BALLISTIC RAIL GUN – SOFT RECOVERY TECHNIQUE

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ABSTRACT

The ARDC 155mm Ballistic Rail Gun Test Facility permits the soft recovery of a test projectile and its payload after subjection to an actual gun launch environment. High G hardening and testing of various electronic and mechanical components can be conducted by use of this system.

This paper will discuss the conception, operation and reliability of the Ballistic Rail Gun, and the advantages and limitations of its use in qualification of components.

Also discussed will be the development of a novel radar technique to determine muzzle velocity for Rail Gun tests, and a separate telemetry system for characterizing in-bore (acceleration) and in-rail (deceleration) environments.

INTRODUCTION

The development of projectiles incorporating guidance, sensing systems, or sophisticated mechanical or electronic devices created the need for an apparatus to conduct studies of the dynamic performance of such systems or their components. One method involves subjecting the mechanical, electronic, or optical devices to the full-up gun environment by firing them from a weapon in a suitable carrier. Upon recovering the carrier projectile, a diagnosis could then be performed on the test components.

In the last few decades, a variety of techniques have been employed for recovering projectiles with minimal damage such as:

Vertical recovery into a plowed dirt field
The use of coastal water as a recovery medium
Parachute recovery.

During the last 15-20 years numerous types of apparatus have been designed to provide for projectile soft recovery one of which is the ballistic rail gun. Honeywell Inc. was the first to design and build a ballistic rail gun soft recovery test facility and has been successfully using this facility since 1971. Since that time, a single caliber facility has been constructed at ARDC, Dover, N.J. (1974) and a multicaliber facility at BRL, APG, Maryland.

DESCRIPTION OF OPERATION

The Ballistic Rail Gun at ARDC permits the soft recovery of a test projectile within 104 feet after being subjected to the actual gun launch environment. Projectiles are fired from a standard 155mm Howitzer into a captive water/rail deceleration system for a closely controlled soft recovery. Tests may be performed on complete 155mm shell bodies, sub-missile, fuze, S&A, guidance system or other components which may be carried within standard or special 155mm shell bodies; the limitation being that the test projectile must be fitted at its front end with a special concave hemispherically shaped water scoop which effects the transfer of projectile energy into the water deceleration media. Gun tubes are available in both 1-20 and 1-25 twist; variations of propellant charges and projectile weight and obturation may be used to duplicate given parameters of velocity, G loading, and spin.

The M1A1 cannon and M6 recoil mechanism are mounted on a massive concrete pedestal that eliminates gun movement other than straight line recoil, the gun is fixed at an angle of five minutes depression. The four steel constraining rails and water trough, and their supporting structure are mounted rigidly on top of a 104 foot long concrete beam; the near end is supported on a jack and saddle hung on the muzzle end of the gun pedestal to maintain the beginning of the rail system in alignment with the gun axis, the far end is carried on jacks set on a heavy concrete footing. Normally, the beam and rail system is also set at five minutes depression which equals about 2 1/4 inch increase in water depth over the length of the trough; the far end jacks may be adjusted to change the effective water gradient, if the deceleration is to be increased. Frangible (balsa wood) dams are used at midpoint and three-fourths positions for a stepped water level. A balsa wood dam is always used at entry point of the rail/trough system to start deceleration with the scoop entering one-quarter inch of water, another dam at the far end permits the projectiles remaining energy (approximately 30 fps at zone 7) to be absorbed by crushup of paper honeycomb in the five foot overrun end of the rail.

The design objective of the soft recovery is to stop the projectile in a controlled and gentle manner without the introduction of forces which act along axis other than those seen by the projectile during the test or launch environment. Of primary concern in that the resolution of forces between the projectile and the stopping medium act along the axis of motion or that the projectile be constrained to a linear path and the component of the force acting along any other axis be kept to a minimum. If the projectile is constrained to a path and allowed to deviate from this path by no more than one percent of its total length, the constraining force required to maintain this attitude is quite small.

In order to reduce the severity of balloting that may occur in the recovery system to an acceptable level, it is necessary to remove the rifled rotating band material from the projectile body. The band acts as a fulcrum, and the more band material present, the greater the looseness of fit and side-to-side motion about this point. The rotating band material is machined off, just as the projectile emerges from the weapon muzzle, by means of a cutting or stripping device. This device basically consists of twelve tempered steel teeth evenly spaced in a housing which is fitted to the weapon muzzle. On firing, this stripper removes the rotating band to a diameter .015" above bourellet diameter. The rails are held to a tolerance of .025" minimum to a maximum of .100" above bourellet diameter, and the axis of the rail system was set up within a maximum deviation of 1/8" from coinciding with an extension of the gun tube axis. Balloting or deviation of the projectile from a straight path has a maximum value of approximately one-half of one percent of the bearing length of a standard projectile on the rails, this is considered an acceptable level. A removable gate at the end of the overrun section permits the projectile to be removed after completion of the shot.

As mentioned previously, the deceleration needed for the soft recovery of the projectile is accomplished by converting the impulse of the projectile into the momentum of the water in the trough that is ejected forward on impact. This can be expressed as follows:

$$F_p (\Delta t) = M_w (V_f - V_o) \qquad (1)$$

Where:

F_p = Axial force on the projectile
Δt = Time increment over which the force acts
M_w = Mass of water acted on
V_f = Final velocity of the water
V_o = Initial velocity of the water.

The mass of water ejected forward by the scoop during Δt can be expressed as:

$$M_w = (A_w)(V_p)(p)(\Delta t) \qquad (2)$$

Where:

A_w = Cross sectional area of water interacting with the scoop.
V_p = Projectile velocity
p = Density of water, or water and anti-freeze.

Substitution of equation (2) into (1) gives:

$$F_p (\Delta t) = (A_w) (V_p) (p) (\Delta t) (V_f - V_o)$$

or

$$F_p = (A_w) (V_p) (p) (V_f - V_o) \qquad (3)$$

The velocity of the water prior to impact is zero. Water enters the scoop at a velocity equal to that of the projectile. Neglecting the small drag due to the scoop surface, it will exit the scoop at the same velocity. However, the projectile is also moving at that velocity, so that the total exit velocity of the water is twice that of the projectile, thus:

$$F_p = (A_w)(V_p) (p) (2V_p) = 2pA_wV_p2 \qquad (4)$$

The differential equation for the motion of the projectile in the water can then be expressed as:

$$M_px = 2p\ A(x)\ x^2 \qquad (5)$$

Where:

x = Projectile deceleration
M_p = Projectile mass
x = Projectile velocity
A(x) = Cross sectional area of the water contacting the scoop at impact, as a function of projectile displacement.
x = Projectile displacement within the recovery system at the time, t.

INSTRUMENTATION

Sophisticated instrumentation techniques for the ARDC Ballistic Rail Gun have been slow in developing due to a lack of funding. However, radar and telemetry have been two techniques under investigation for the past few years.

From its inception, the Ballistic Rail Gun has been utilizing a Wheatstone bridge strain gage for recording chamber pressure versus time with excellent results. The data is recorded on magnetic tape and then played back on a standard oscillograph. Attempts to measure muzzle velocity by laser and magnetic pick-up have met with intermittent success because of interference from vibration and water. High-speed photography has also been utilized but is not capable of recording all the necessary parameters. Honeywell Inc. has used successfully for a number of years an on-board digital recorder for measuring such parameters as axial acceleration and strain and Aberdeen Proving Grounds has been successful with recording in-bore data by means of telemetry.

The Test & Instrumentation Division of TSD, ARDC has been in the process of developing a radar technique for measuring muzzle velocity and a telemetry system for the acquisition of in-bore and in-rail data.

The former utilizes a KU band doppler radar accurately positioned to one side of the weapon. The beam is directed to a point just forward of the muzzle and then reflected down the barrel by means of a steel supporting plate at the bell-mouth of the rail system. The beam then impinges upon the concave surface of the water scoop and is reflected back out the barrel to the supporting plate and then returned to the transmitter. By accurately locating the transmitter and then determining the angle between the radar beam and axis of the barrel, good results have been achieved for in-bore data and muzzle velocity.

Efforts by the Telemetry Branch at ARDC to acquire in-bore data have been successful from the outset. A ten channel FM/FM telemetry system is used to monitor various functions of a projectile and its associated components. The transmitter is housed in the forward end of the carrier projectile and linked to the scoop antenna by a connector mounted in the base of the water scoop. Initial attempts at data acquisition utilized a scoop with a stub antenna located at the base of the concave surface. The receiving antennas, located forward of the muzzle, were able to successfully acquire in-bore data. However, upon interaction with the water, the stub antenna is destroyed. A new scoop was subsequently designed in which the tuned antenna was wrapped around an undercut area on the outside cylindrical surface of the scoop. This design proved to be successful in acquiring both in-bore and in-rail data and left the antenna undamaged. Two water scoops of this design were fabricated: one from a high strength alloy steel and, one from a titanium alloy with strength characteristics similar to the steel. The purpose of the titanium was a 40% reduction in scoop weight thereby increasing the amount of test componentry that could be housed in the carrier projectile.

Telemetry is associated with the Ballistic Rail Gun not only as a means of instrumentation but also as a tool for qualifying telemetry systems. Many artillery projectile and missile programs rely on telemetry for in-flight data acquisition when conducting test programs at the various proving grounds. All systems designed and built by the Telemetry Branch at ARDC are fired in the Ballistic Rail Gun for high G survivability.

RELIABILITY

The Ballistic Rail Gun at ARDC has been in existence since 1974 with 500 firings to its credit. Extensions have been added to the standard carrier projectile, both forward and aft to accommodate in-house work as well as commercial requests with no adverse effects to the weapon or deceleration system. Only recently has the first damage been incurred as the result of an active telemetry firing. The projectile was assembled with the titanium scoop (wrap-around antenna) and fired with a zone 7 plus propelling charge. Shortly after entering the water/rail system, the scoop failed for no obvious reason. The extreme balloting that resulted caused appreciable damage to the rail but nothing that can’t be repaired within 3-4 weeks. The loss of the water scoop negated the energy transfer resulting in the projectile breaking through the gate at the far end of the rail. An investigation is underway to try and determine the cause of scoop failure.

CONCLUSIONS

The Ballistic Rail Gun soft recovery technique is an effective and relatively inexpensive tool for subjecting test components to an actual gun launch environment. Subsequent to the controlled recovery a diagnosis can then be performed on the undamaged test components. Substantial savings can result from using this facility rather than conducting extensive test firing programs at one of the proving ground facilities.

Although the telemetry and radar techniques show tremendous promise, there is still work to be done in the area of transmission in view of the scoop failure. The wrap-around antenna design proved to be the most effective means of transmitting through the steel rails and water; however, a redesign may be necessary if a replacement is to be fabricated from a titanium alloy. Measurements of the behavior of the projectile and its components during in-rail travel are required to characterize the projectile behavior so that this environment is known during analysis of test results. Efforts concerning all aspects of the data acquisition process are being addressed as expeditiously as possible.