SOFT RECOVERY SYSTEM FOR 155MM PROJECTILES

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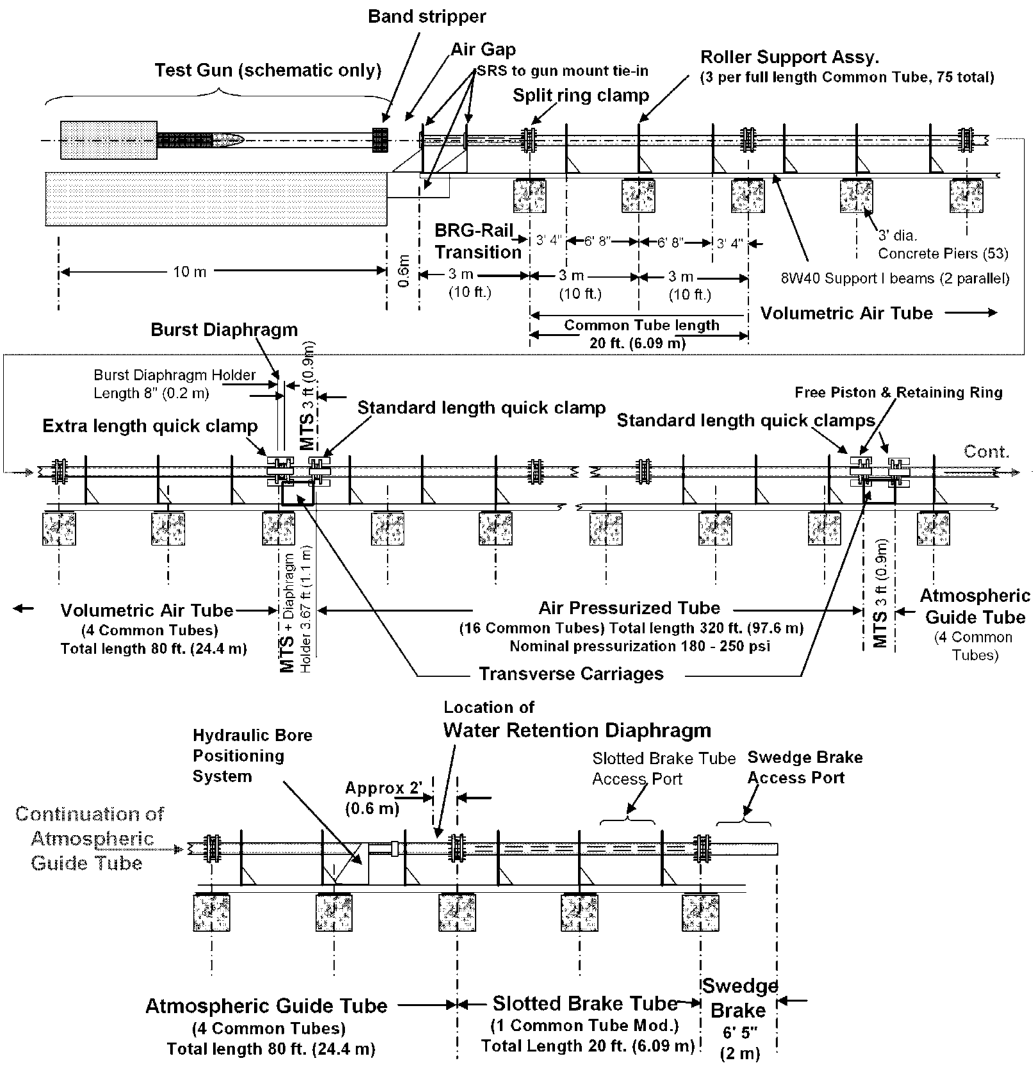
For smart projectile developmental efforts, the US Army has constructed a soft recovery system (SRS) that soft-catches controllably within less than 300 m, without exceeding an axial deceleration rate of 1,600g and transverse accelerations of 500g, unmodified 155-mm projectiles fired at up to 1000 m/s. The concept entails aerodynamic deceleration of the projectile in a long tube that is aligned with the gun barrel but not attached to it. The midsection of the tube is bound between a diaphragm and a free piston and is pre-pressurized to about 1.5 MPa. As the projectile enters the tube, the shock wave preceding it ruptures the diaphragm and the projectile decelerates as high pressure builds between it and the free piston. The piston disengages and travels forward into a section containing air at one atmosphere and partially filled with water. The water scooped in front of the piston effectively increases the piston's mass. The escaping water/air mixture effectively disperses the energy absorbed from the decelerating projectile. The projectile exits the tube with a velocity of about 10 m/s it and is caught in an air-bag arrangement. Special engineering features of the facility include quick acting clamps for inserting the diaphragm and free piston, a quick-open catching arrangement, and a suspension system allowing quick tube realignment and free expansion or extension of the entire tube assembly. The design provides a minimum cost per test facility allowing the complete launch testing of full operational configurations.

THE SRS CONCEPT

The general concept of the SRS system was published before[1]. It is based on the ballistic compression principle. Unique to the concept is the incorporation of a water-controlled free piston in a decelerator tube. The outline of the system is shown in Figure 1. The principle of operation is as follows. The rotating band on the spin-stabilized 155mm projectile is stripped at the muzzle and the projectile enters, across an air gap, and via a rail transition-tube (BRG-Rail Transition) into the Volumetric Air Tube which is at atmospheric pressure. The shock wave that precedes the projectile ruptures the



General Specifications:

1. Overall length 160.1 meters from the gun muzzle exit to the end of the Swedge Brake
2. 26 Common Tubes are used
3. There are 75 Roller Support Assemblies in this configuration
   (the Swedge Brake is unsupported and the BRG-Rail Transition Section is supported by the SRS to Gun Mount Tie-in system)
4. 53 Concrete Piers are used in this configuration
5. 2 MTS sections

Figure 1. Outline of the SRS

Burst Diaphragm that holds pressurized air in the Air Pressurized Tube. When the shock wave reaches the Free Piston and reflects from it, the Free Piston overcomes its Retaining Ring that holds it against the pressurized air. The Free Piston then moves down the Atmospheric Guide Tube pushing ahead a growing column of water. The Free Piston, made of light material, is light enough so that initially it accelerates quickly and thus prevents high-pressure spikes from developing in the pressurized tube section. The water effectively increases the Free Piston mass with time and also adds frictional force due to the water boundary layer on the tube wall. The growth of the Free Piston mass and the added water friction retard the Free Piston motion and thus regulate the air pressure between the Free Piston and the projectile to a sustained level between 15 to 30 MPa. This pressure is sufficiently high to slow the projectile from 1000 m/s to 10 m/s within 100 m without exceeding the 1600g deceleration limit. The water and compressed air escape in the Slotted Brake Tube, and the projectile is stopped in the Swedge Brake tube. In operation of the SRS, the initial pressure and water mass are easily adjusted to allow fine control of the projectile exit velocity into the Slotted Brake Tube. The main expendable parts in this SRS concept are the Burst Diaphragm and the Free Piston.

NUMERICAL MODEL

A numerical model was constructed to simulate the transient flow fields generated in the SRS tube. The model consists of four separate zones linked by boundary conditions across the projectile, the Free Piston, two shock waves, and the exit plane. Figure 2 illustrates the four zones.

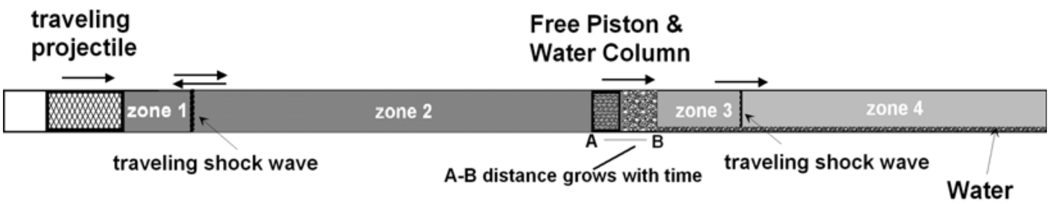


Figure 2. The Zonal Construction of the SRS Tube Flow

Zone 1 is between the projectile and the traveling shock wave that originally is generated by the supersonic entry of the projectile into the Volumetric Air Tube. Zone 2 is the region between this traveling wave and the Free Piston. Initially, the shock wave leading the projectile reflects back and forth between the Burst Diaphragm and the projectile. (The Diaphragm is located in zone 2, although not shown in Figure 2. The transient flow in the pressurized gas between the Diaphragm and the Free Piston initiates after the Diaphragm bursts.) The traveling wave may reflect a few times between the Free Piston and the projectile until the Free Piston has exited the atmospheric Guide Tube. In the numerical solution procedure, the decision to reflect the wave from either the projectile or the free piston is made when the thickness of zone 1 or 2 becomes less than 1% of the distance between the projectile and free piston.

Zone 3 is between the front of the water column and the traveling shock wave generated by the fast acceleration of the free piston. The water column thickens as the free piston sweeps the water layer ahead of it. The water column forms in front of the piston because the piston velocity is an order of magnitude greater than the water gravity wave (for wave amplitude that equals the tube diameter). Zone 4 is between the traveling wave and the exit into the Slotted Brake Tube. Zone 4 disappears when the traveling wave reaches the exit, and at this time zone 3 becomes the region between the Free Piston and the exit. Then zone 3 disappears when the front of the Free Piston enters the Slotted Brake Tube. Zone 2 disappears when the traveling wave between zone 2 and 1 reaches the Slotted Brake Tube, and at this time zone 1 becomes the region between the projectile and the Slotted Brake Tube. Figure 3 shows typical results of the simulation.

The time-dependent governing equations in each zone assume isentropic flow of a Noble-Abel gas with constant molecular weight, co-volume, and ratio of specific heats. Furthermore, the flow is assumed to be one-dimensional and inviscid, which of course neglects heat transfer to the tube wall. The one-dimensional treatment of the problem necessarily assigns a flat front to the projectile, a front that in reality is an elongated ogive. Obviously, boundary layer effects are not accounted for. In practice, the growth of boundary layers in the long sections of the tube will constrict the flow and modify the strength of the traveling shock waves. Intuitively, viscosity and boundary layer effects will tend to dissipate the wave motion in the tube thus resulting in lower peak pressure

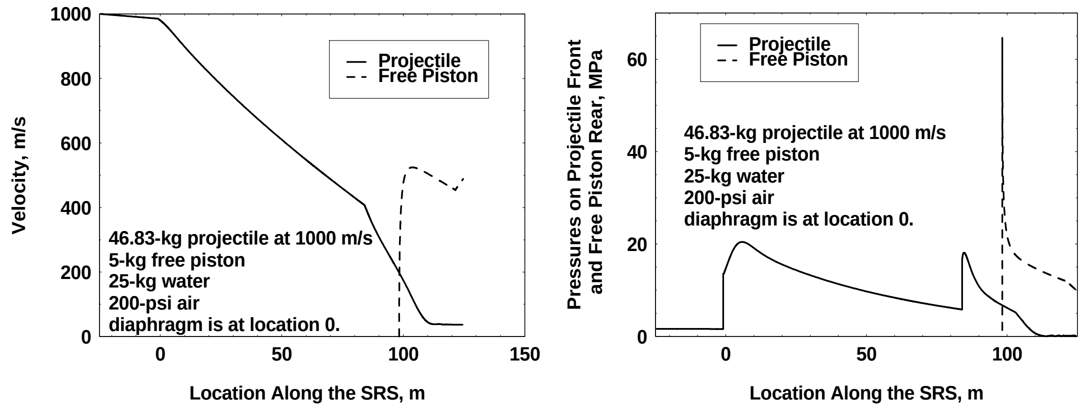


Figure 3. Typical performance of the SRS

loading (and hence deceleration) on the projectile. Thus, the simplified assumptions are likely to result in conservative peak pressure values. The numerical solution is based on the method-of-characteristics which to a great extent faithfully reproduces local wave motion without spurious numerical oscillations. For detailed equations and methodology refer to [1]. The present model incorporates the most important aspects of the flow physics and it is therefore adequate for the purpose of setting up the operational parameters for the initial SRS test runs. The reliability of the model is yet to be determined.

UNIQUE FEATURES OF THE SRS

The transformation of the analytical model into a working system was quite challenging considering the goal of maintaining low operating costs. The cost goal could only be realized if the device were able to be prepared for firing such that 3-5 firings could be performed in a 6 hour time frame. This goal has led to the near total automation of the system.

An interior ballistics calculation will be performed using the system's computer to determine the velocity of the projectile entering the catch system. Based on this the pressure and water depths are calculated and the operator chooses the proper water retention diaphragm and pressure level in the system. The water retention diaphragms are designed so as to preclude overfilling the system which would affect the catch operation.

The system incorporates a unique hydraulically operated tube retraction system to axially separate the tubes for maintenance and diaphragm replacement. The diaphragms are installed in a small section of tube known as the Multi-function Test Section (MTS) that is locked into the catch system using a hydraulically operated clamping mechanism. This mechanism is disengaged remotely by the operator prior to tube retraction from one of several control panels located along the length of the system. Once the clamps are disengaged, the tube can be retracted and the diaphragms replaced. Diaphragm replacement is facilitated by the location of the MTS on a small shuttle that can roll transverse to the tube allowing easy access.

Once the diaphragms have been replaced the pressurization of the pressurized section can occur as well as the filling of the water trough. Both of these operations can be controlled remotely from the master control station or one of the control stations located along the length of the system. Safety systems prevent the system from operating should one of these events not occur.

When the system is properly operated the projectile will stop in the recovery section. Should an error in the calculations occur or some malfunction take place, a novel braking mechanism which incorporates heavy steel plates that must be pushed vertically by the projectile ogive against commercial truck "air ride" dampers will stop the projectile.

The system was designed with maintenance in mind. Several novel features such as inspection bore "crawlers" containing cameras and sensors and cleaning "pigs" were developed to facilitate cleaning and upkeep.

INSTRUMENTATION

The system is completely instrumented with pressure and proximity transducers. This instrumentation allows the predictive models to be validated and the system firing models to be fine tuned to account for effects such as friction and gas leakage past the projectile. Although every 20 foot section of tube can be instrumented with sensors it is envisaged that in daily operation all of these sensors will not be used.

Test projectiles have been designed to track acceleration, nose, base and blow-by pressure. These devices will be used to characterize the system prior to operational use. In addition to these test projectiles cargo projectiles were also developed that will allow electronic devices to be tested without the expense of a complete tactical projectile in the same manner as current soft catch systems deployed by various nations around the world.

SUMMARY AND FUTURE PLANS

A novel soft catch facility is currently in the final stages of completion at the U.S. Army ARDEC, Picatinny Arsenal that will allow for testing and recovery of projectiles. This facility incorporates novel features and state of the art technology to maintain a low cost test bed for the advancement of smart munitions.

After characterization and operational use of the current 155mm system the site has been prepared for smaller diameter tubes that use the same technology. Five or more calibers can be accommodated at the current site; the next planned stage is a 120mm mortar variant.

REFERENCES

[1] A. Birk and D. E. Kooker, A Novel Soft Recovery System for the 155-mm Projectile and its Numerical Simulation, *US Army Research Laboratory technical report, ARL-TR-2462,* (2001).