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RESEARCH ARTICLE

INVESTIGATION OF AUTOMATION OF BULLET-LOADING, CARTRIDGE-EXTRACTION AND SHOOTING PROCESSES IN 106mm CANNON

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ABSTRACT

Considering the advent of modern and advanced weaponry and the significance of the needed time for applying these weapons when the country is invaded by enemies, we were committed ourselves to conduct a research military project for automation of 106mm cannon. It must be noted that there were some discrepancies in the conventional cannons for chambering and shooting for which the improving solutions have been investigated in this research so as to take advantage of this crucial defensive weapon in potential wars threatening our nation. This research is intended to automate a weapon called "106mm cannon". So long as this weapon is manufactured, a large deal of time -currently devoted to chambering (bullet-loading), cartridge-extraction and shooting- will be saved, and all the procedures will be done automatically and more precisely requiring less operators.

INTRODUCTION

Armored forces were primarily applied by British Army during First World War. Military machines invalidated many war theories and the tactic of using tanks along with infantry in battlefields was formed. With tanks, infantry forces were displaced more rapidly and blitzkriegs emerged in new ways.

During Second World War, tanks made many difficulties for infantry revealing the significance of anti-tank weaponry. The most famous anti-tank weapons were 57-75-90mm guns at that time. Following the Second World War and as a result of advances in anti-tank weaponry, USA manufactured the prototype of 106mm gun- model M40. The models M40A1 and M40A2 were subsequently presented. 106mm gun is one of the most well-known anti-tanks weapons in the whole world; except for US, it is produced by countries including UK, Spain, South Korea, Pakistan, etc. It is applied by many other countries such as Islamic republic of Iran and Iraq as an anti-tank weapon. 106mm gun is a heavy, anti-armor, collective, solid-base (the bullet enters the chamber from the end) weapon without withdrawal; it is fed with prepared ammunition and its barrel is cooled with air current. The propellant device is percussion-type and it also has an auxiliary trigger as cracker-mover. 106mm gun has the possibility to shoot directly or in projectile trajectory (with the aid of goniometer). This weapon is held on the ground surface or on light vehicles (JIP) supported by its 3 standard 79M legs. Artillery systems shoot the cannon balls to the targets. These systems are usually used in defensive sectors- both in sea and land- as the final defense. They are very effective for ranges less than 4kilometers and against targets with low crossing angle and low acceleration. These weapons can be absolutely lethal in the ranges below 1 kilometer. The artillery systems mistakenly seem to be futile owing to their limited range. Many guided missiles have a minimal range, in this range; they are ineffective due to the delay of the fuse to be equipped and also because of the necessity for reaching a minimal missile speed needed for aerodynamic stability control. Land-to-air missiles also encounter challenges for targets flying in low altitude. The cannons fill this gap where missiles are ineffective. Furthermore, the cannons are single-mission and require cheaper ammunition than the land-to-air guided missiles. In comparison with guided missiles, having a certain budget, more number of cannons can be applied for final defense. As the missiles and cannons are compared; it can lead to enhancement of aerial defense effectiveness and reduction in expenditures for a certain war arena. Cannon bullets traverse the ballistic flight trajectory without guidance. The only controlling parameters are targeting angle and height of the cannon. These angles are computed based on the brief data concerning the position, velocity and acceleration of the target. Also, atmospheric conditions, initial velocity of bullet, bullet weight and its drag force affect evaluation of these angles. The motion equations are expressed using the factors which are normally affective on bullet projectile simulation. They will then be used to evaluate differential effects as a

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function of the range. Differential effect is the amount of variation in collision error generated via one unit variation of those variables which are influential on the projectile motion. The error budget method and its relation with differential effects have been mentioned in accuracy analysis. Lastly, some methods are presented for determining the collision probability of cannon system. Figure 1 illustrates the general overview of cannon components. Cannons are open-loop systems. The next position of target is predicted and the cannon targeting angles are calculated just like a projectile. After firing, the bullet will hit the target without any additional modifications. The errors in target tracking, filtration and prediction process have considerable impacts on the accuracy.

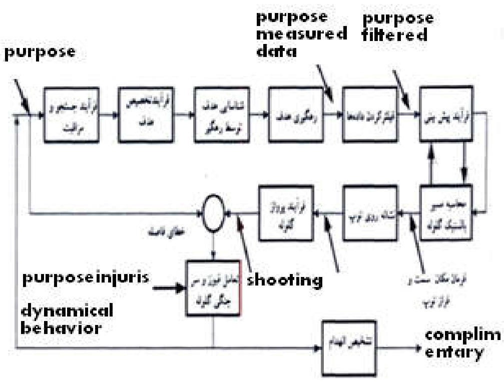

Fig. 1: Components of cannon system

{First row-From left to right}: Current target position- Searching and surveillance process- Process of Concentration on Target - Target detection by radar- target tracking- Measured data of target- Data filtration- Filtered data- Prediction process {Second Row-From right to left}: Computation of bullet's ballistic trajectory- Commanding cannon's angle and height -Aiming in cannon- The response to cannon's angle and height- Bullet projectile motion process- Position of bullet- Distance error {Third row-From left to right}: Target vulnerability- Interaction of fuze and bullet warhead {Fourth Row-From right to left}: Dynamic behavior and target structure- Destruction assessment- Decision for continuing or stopping the bullet firing Two kinds of ammunition are used in cannons. Fixed ammunition are nearly found in all cannons except for large ones. They consist of an ensemble containing cartridge, bullet, detonator, gunpowder and other elements. Their storage, usage and loading are easily done and are usually fired more rapidly than other sorts of ammunitions. In some cases, the bullet weight and dimensions are too large to be applied by one person. In addition, it is structurally difficult to apply large calibers and fixed ammunitions simultaneously. Partially-fixed ammunitions consist of a gunpowder ensemble and a bullet ensemble. These ammunitions are mainly used in cannons having calibers larger than 10mm.

Figure 3 displays selected specifications of an ordinary cannon bullet. Small-caliber cannons are used in anti-air systems. One sabot (not illustrated here) is placed around the small-caliber cannons preventing the gunpowder gas propulsion and causing the bullet to spin. The sabot will be separated when the bullet leaves the barrel. Sabot-bearing bullets can reach higher initial velocity and shorter projectile duration in their effective range.

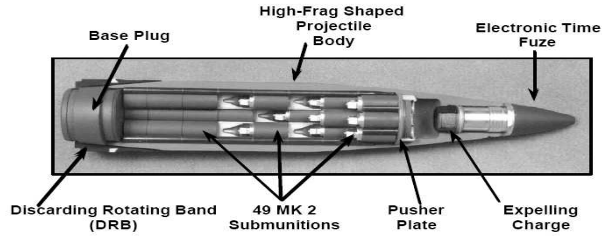

Fig. 2: Specifications of a cannon bullet

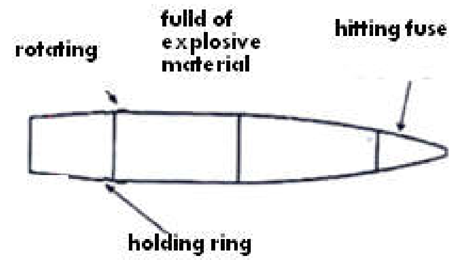

Fig. 3: Different components of cannon bullet

{Top of figure: from left to right}: Rotating band- The explosive-filled body- Nose fuze (adjacent or percussion-type) {Under the figure: from left to right}: Base plug for drag reduction- Cartridge holder ring. For firing a cannon bullet, its tuitions is combusted. This tuitions burns quickly but does not cause detonation. In most of cannons, the bullet moves slightly during combustion process. The evolved gas resulting from gunpowder combustion has a pressure around 8000-1000 kg/m^2. This gas exerts an extremely high force on the bullet base, and as the bullet displaces along the cannon barrel, gas volume is increased and its pressure declines. Immediately after expulsion of bullet from the barrel, the remaining pressure still is exerted on the bullet for a short time; the gases are then propelled into the atmosphere. Ultimately, the terminal part of barrel opens and the empty cartridge is extracted. Again, another bullet from ammunitions is input and the above process is repeated. Internal ballistic designing signifies shooting the bullet from the barrel with a reliably predicted velocity. When the bullet leaves the barrel, bullet belt (the surrounding ring strip) causes the bullet to spin by means of internal rifling. Rifling incorporates a helical groove extending all over it. Rifling turn depends on the number of calibers which bullet should cover to have a complete rotation. For example, rifling turn 1 in 25 means a complete rotation of bullet covering 25 calibers along the barrel. Rotation rate in the "barrel exit" is calculated through the following equation:

$$P = \frac{2\pi v_{\circ}}{nd} \qquad (1)$$

Where; "P" is rotation rate in "rad / s", "v_0" is the bullet velocity as it exits the barrel, "n" is rifling turn in calibers per rotation, and "d" is the length of a caliber having the same length unit as the exiting velocity. Error analysis of cannon systems depends on the flight simulation tools which are used for making estimations of the collision error statistically. These estimations are generated based on the perturbations in the nominal parameters of the system including bullet's weight and initial velocity. A principal assumption states that it is possible to write the motion equations in the form of the trajectory of a particle. It signifies that longitudinal axis and velocity vector of bullet remain in the same prolongation during the flight trajectory, therefore bullet's attack angle equals zero. In most of the cases, this assumption has no effect on the systematic performance evaluation because the bullet will be a specified model.

The cannons with calibers larger than 35-40mm are operated based on different principles. The ammunitions are inserted into the cannon and placed in the tray; they are directed to the barrel ending via a powerful mechanism. Subsequently, a separate breechblock is locked for firing and is then opened after shooting; the cartridge is again expelled by a separate mechanical system. The simplest types of these cannons use fixed ammunitions. Bullet and cartridge compose a unit; the cartridge firmly holds the bullet. In large calibers such as 5inch cannon of US marine forces, the bullet and gunpowder are separate from each other but are inserted in the same chamber and directed together to the cannon's terminal barrel. Larger caliber mechanisms having partially fixed ammunitions are more complicated because the cartridge and bullet ending are required to be controlled along the trajectory; greater elastic forces are generated as well. Firing rate mainly decreases as caliber rises; it strongly depends on the cannon system lay-out too. Figure (4) shows the coordinate system used for deriving the motion equations. It is assumed that the system is connected to the ground and x-y plane is tangent to bullet position plane. The origin or point of start of bullet motion is located in the point (0, 0, 0).

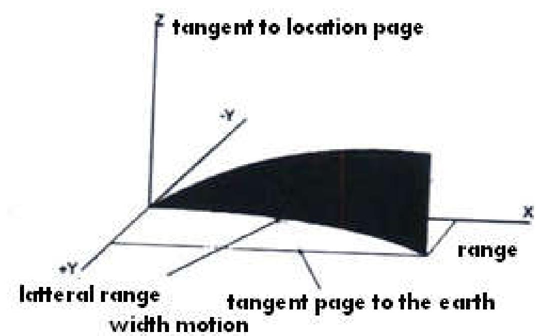

Fig.4: Coordinate system for deriving the motion equations of bullet

{Clockwise from top}: -Vertical (proportional to tangent plane to bullet position)-Range-Tangent plane to ground surface-Lateral movement due to lateral winds or error in aiming angle-Lateral range. X axis shows the main direction of bullet motion normally referred as "range axis". Y axis represents "lateral range or deviation axis". If deviation is neglected and no error in aiming angle and lateral wind component exist, then there will be no movement in Y direction. Vertical axis is perpendicular to x-y plane in bullet position, in such a way that extends opposite to gravity direction. These flight trajectory baselines do not have component of lateral movement. These deviations might be caused by lateral winds and errors in aiming angle. The motion equations can be defined in the abovementioned coordinate system. Figure (5) demonstrates the forces exerted on the bullet. According to Newton's first law:

$$
\begin{aligned}
m\ddot{x} &= \sum F_x \\
m\ddot{y} &= \sum F_y \\
m\ddot{z} &= \sum F_z
\end{aligned}
\qquad (2)
$$

As indicated in figure (5), drag force acts exactly in opposite direction of air velocity vector and can be resolved in terms of x, y and z components. The gravity force always acts in –z direction. Only drag and gravity forces are taken into account in bullet motion equations. Thus, the above equations can be rewritten as:

$$
\begin{aligned}
m\ddot{x} &= D_x \\
m\ddot{y} &= D_y \\
m\ddot{z} &= D_z - W
\end{aligned}
\qquad (3)
$$

Where; D_x, D_y and D_z are components of drag force.
The lateral winds blowing from –Y to +Y intensify the drag force.

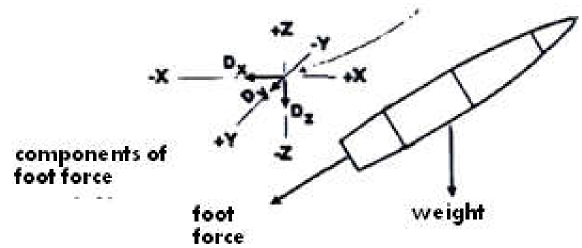

Fig.5 : Forces acting on the fired bullet

Drag force is dependent on air velocity. With initial calculation of its components in X and Y directions, the air velocity is evaluated. (Wind velocity component in Z direction is assumed to be zero) Air velocity is the difference between bullet inertial velocity and wind velocity. In this paper, inertial velocity signifies the bullet velocity with respect to the ground. Air velocity components and their resultant velocity are evaluated as follows:

$$
\begin{aligned}
\dot{x}_A &= \dot{x} - W_x \\
\dot{y}_A &= \dot{y} - W_y \\
\dot{z}_A &= \dot{z} \\
V_A &= \sqrt{\dot{x}_A^2 + \dot{y}_A^2 + \dot{z}_A^2}
\end{aligned}
\qquad (4)
$$

Where:

$\dot{x}, \dot{y}, \dot{z} =$ components of inertial velocity

$\dot{x}_A, \dot{y}_A, \dot{z}_A$ = components of air velocity

W_x and W_y = components of wind velocity in the directions of the range and lateral range axes respectively

V_A= resultant air velocity of bullet

Bullet motion is expressed in inertial terms. However, drag force must be written in terms of air velocity. The axial drag force equals:

$$D = \frac{1}{2} C_{D\circ} \rho A_r V_A^2 \qquad (5)$$

The new terms appearing in the equations include: "ρ" = air density, "C_{D0}" = zero drag coefficient and "$A_r = Jld^2\rho / A$" or reference cross-sectional area.Drag force components are evaluated via total axial drag coefficient having equal ratio of the air velocity vector components. Therefore, substituting the squared velocity term by the velocity component in total velocity, we will have:

$$D_x = \frac{1}{2} C_{D\circ} \rho A_r V_A \dot{x}_A$$
$$D_y = \frac{1}{2} C_{D\circ} \rho A_r V_A \dot{y}_A \qquad (6)$$
$$D_z = \frac{1}{2} C_{D\circ} \rho A_r V_A \dot{z}_A$$

The final differential equations are obtained via dividing both sides of the equation by bullet mass and substituting drag force formula in these equations. Consequently, three components of inertial acceleration will be achieved in the left side of equations. "g" or the vertical acceleration of bullet resulting from gravity is simply derived as the weight is divided by mass.

$$\ddot{x} = \frac{\frac{1}{2} D_{DO} \rho A_r V_A}{m} \dot{x}_A$$
$$\ddot{y} = \frac{\frac{1}{2} C_{DO} \rho A_r V_A}{m} \dot{y}_A \qquad (7)$$
$$\ddot{z} = \frac{\frac{1}{2} D_{DO} \rho A_r V_A}{m} \dot{z}_A - g$$

For this purpose, the appropriate values of drag and air density must be determined along the flight trajectory. Drag coefficient depend on Mach number. Mach number in turn is a function of air velocity and temperature. We assume standard atmosphere in all calculations of nominal flight trajectory. In standard atmosphere, air density and temperature are functions of altitude. The interesting point is though the bullets with larger calibers have greater maximal theoretical range, but they are not effective enough for targets in 5-6 km ranges. These bullets normally have adjacent fuse and a "splintering warhead" enhancing their fatality radius; however, shooting error severely increases as the range increases. One of the common errors influencing the effective shooting of cannon system occurs in firing rate. Larger caliber bullets are not able to fire at high rate so as to reach greater ranges in suitable times and compensate the exceeded collision error.

Conclusions

The main constituents of automatic cannon can be categorized as follows: Automated machine (automatic vehicle) - Hydraulic jack for adjusting the angle- Hydraulic jack for opening and closing the terminal door of the barrel- Hydraulic jack for inserting the bullet into and extracting the cartridge from the barrel- Hydraulic jack for extracting the cartridge from the magazine and inserting new bullet into it- Stepped motor for activating the circular magazine- Cannon barrel- Bullet cellar for storing reserve bullets- Bullet container for loading bullets into magazine- Cartridge container for gathering the cartridges- Shooting system which can be controlled mechanically or electronically- Hands and indicators for precise adjustment of shooting- Various sensors for better cannon performance. The functions and design of different elements must be in such a manner that they operate automatically and all the parts mounted on the vehicle shall be simultaneously adjusted in different slopes for shooting; this can be done by means of an underlying hydraulic jack. The bullets must be inserted in their place, i.e. the circular magazine which moves around a rotational axis with the aid of a ball-bearing. The magazine keeps working thanks to a highly precise stepped motor; extremely sensitive sensors are installed in different locations so as to move the magazine once more when it is empty and to insert the next bullet into the barrel.

The bullets are loaded into the barrel by means of a hydraulic jack following the adjustment of all stages; this jack pushes the bullet in the terminal part and expels them from the magazine to insert them into the barrel. The door behind the barrel is shut like drawers by means of another hydraulic jack preparing the cannon to fire. Now, it must be noted that having mounted the sensors, it is possible to allow the cannon to shoot only if the bullet is perfectly loaded into the barrel. The stepped motor of circular magazine can be moved by a tape, chain or gearbox coupling. Now, immediately after shooting and confirmation by respective sensors, the terminal door of barrel is opened and the cartridge is pulled out by the same hydraulic jack which had inserted the bullet into the barrel. The cartridge is placed in a specific container and then the stepped motor starts working; it moves the magazine very precisely and inserts the next bullet in front of the barrel; the aforementioned procedures are similarly repeated. Some of the features of this type of cannon in comparison with its conventional versions can be listed as:

1. The whole cannon can move in any direction (angle) without requiring any displacement of the carrying vehicle; it can be adjusted in different angles either by rotational motion caused by cogwheels or by means of the underlying hydraulic jack.
2. It requires minimal number of crews for usage; i.e. one driver and one or two operators are enough for adjustment and shooting.
3. Due to being automated, considerable number of bullets can be stored in the cellars for transferring to remote locations from the supply and logistics position.
4. Least time duration is devoted to bullet-loading, shooting, and cartridge-extraction processes because the whole actions are conducted automatically.
5. No need for several persons serving as operators for the abovementioned actions, requiring less people as well as consuming less energy for operators can be implied as other advantages.
6. Protection of operators against ambient hazards is another positive point because the driver and operator(s) can control the process inside the machine and avoid being exposed to enemy's bullets and splinters of explosives.

7. Rapid displacement: as these cannons are automatic, they can leave their location as soon as the position is revealed to enemy.
8. Another privilege is storage of cartridges in the specific container.
9. If one of the magazine chambers is empty, this chamber is not located in front of barrel thanks to presence of sensors; the magazine continues rotating till a chamber having a bullet inside is located in front of the barrel. The internal systems of these cannons include measurements of internal and external temperatures and even the temperature of the barrel.
10. Other qualities can be implied as equipping without human intervention, high maneuverability, shooting ability in different atmospheric conditions and in most awkward situations, and finally short preparation time.

The procedures of system operation can be summarized as follows: Initially, the container and reserve cellar in both sides of the machine are supplied with bullets in the logistics section. The cannons are dispatched to the destination where the automatic system is activated; the magazine chambers (right side of magazine) are filled with bullets to locate the first bullet in front of the barrel. Now, the aforementioned hydraulic jack loads the bullet into the barrel and the terminal door of the barrel is shut by another jack. The cannons are ready to fire following the required rotation of machine and reaching the desired angle. After shooting, the terminal door of barrel is opened and the cartridge is expelled through the terminal groove and by the same jack which had inserted the bullet. It is placed inside the empty segment of the magazine (formerly filled with bullet); the magazine is moved one step ahead by means of the stepped motor; then the next bullet is placed in front of the barrel and the subsequent stages are repeated as before. When the first cartridge reaches the cartridge-propellant, the associated jack system which is located beneath the magazine pulls the cartridge out of the magazine and inserts a new bullet from the container into the magazine. The extracted cartridge is cast on an inclined surface directing to the cartridge cellar. Note that cartridge-extraction and loading new bullets do not take any time because they are performed while the bullet-loading and shooting are being done in the upper magazine sections. When the magazine does not move and the shooting is going on, cartridge-extraction and insertion of new bullets are carried out in the lower parts. By the way, it must be reminded that the bullets have been already stored in a container behind the magazine and can replace the fired ones in a well-defined order after the respective cartridges are pulled out from below.

Recommendations

It is recommended that the barrel is made of refined ESR steel. This steel is one of the most premium sorts worldwide having very high strength. The cannon shall be equipped with a thermal insulator, a reference system installed in the barrel exit, and a smoke discharge system. The internal surfaces shall be covered with a chrome coating in order to have a stronger structure and softer interface. This coating causes the bullet to have less abrasion with barrel walls, be more accurate, move faster and as a result, have larger penetration power. Large amount of valuable metal of titanium can be used for manufacturing these cannons bringing about lighter weights. The lightness of cannon will not lead to reduction in its stability while shooting, and consequently, the accuracy of the system will not be negatively affected by its light weight.

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