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Estimation of Recoil Energy of Water-Jet Disruptor

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Abstract. Water is used as a liquid projectile in a disruptor for destruction of various dangerous objects such as improvised explosive devices (IED's). This weapon is light weight and experiences certain recoil during a firing action. As there is motion between a projectile and a barrel, a recoil is experienced by the weapon. The recoil of weapon works on a conservation of momentum equation which is based on Newton's second law of motion. A water-jet is created due to intense gas generation by a propellant burning inside the cartridge. The gas energy obtained by burning the propellant is responsible for pushing the projectile in a forward direction through the barrel. Due to gas generation by propellant burning, there is forward motion of the projectile. An attempt is made to determine the theoretical recoil velocity, its energy for the projectile in a water-jet application.

The minimum and maximum recoil velocities of a water-jet varies from 2.311 m/s to 2.611 m/s. The order of magnitude for the recoil velocities is small and can be compared with a recoil of small calibre weapons that these weapons experienced during a firing mode. Based on recoil velocities, minimum and maximum kinetic energies of recoil parts are determined as 3.73 kJ and 4.77 kJ, respectively. The maximum gas force experienced by the projectile is worked out as 13.46 kN. The minimum and maximum energies to overcome the resistance force are determined as 14.657 J and 18.711 J, respectively. A small exercise for spring design is also covered.
Keywords: momentum, water-jet disruptor, recoil velocity, recoil energy, gas force

1. INTRODUCTION

A water-jet disruptor has capability to destruct hazardous improvised explosive devices (IEDs) which constitute assembly of various parts having different role and function. It is vitally useful for destruction of suspected unknown samples. This device plays crucial roles for security operations at airports, railway stations, shopping malls, multiplexes, schools, colleges, universities, and all strategic locations. Besides armed forces also paramilitary forces can use it for their operational purposes. The main parts are: a power cartridge responsible for gas, the propellant in the cartridge case, barrel, and compensator for holding the water inside, projectile, sleeve and spring assembly for absorbing the recoil energy to a complete weapon. The weapon is either mounted on a portable tripod or deployed on a remotely operated vehicle (ROV). In the present case, the barrel diameter at the muzzle end is 20 mm and its length is 250 mm. The total mass of the weapon is 1.4 kg. The energy created by burning the propellant inside the cartridge creates water-jet in short duration. The projectile coming out of the barrel experiences a huge force due to a burning action of the propellant towards the intended target from the muzzle end of the weapon. This article explained about the recoil energy of the water disruptor related research work carried out on behalf of the Armament Research & Development Establishment (ARDE), Pune, India.

1.1. Aim of experimental and theoretical studies

The aim of this present research is to determine the recoil velocity and recoil energy for the disruptor's application. Experiments were conducted using a double base propellant for the cartridge.

1.2. Earlier studies

The recoil systems are used in the artillery weapons since their inception into the services. In general it comprises a gun, mounting structure, and its various accessories. The recoil system helps to reduce the mass during the firing. This brings the gun body in an original location.

For this ground, the gun designer, designs the gun with a heavy mass to evade a great recoil force. This takes more time to bring the weapon to its original location and be ready for the next firing again. The objective of recoil system is to absorb the recoil force in a firing mode [1]. The recoil effect and the related issues such as stability of guns are described in details [2, 3]. The stability conditions and internal ballistics for recoil pertaining to the water-jet disruptor and the recoil gun system of a general internal ballistic model of a gun propellant system was discussed by Radomski and Surma [4, 5]. The recoil shift is due to the finite mass of an absorbing body. It is true both in the small speed and relativistic limits and for the reflection of light from a low-mass mirror. Barnett reported that a total shift is perhaps more correctly viewed as simply a Doppler shift. However, that the relevant velocity is the average of the absorbing body before and after the absorption happened [6]. In the conventional armament systems, such as small arms canon and battle tank, the barrel is firmly attached to the main body. In a small arm system, the recoil force is transferred through the barrel and finally to the fireman during firing. Russell patented for a 7.62 mm gas-operated rifle small arm in a recoil reduction using the ADAMS Model [7]. With reduction in a recoil force, the accuracy of weapon increases effectively. Hajihosseinlo has investigated the performance of gun recoil pertaining to fighting an armament vehicle such as a tank gun. This was explained with the help of a theoretical model which predicts the recoil velocity [8]. Szmidt had reported comparison of the recoil of a conventional and an electromagnetic cannon [9]. Fedaravičius presented the recoil of a rifle with a LASER simulator for single, series of shots and for sound with the help of theory and experiments [10]. Lukáč has carried out the experiments to simulate the recoil of an assault rifle. These rifles were used to train the fireman or shooter in the professional manner to simulate the recoil [11]. Szmit *et al.* [12] have examined the recoil and weapons jump of a laboratory test stand using small arms. Weldon reported that the projectile in electromagnetic gun experiences the recoil when it is accelerated through a magnetic field [13].

1.3. Problem statement

A water-jet disruptor is employed as a weapon platform to destroy the suspected dangerous goods effectively and safely (Fig. 1). It consists of breech plug, cap closure (Top), breech module, spring, closure cap, barrel, sleeve, projectile, compensator, cap closure (Bottom) and capture gate. The barrel and compensator are filled with water as indicated in blue colour shown in Figure 1. The cartridge is loaded inside the breech module. An attempt has been made to determine the recoil velocity and recoil energy of a weapon using the momentum equation.

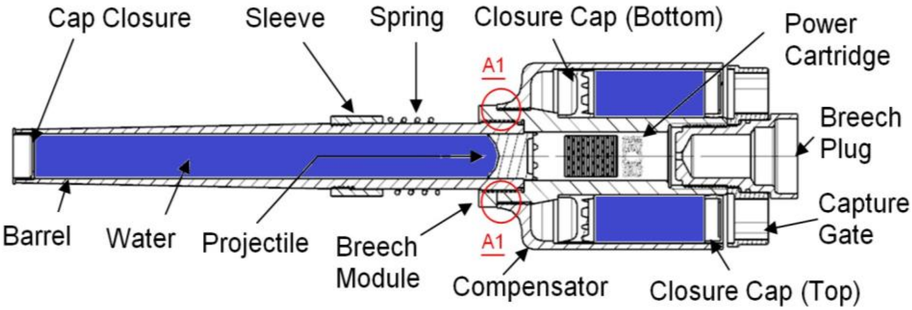

Fig. 1. A schematic 2 D view of a water-jet disruptor

The place where the friction takes place between the projectile and barrel is clearly shown at section A1-A1 in Figure 1 during its entire motion throughout the barrel. When two parts are in contact during the motion, the researcher tries to reduce the friction which is undesired. That is the reason why a nylon material is used as a projectile in this weapon to reduce the friction between two parts. Therefore, it is very essential to maintain a good surface finish of the barrel.

2. WORKING PRINCIPLE OF A WATER-JET DISRUPTOR

The water-jet disruptor works on Newton's third law of motion that states for every action there is an equal and opposite reaction. The cartridge is an electrically initiated from the battery source. As the power cartridge is fired, it generates the gases. The gas pressure acts on a projectile that is assembled in the barrel. The part of gas energy is used to propel the projectile and water from the barrel in a forward direction. The moment water comes out, it gets atomized in fine particles. The water jet and projectile both move together. Projectile white in colour gets camouflage with water droplets. During tracking by high speed, first projectile hit the target followed by water jet. The remaining gas energy passes through an annular hole of breech module and acts on the water inside the compensator. This causes to push the water from the compensator in a backward direction through a capture gate. This helps to counterbalance the forces acting in opposite directions. The water and projectile move in a forward direction with a high velocity. This high velocity water jet demonstrates to destruct the suspicious object. Such type of a disruptor aids to locate, handle, and destroy the hazardous objects safely. The water-jet disruptor can be used with a water charge, frangible or solid projectile. It has an inert tool, specifically designed to disrupt ED and IEDs. Because of this feature, the weapon itself does not require a heavy mass for the recoil.

This helps to reduce the recoil. It comprises different components as shown below. The barrel and compensator are filled with water as indicated in blue colour. A schematic 2D view of the weapon indicating all essential parts with proper labels is illustrated in Figure 1.

The principal element of the recoil system in the water disruptor consists of the assembly of barrel, spring, and sleeve. The barrel is made of high strength steel, and the spring is made of spring steel wire. The sleeve is made of an aluminium material. An image of the assembly of the barrel, spring, and sleeve used for the destruction purpose is shown in Figure 2.

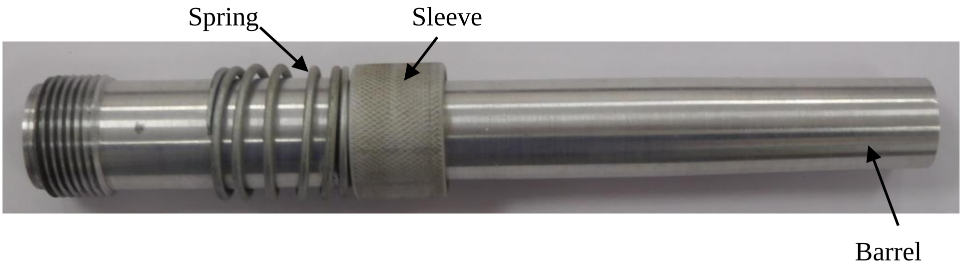

Fig. 2. An image of assembly of barrel, spring, and sleeve

3. MATERIALS AND INSTRUMENTS

3.1. Materials

A spherical double base propellant is used as an energetic material for carrying out various experiments. The propellant weight of 3 g is used in the filling of a cartridge. An image of the propellant is shown in Figure 3. The propellant with qualified chemical and physical properties is used in the filling and assembly of cartridges.

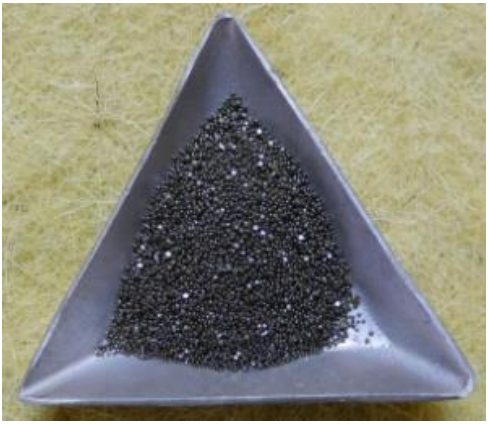

Fig. 3. A spherical double base propellant

3.2. Instrument

The projectile velocity measurement is carried out by a high-speed camera. The projectile velocities were measured near the muzzle of the barrel using high speed photography in a specially designed and fabricated test rig known as a velocity test rig (VTR). It is designed and fabricated basing on the thick cylinder theory [14]. It is utilised to determine the projectile velocities at the muzzle’s end of the barrel. In the earlier study, Parate *et al.* [15] reported the experimental and theoretical determination of a water-jet through a barrel of a disruptor. The experiment set up is like the earlier one, except VTR without use of water in the barrel. In the disruptor, the projectile gets camouflage with the water and cannot be traced by high speed photography. A projectile velocity assessment is one of the vital parameters in an armament field. The projectile velocities vary from 323.56 m/s to 365.58 m/s as measured experimentally in VTR [16, 17].

4. RESULTS

4.1. Theoretical determination of a recoil velocity

A recoil is rearward motion of weapon when a projectile is fired from a barrel. A force that produces a recoil is due to propellant gases and related moving parts of a gun. The recoil is undesirable as it affects the accuracy of weapon and a shooter. The main purpose of a recoil system is to absorb the recoil force very smoothly during the gun firing. Recoil energy is generated when the projectile is fired from the gun. This can be conveniently achieved by a device such as a spring to return the weapon to its original location. Due to gas generation, the thrust is generated. Such kind of a force generates the recoil due to motion of the propellant gases in the system causing the motion of different assemblies and sub-assemblies.

The recoil phenomenon is undesired as it affects the accuracy of a projectile fired from the gun. Less recoil force will therefore improve the accuracy of weapon. The recoil of the weapon is the balance of momentum for a complete weapon platform during its firing. According to Newton’s second law of motion, it is called as conservation of momentum. The recoil momentum gained by a water-jet disruptor exactly balances the forward momentum of the exhaust gases and the projectile. Weapon with the recoil are designed with less weight. They are usually mounted on light vehicles. They are used where there is insufficient mass to counteract the recoil forces of a projectile firing. This is accomplished by venting the high-pressure gas out of a breech module in such a way to counter the normal recoil force.

4.2. Assumptions

Before firing, any projectile both the gun and the projectile are at rest and hence total initial momentum is zero. The momentum of the gun is attributed due to momentum of the projectile and momentum of propellant gases. This depends upon the propellant mass, gas velocity, muzzle velocity and projectile mass and it is inversely proportional to the gun mass. Firing with the same mass, heavier is the gun, lower will be recoil energy. The recoil is explained mathematically on the law of conservation of momentum.

Data adopted for calculations: mass of the projectile m_p=7 g, mass of the propellant m_c=3 g, the projectile exit velocity when it is fired from the gun V_e= 323.56 m/s (minimum velocity) [17].

Assuming that the whole burning has occurred before the projectile's exit, an upper bound for a momentum of the projectile and propellant gases at the projectile exit is

$$(m_p + m_c)\, V_e \tag{1}$$

Therefore, a momentum of a barrel, breech etc. is given by equation 1, and so at the projectile's exit, the recoil parts will have the velocity

$$\frac{(m_p + m_c)V_e}{M} \tag{2}$$

Here M denotes the total mass of recoiling parts which is 1.4 kg.

The kinetic energy must be dispersed, and the barrel brought to rest. The barrel must be returned to a firing position. Substituting, values in equation 2 gives the minimum velocity 323.56 m/s and the recoil velocity as 2.311 m/s. Similarly, substituting the maximum velocity 365.58 m/s, gives the maximum recoil velocity as 2.611 m/s

The kinetic energy of recoil parts is obtained using the equation [18]

$$\frac{(m_p + m_c)^2\, V_e^{\,2}}{2M} \tag{3}$$

Putting the minimum and maximum values of the projectile velocities in equation 3, gives the minimum and maximum kinetic energies as 3.73 kJ and 4.77 kJ, respectively.

4.3. The gas force on projectile (F_R)

The forces are acting on the gun, as the projectile is moving through the barrel. During and after, the firing the unbalanced forces on, the gun can be categorized as the gas force.

The gas force on the projectile can be expressed as

$$F_R = p\frac{\pi}{4}d^2 \tag{4}$$

Here p is the internal pressure 50.12 MPa and d is the internal diameter of the projectile (18.5 mm). Substituting them into equation 4, gives 13.46 kN as the maximum gas force on projectile.

4.4. Energy to overcome the resistance force (E_{res})

The energy required to overcome the resistance force is equated with the kinetic energy of the projectile moving through with that velocity. This term is not more than 4% or 5% of the kinetic energy of the projectile. Thus, in early work it is usual, if this term was included at all, to take and can be expressed as [18].

$$E_{res} = 0.04 \cdot \frac{m_p \cdot V_e^2}{2} \tag{5}$$

Putting the minimum and maximum velocity as 323.56 m/s and 365.58 m/s, respectively, in equation 5, gives 14.657 J and 18.711 J respectively, as the minimum and maximum energies to overcome the resistance forces.

4.5. Spring design

The spring data was determined from the Material Analysis Group. Steel spring to Indian Standard specification IS: 4454 Pt 1, Grade SM having tensile strength from 1760 to 1970 MPa is used in the present design. The spring subjected to load testing is shown in Figure 4.

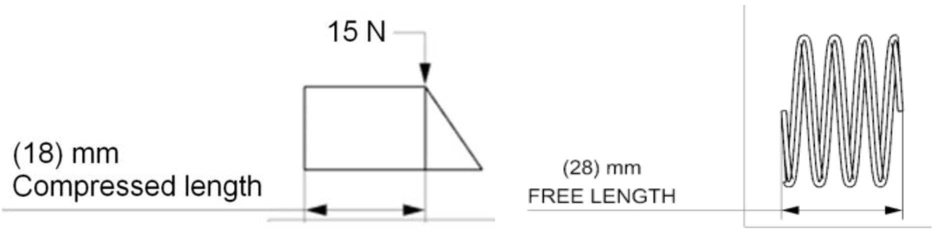

Fig. 4. Spring subjected to load testing

Using spring theory, design calculations are carried out. Spring leading after design is given at Table 1.

Table 1. Spring leading particulars

Spring load (W): 15 N	Displacement (δ): 10 mm
Wire diameter (d): 2 mm	Outer diameter (D_o): 32 mm
Inner diameter (D_i): 28 mm	Mean diameter (D): 30 mm
Active coils: 2	Total number of coils (n): 4
Solid length (L_s): 8 mm	Max travel: 18 mm
End type: Closed & square	Modulus of rigidity, G = 70,000 N/mm^2

4.6. Discussions and analysis of results

As explained in the calculation in paragraph 4, the following results were obtained.

The minimum and maximum recoil velocity of water-jet varies from 2.311 m/s to 2.611 m/s. The recoil velocities exist for this weapon to counterbalance between the projectile and moving water in opposite direction. The recoil velocities increase as the projectile velocities increase.

Based on recoil velocities, the minimum and maximum kinetic energies of the recoil parts were determined as 3.73 kJ and 4.77 kJ, respectively. As the projectile velocities increase, the recoil energies increase too. The minimum and maximum energies to overcome the resistance force are calculated as 14.657 J and 18.711, respectively.

5. CONCLUSIONS

The test facility was used to examine the recoil performance of the water-jet disruptor. The recoil velocity and recoil energy of the water-jet disruptor can be determined using the above calculations explained in Paragraph 4.

These parameters were evaluated as a part of the research and development programme. The projectile velocities can be conveniently measured using high speed photography. This research paper explained theoretical determination of various parameters such as recoil velocity, recoil energy, energy to overcome resistance force, and projectile resistance force. From the above discussions, the recoil velocity, recoil energy, and energy to overcome resistance force and projectile resistance force increase as the projectile velocity increases.

In context of the above exercise explained in this research work, it is recommended that, additional trials plan to measure the recoil experimentally using a sophisticated instrument. High speed videography could be used to ensure or observe the proper disruptor functioning.

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