A Fast-Acting, Self-Energized, Low-Cost Valve for Air Cannons

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Abstract

A novel pneumatic valve has been developed to control pressurized air for an air cannon. It offers very rapid opening time, is self-energized when opened, self-locking when closed, and is of relatively low cost. The valve uses a variation on the classic four-bar linkage which enables the valve to be self-locking against pressure when closed, yet self-energized and opens very rapidly when the valve mechanism is tripped. The valve has been tested and has been used in the field to test munitions fuzes.

Background

Air cannons have long been used for dynamic testing of electronics and mechanisms. These air cannons are used to simulate high-G environments such as artillery fire or high-speed impacts. They can also be used to propel electromechanical devices past objects of interest, such as testing munitions fuzes against specific types of targets. The use of air instead of chemical propellants greatly simplifies these kinds of tests and greatly reduces the cost of such testing.

The key component in any air cannon is the means by which the high pressure air is controlled. A very rapid rise in pressure is needed to accelerate the projectile to the desired muzzle velocity within the shortest possible barrel length.

The oldest means of obtaining a very rapid pressure rise is through the use of a burst disk. A burst disk is a membrane designed to fail at a specified air pressure and thus achieve a sudden release of air into the cannon's chamber. Burst disks are capable of controlling very high pressures and are usually designed with scoring or grooves that give fairly repeatable failure pressures.

The drawback to burst disks is that they must be replaced after each shot which is time consuming. High pressure burst disks are often precision machined elements which adds to the cost per shot. At lower pressures metal or plastic foils are employed; however, they tend to operate with less consistency and thus higher variations in projectile velocity.

More recently, electromechanical pneumatic valves have been tried in lieu of burst disks. These valves avoid the per-shot expense of burst disks but the initial purchase price of valves capable of handling high pressures can be quite high. Electromechanical valves also offer substantially longer pressure rise times than do burst disks and longer barrels are necessary unless some sort of retarding mechanism is used to hold the projectile in the chamber until peak pressure is achieved.

Requirements

In the spring of 2015 Electronics Development Corporation undertook the development of a 75-mm bore air cannon to be used for the testing of munitions fuzes. The design goal for the 75-mm air cannon is to propel a 1-kg projectile with a muzzle velocity of at least 75 m/s. It must use the shortest possible barrel length and be very easy to operate. Low cost, both for cost of acquisition and cost per shot is also a factor.

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It was decided that this air cannon should use a portable air compressor or “shop air” in the range of 400 to 800 kPa. Early experimentation with burst disks showed that metal foil disks yielded erratic results at these pressures and they tend to shed foil debris which causes serious problems for some types of electronic fuzes. Conventional electromechanical pneumatic valves were ruled out due to slow opening times.

Given the drawbacks noted above, Electronics Development Corporation elected to develop a novel type of pneumatic valve that offers fast pressure rise times comparable to burst disks yet be simple and inexpensive. This valve is self-locking against pressure when closed yet be self-energized when opening.

Design

The schematic design of the air canon is shown in Figure 1. Pressure is supplied by a 75 L pressure vessel with a 50 mm diameter opening. The valve inlet and outlet apertures are also 50-mm diameter. Downstream of the valve the aperture increases to 75-mm diameter for the breech and the barrel.

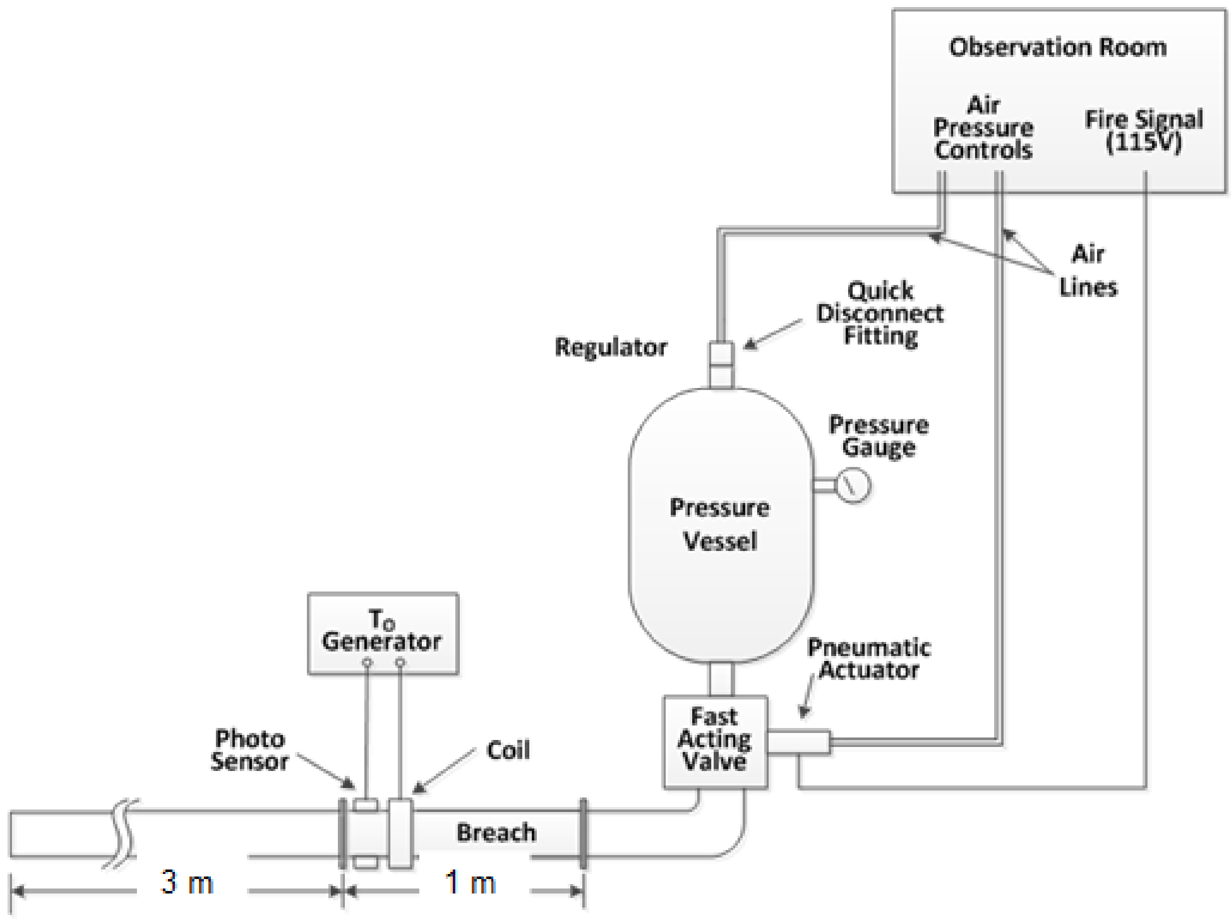

Figure 1: Schematic Arrangement of air cannon

The valve’s components are arranged as shown in Figure 2. The valve consists of an inlet and an outlet aperture, a flapper element, the flapper linkage, and an impact absorber. A pneumatic actuation cylinder and a trip lever are mounted on the rear of the valve and may be seen in Figure 3.

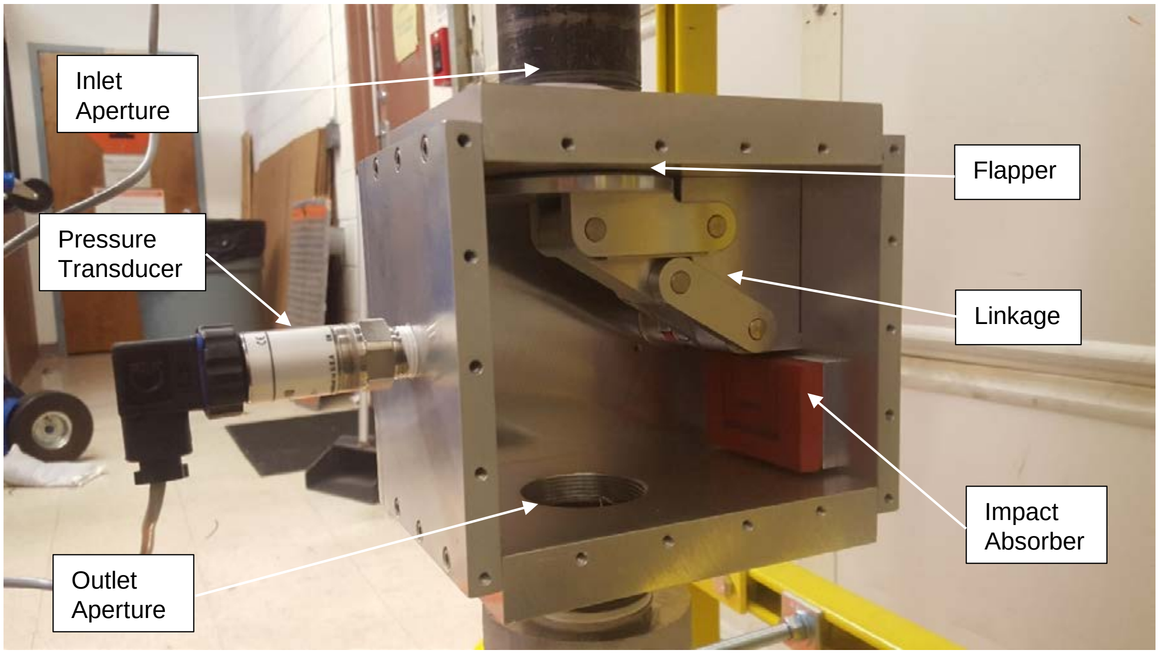

Figure 2: Physical arrangement of valve

In order for the valve to achieve the self-locking and self-energizing requirements a design variation on the classic four-bar linkage was chosen as shown in Figures 4 and 5. This linkage (a-b-c-d) goes over center (angle b-c less than 180^{o}) to lock against the pressure force but only requires a small external torque to trip

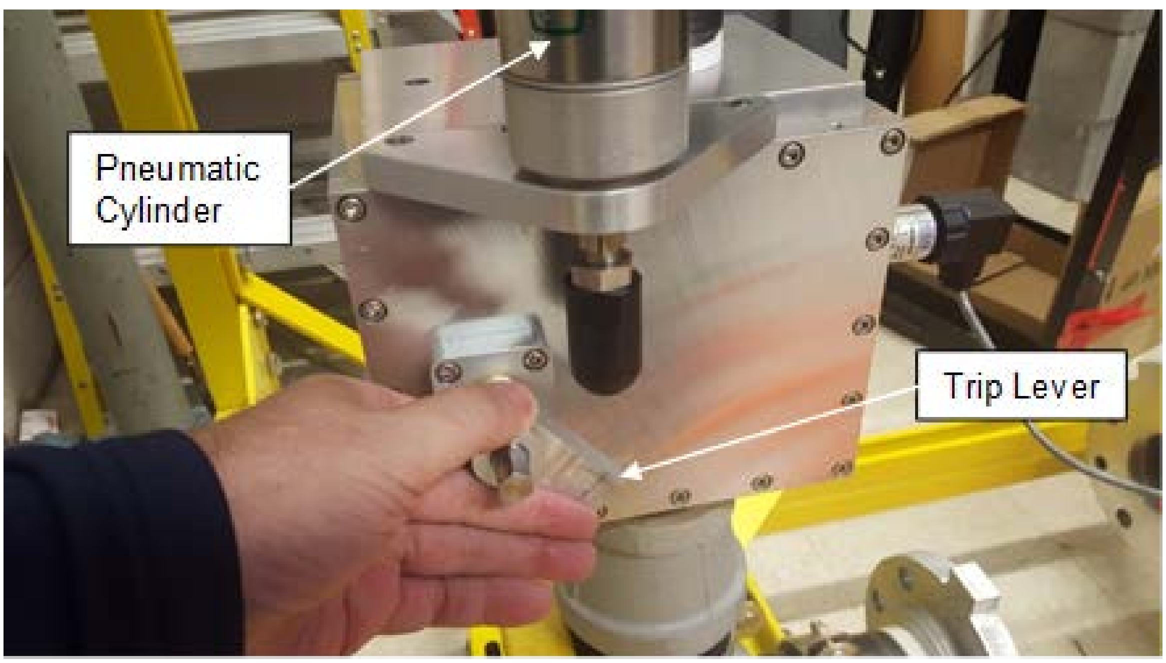

Figure 1: Resetting the valve

the mechanism out of the over center lock whereupon the pressure rapidly throws the valve open. An impact absorber is provided to stop the moving linkage when opened. If the over center angle is kept small very little torque is required either to trip the valve or to reset it. The torque to actuate the valve is supplied by a small pneumatic cylinder attached to the back of the valve. This version of the valve is simply reset by hand as shown in Figure 3.

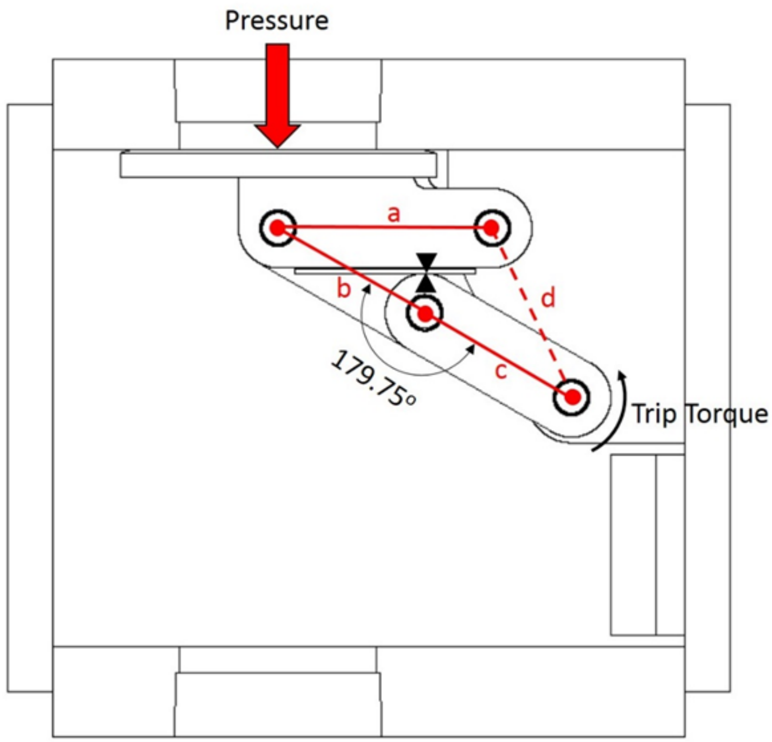

Figure 4: Valve in Closed position

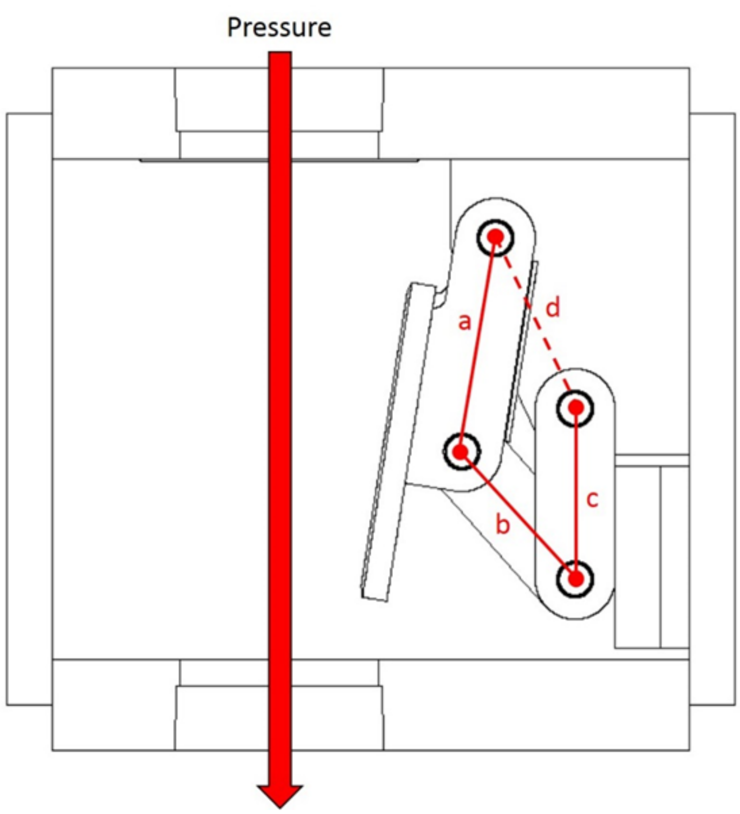

Figure 5: Valve in open position

Testing

A sample pressure curve is shown in Figure 6. Of note is the rapid pressure rise time of ~10 ms. While this is not quite as fast as a burst disk it is much faster than the majority of electromechanical pneumatic valves of similar aperture. The 75-L pressure vessel completely empties in ~200 ms.

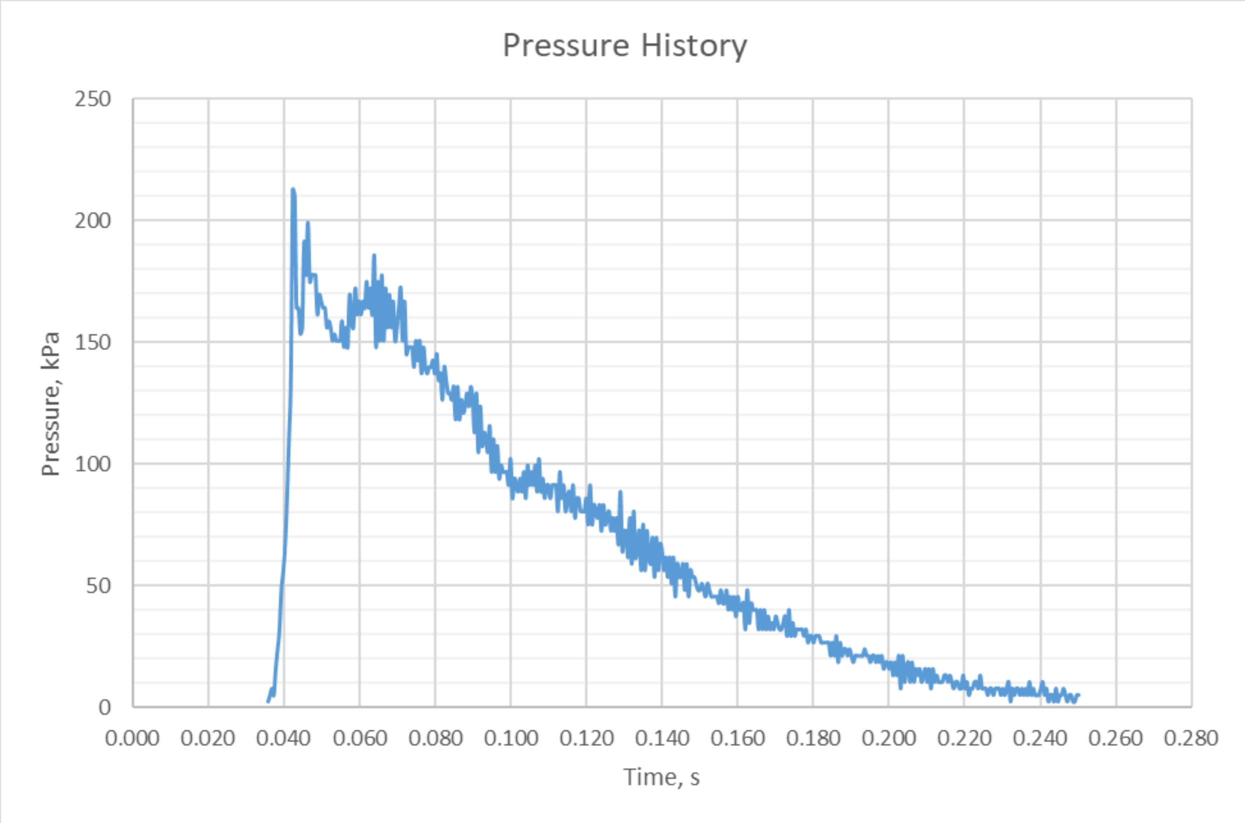

Figure 6: Sample pressure curve

Live fire tests with 1-kg dummy test projectiles showed that the desired muzzle velocity of 75 m/s is easily achieved at ~250 kPa pressures using a 3-m barrel. 100 m/s is possible using the full 400 kPa max operating pressure.

Field Use

The first field use of the finished 75 mm air cannon was testing prototype munitions fuzes by mounting them into test projectiles and shooting them past targets of interest. Figure 7 shows one of the test setups (note the barrel in the foreground.) This testing required hundreds of shots to be fired in as rapid a succession as possible. The valve held up extremely well with no misfires or other mechanical deficiencies. No adjustments to the valve were required throughout the testing.

Figure 7: Use in the field

Conclusions

The valve for the 75-mm air cannon has met or exceeded all requirements. The over center four-bar linkage is surprisingly robust, needing no adjustment over the course of hundreds of shots. The valve can be manufactured at a relatively low cost as the parts are simple and few tight tolerances are required.

It bears noting that this valve design is not limited to use on air cannons. The design is easily scalable and could potentially be used in any application which requires the rapid venting of a pressurized fluid.