shock environments up to 20,000 Gs. The MinPen instrumentation development has resulted in a rugged, versatile, miniature acceleration recorder and is a valuable tool for penetrator testing in a wide range of applications.

INTRODUCTION

The primary goal of the MinPen development was to modernize and miniaturize the acceleration recorder technologies used in penetration testing for a variety of applications. The interest in instrumenting small penetrators or minimizing installation concerns in larger weapon assemblies drives a continuing desire for miniaturization. In very high-g applications it becomes all the more valuable to keep size and weight down to insure electronics survival (Figure 1). The major goals of the MinPen acceleration recorder development are listed below.

(1) Minimize size and weight of the three channel acceleration recorder.
(2) Utilize micro-controller architecture for operational flexibility.
(3) Analyze component loads to verify survival to 30,000 Gs.
(4) Demonstrate acceleration recording capability to 20,000 Gs in gun testing.

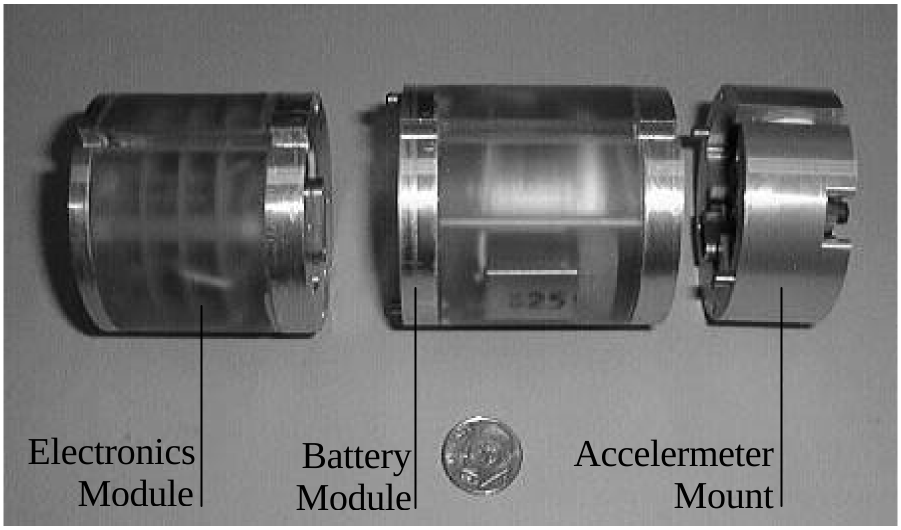

Figure 1: Photograph of MinPen Acceleration Recorder

The engineering approach used for the MinPen development was to build on the successes of previous high-g acceleration recorders developed in our laboratory over the years. The harsh environments involved at impact and in penetration testing justify a cautious, incremental development philosophy. Selection of electronic devices and associated package styles is subject to careful observance of the High Shock Electronics Design Guide developed over years of field test experience. These guidelines spell out preferred integrated circuit, and discrete component package styles for use in high-g electronics designs. The MinPen development is based on circuit designs used in previous acceleration recorders allowing the use of electronics devices which had been proven reliable. The MinPen design builds on technologies and field test experience used in DOE nuclear weapon development programs, DoD munitions and penetrator testing.

ACCELERATION RECORDER DESIGN

RECORDER SPECIFICATIONS

Penetrator designs must deliver high fidelity data for model validation and component characterization studies in harsh test environments. The operating requirements and specifications for MinPen are provided in Tables 1-3.

Accelerometer Channels:	
Number of Channels:	Three acceleration
Lowpass Filter (all transducers)	5-pole, Bessel
Measurement Bandwidth (3dB)	DC to 3,000 Hz
Sampling Rate (all transducers)	12,000 sam/sec/chan
Full Scale Range	± 35,000 Gs
Accelerometer Model:	Endevco 7270A-60K
Monitor Channels:	
Housekeeping Channels	4 voltage channels
Lowpass Filter	None
Sampling Rate	3,000 samples/sec/channel
Digitizer Section:	
Data Resolution	12 bits (17.09 Gs/cnt)
Memory Capacity	32,768 samples (16 bits wide)
Data Window:	Pre-Trigger: 170 msec (min) Post-Trigger: 340 msec (min) Total: 683 msec
A/D Input Range	0 to 4.096V
Storage Algorithm	Circular Buffer Operation Pre/Post Trigger Setting Programmable

Table 1: Data Acquisition Specifications for MinPen

Input Power Voltage	+13V to +15V
Operating Current	100 ma
Operating Power	1.5 Watts
Primary Power Source	0.5 Farad Capattery (Evans # RES160504)
Standby Battery	LTC-7PN (two series)
Standby Current	0.5 ma
Data Retention Life	60 days

Table 2: Power Requirements

Operational Shock	axial: 30,000 Gs @ 1 msec lateral: 30,000 Gs @ 1 msec
Operational Temperature	0°C to +70°C
Storage Temperature	-40°C to +80°C
Accelerometer Mounting Configurations	Two Interchangeable Mounts: 1. Three axial mounted gauges 2. Three gauges mounted in a triaxial configuration
Acceleration Recorder Weight	1.10 lbs.
Acceleration Recorder Materials	Headers and Accelerometer Mount: Aluminum 7075-T7351 Potting Material: Hysol RE2039 & HD3561 – Unfilled Epoxy
Acceleration Recorder Dimensions	Assembled Package: ∅ 2.00” x 5.096” Electronics Pack: ∅ 2.00” x 1.866” Battery Pack: ∅ 2.00” x 2.300” Accelerometer Mount: ∅ 2.00” x .910”

Table 3: Environmental Requirements & Mechanical

ELECTRONICS DESIGN

The MinPen acceleration recorder is designed to digitize high speed transient event data generated in impact and penetration testing. A block diagram of the MinPen recorder is provided in Figure 2. The three major elements of any high-g instrumentation system are the power supply, transducers, and recorder electronics. The power supply is particularly vexing in high-g applications because the internal construction of batteries and high energy capacitors limits their survival in these environments.

The MinPen power supply is based on a Capattery, which is an 0.5 Farad capacitor developed for nuclear weapon applications. Their internal construction is rugged and has been demonstrated in high shock environments. The use of a capacitor to power the recorder introduces a testing dilemma. Since the capacitor can only power the recorder for about 1 second, it must be charged continually until launch time. Primary battery cells don't suffer from this limitation, but they are not rugged enough in construction for this type of application. In order to keep the Capattery charged prior to launch, an external power source is required. We can either supply power remotely or with 9 volt batteries embedded inside the penetrator case. Also, a data retention battery is required to keep the static RAM powered until the data is recovered. The Eagle Picher #LTC-7PN, which has been proven to survive very well in similar environments, will power the static RAM.

The transducers utilized in MinPen (or any instrumentation system) limits the quality of the data it produces. The Endevco 7270A accelerometer was chosen for several key reasons. First, they have high mounted resonance, offering the best opportunity to collect wide bandwidth data without exciting transducer resonance. Second, they are rugged and have been proven to survive in extreme shock environments. Third, since they are piezo-resistive, their frequency response extends to DC. This is particularly important in penetration tests with very long trajectories in soft soil or water. Fourth, they are small and lightweight.

The MinPen electronics implement a simple, stored data transient event recorder. The recorder is armed before launch and digitizes and stores data in a circular static RAM buffer waiting for the acceleration event to occur. Upon sensing the acceleration event, the recorder continues to digitize and store data for another 340 msec. It then powers down into data retention mode. Since the full memory is not over written after the trigger, at least 170 msec of pre-trigger data is retained in RAM as well. The data is retained in RAM until the recorder is recovered and the event data is transferred into a lap top computer. The data retention current for the recorder is low and allows recovery of the data even months later. Since the electronics design is based on an 87C51 micro-controller, many of the record parameters are software programmable, allowing for flexibility in deployment and data recording needs.

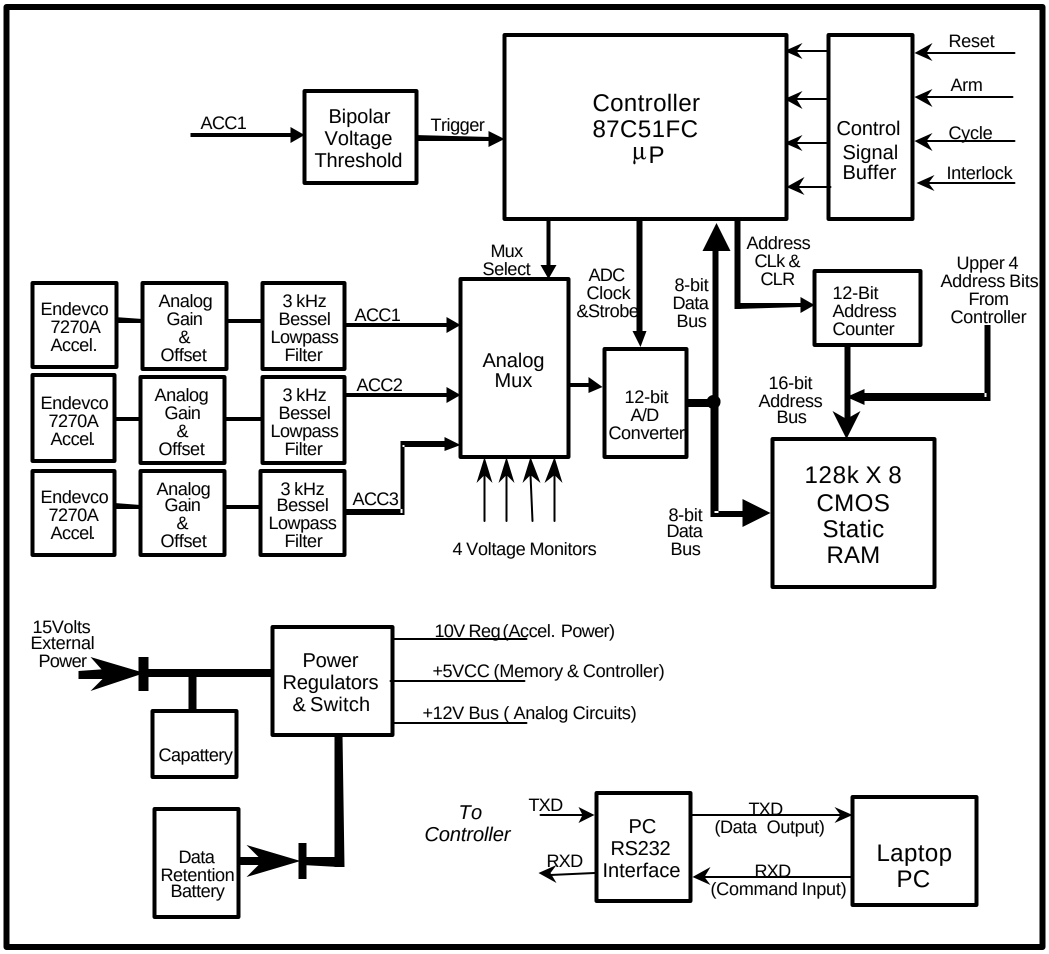

Figure 2: MinPen Block Diagram

MECHANICAL DESIGN AND ANALYSIS

The mechanical packaging, design and analysis of the MinPen acceleration recorder is based on experience with high-G instrumentation systems. Knowledge gained from past history was extremely valuable in the design of the MinPen acceleration recorder. MinPen was designed to measure penetrator deceleration to 30,000 Gs as compared to previous maximum levels of 10,000 Gs. Don Longcope, Sandia National Laboratories, developed 2-D and 3-D models of the acceleration package for both launch and impact conditions. His results indicate a safety factor of over 2.5 for the high impact epoxy encapsulant surrounding the electronic components. His analysis showed the stress in the encapsulant could be reduced significantly by reducing the gap around the instrumentation package and the penetrator.

Refer to Figure 3 for a detailed look at the MinPen acceleration recorder. The mechanical design followed the guidelines outlined in the High Shock Electronics Design Guide developed by department 2664, Sandia National Laboratories. Our approach was to design a small, lightweight, rugged and highly reconfigurable system. The recorder is comprised of three subsystems; the Electronics module, the Battery module and the

Accelerometer mount. The Battery module contains the Lithium keep-alive batteries, which are limited life components and must be replaced periodically. The Accelerometer mount can be designed to meet any customer needs. Currently we have 2 designs; a triaxial mount with 3 gauges mounted in a triaxial configuration and an axial mount with all three gauges configured to record axial loading. All interconnections between modules are accomplished using ITT Cannon Micro-D (MDM) connectors.

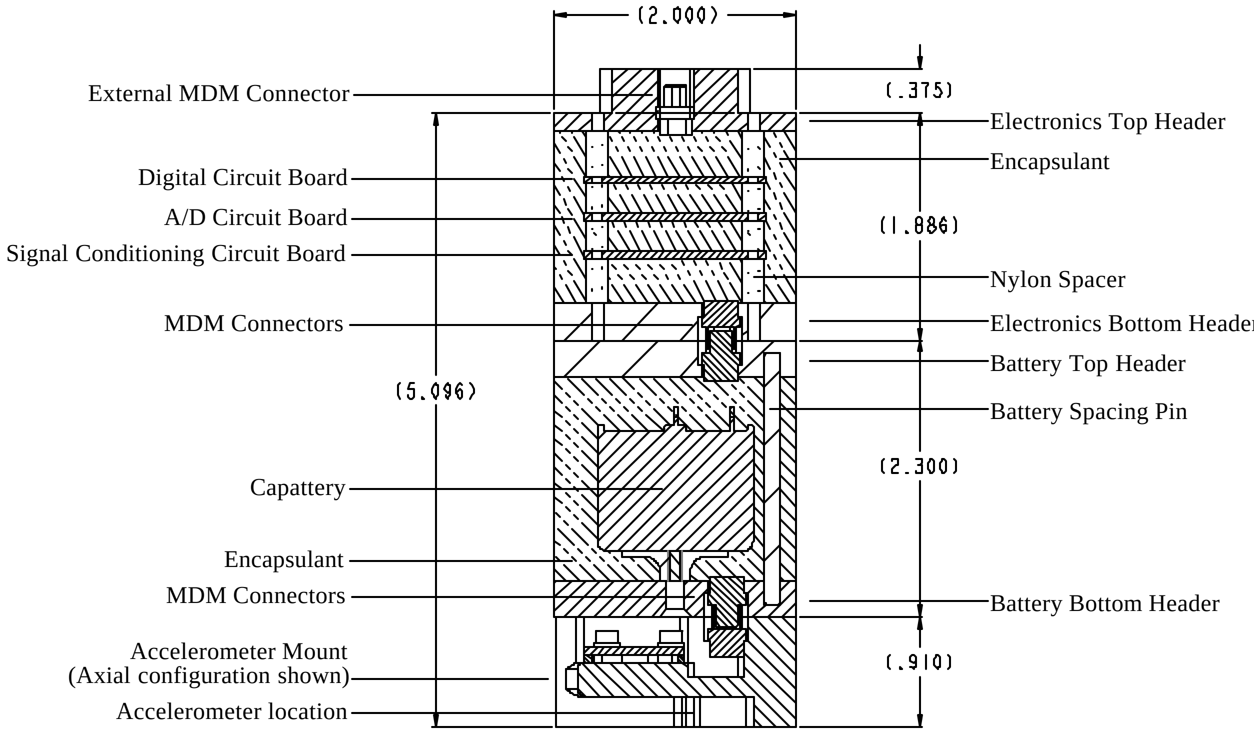

Figure 3: Cross-section of MinPen Acceleration Recorder

MECHANICAL ASSEMBLY AND PROCESSES

ELECTRONICS MODULE

The three circuit boards are coated with a Polysulfide rubber sealing compound to protect surface mount components during the encapsulation curing process. The circuit boards are stacked together using nylon spacers and temporary attached to aluminum headerplates. All internal wiring is completed and secured prior to encapsulation. Circuit board to circuit board connections are by way of slide wires which interconnect all three boards. The potting mold is sprayed with a release agent to assist with the removal of MinPen after the curing period. The recorder is slid into the potting mold, the epoxy resin (Table 3) is poured into the electronics module through two holes located in the top headerplate, and lastly the assembly is placed in a vacuum for approximately 30 minutes to remove air trapped inside assembly. After a 24 hour cure period, the assembly is removed from the mold and screws holding the circuit boards together are removed.

BATTERY MODULE

The top and bottom headerplates are pinned together to control final module thickness. The Capattery and Lithium keep-alive batteries are bonded into a phenolic (G10) saddle and attached to the bottom headerplate. All internal wiring is completed and secured prior encapsulation. The Battery module is potting using the same process described for the electronics module.

ACCELEROMETER MOUNT

A thin layer of 5–minute epoxy is applied to the underside of the accelerometers before installation. The accelerometers are attached and screws are torqued between 6-10 in lbs. Accelerometer wires are routed and secured in channels cut in aluminum housing using a flowable Silicon Rubber (3140 RTV, Dow Corning). Connector wiring is completed and secured to circuit board using same process for accelerometer wiring.

PENETRATION TEST APPLICATIONS

PENETRATION FIELD TEST SETUP

The MinPen acceleration recorder is designed to operate with minimal support equipment in remote test areas. Only a small interface box and laptop computer are required to initialize the recorder for the test or to download and plot the data after the unit is recovered. The micro-controller serial port in MinPen allows for computer control and data recovery using one full duplex RS-232 interface. The MinPen control functions are implemented on the laptop with a Windows based screen interface that allows user friendly interaction with the recorder. Graphical display and data reduction are available in the field with data plots available minutes after recovery of the recorder. All of the equipment is battery powered and can easily be operated from the back of a minivan.

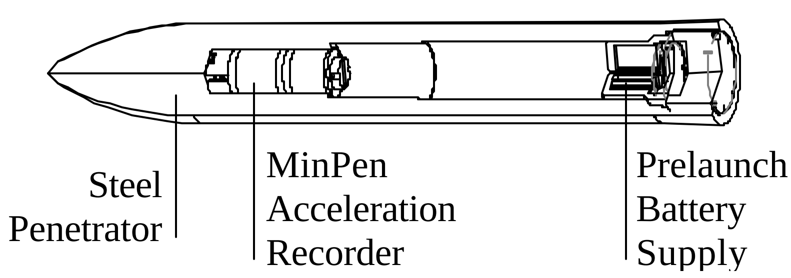

Figure 4: MinPen secured inside Penetrator

PENETRATOR ASSEMBLY PROCESSES

A generous amount of grease (Molykote 55, Dow Corning) is applied to the outside and front surface of the acceleration recorder prior to installation into penetrator. This grease fills the small gap between the acceleration recorder outside diameter and the penetrator's inside diameter and also acts as a high frequency mechanical filter. The assembly is installed in the front end of the penetrator as shown in Figure 4. The package is compression loaded into the penetrator case at 3000 lbs. A steel locking ring is threading into the penetrator and secured onto the aft face of the acceleration recorder. The compression load is removed from the recorder and the package is secured and ready. Four 9 volt Lithium batteries are installed into the aft battery housing and secured using a steel locking ring. Wires from the acceleration recorder are spliced with the aft batteries to power MinPen prior to launch. A large threaded ring is installed providing a barrier from the high pressure gun blast.

PENETRATION TEST DATA

The MinPen acceleration recorder was tested in a series of high velocity concrete penetration tests (Midscale 1, 2 and 3). The impact conditions for a representative test (Midscale 2) are described in Table 4. The photographs in Figure 5 show the concrete target before and after the penetration test of Midscale 2.

Impact Velocity (Measured by gun)	3425 ft/sec
Impact Velocity (Recorded by MinPen)	3320 ft/sec
Impact Angle	90° (head on)
Penetrator Weight	79 lbs.
Concrete Target	18 feet thick (5500 psi)
Penetration Depth	15 feet
Peak Axial Acceleration (Recorded)	20,000 Gs

Table 4: Penetration Test Parameters in Midscale #2

Figure 5: Target Setup (Before and After)

In spite of the extreme environment in this test, MinPen accurately recorded the launch and penetration events. MinPen continued to be fully functional in following tests in the series. With over 3000 ft/sec velocities, the penetrator case can bend and deform, requiring the acceleration recorder to be cut out. A data plot of the axial acceleration data from Midscale 2 is provided in Figure 6. This data recording has been carefully analyzed by the penetration test engineers and verified to represent a very high quality time history of this severe event. Our integration cross check with measured impact velocity (Table 4) offers an independent verification of the signal calibration and provides very good agreement in this and other MinPen test applications.

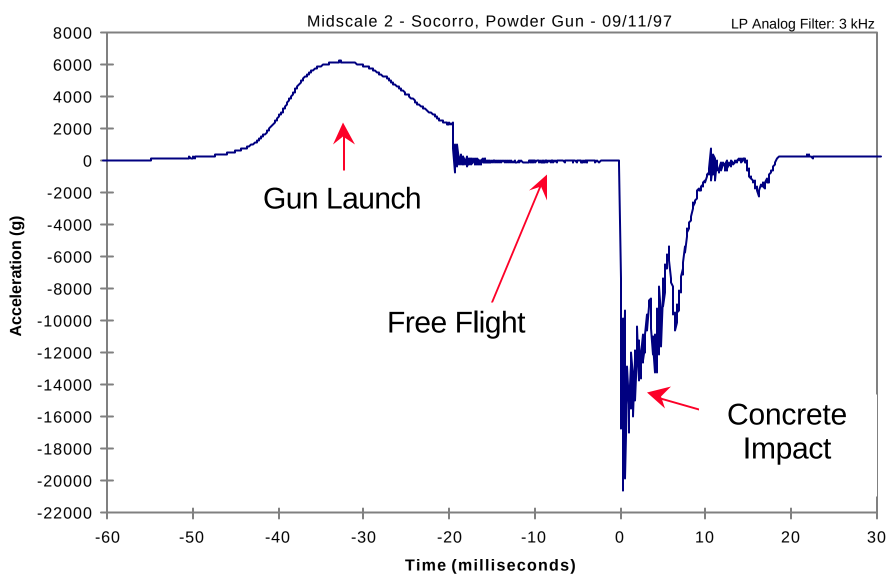

Figure 6: Midscale #2 Axial Acceleration Record

CONCLUSION

The MinPen acceleration recorder was developed to instrument a wide range of penetration and impact tests in extreme environments. This development was carried out with careful attention to lessons learned in past years. Only the most rugged electronic and mechanical components were used, and assembly techniques are closely controlled. Stress analysis of each mechanical sub assembly was performed at the maximum anticipated impact loads, providing confidence in the survival of the mechanical packaging. MinPen has successfully recorded numerous penetration tests and is currently being used on several ongoing test programs. MinPen will be a critically important tool for future penetration testing at Sandia National Laboratories and continues to live up to high expectations.

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