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REVIEW PAPER

Effects of Tank Gun Structural Components on the First Shot Hit Probability

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ABSTRACT

Fire power for a main battle tank is one of the most important performance parameters like survivability and mobility. Fire power effectiveness is directly related to the first shot hit probability, performance of main gun, second armament, gun and turret drive system, fire control system, automatic target tracker, commander and gunner sight etc. First shot hit probability (a measure of cumulative effects of errors) is affected by the variations of the projectile parameters, the main gun structure uncertainties, fire control system errors, interaction between the projectile and the gun barrel and the unpredictable environmental changes. These errors and variations can be eliminated or minimised by understanding and simulating the firing event properly, manufacturing the related parts in high precision, using advanced fire control algorithms, and accurate sensors. In this review study, the effects of main gun structural components on the first shot hit probability are investigated taking into account all of the associated error sources. In order for a main battle tank to have both high and repetitive first shot hit probability under all battlefield conditions the gun structure should respond in a similar manner in successive firings without causing any abrupt change in performance. In this study, first the dynamic behaviour of gun/projectile system is discussed and then the design recommendations for the main gun components such as bearings, gun barrel, recoil system etc. to achieve higher first shot hit probability are reviewed.

Keywords: Gun dynamics; First shot hit probability; Main gun structure; Projectile system

NOMENCLATURE

J	Moment of inertia of recoiling parts to the axis which crosses their centre of gravity perpendicularly to elevation axis
M_e	Moment of force from fire $(M_e = SP(t)e)$
M_b	Moment of recoil buffer resistance $(M_b = F_b h_b)$
M_v	Moment of recuperator resistance $(M_v = F_v h_v)$
M_{tb}	Mmoment of passive resistance of recoil buffer $(M_{tb} = mgf_b h_b)$
M_{tv}	Moment of passive resistance of recuperator $(M_{tv} = mgf_v h_v)$
M_s	Moment of shell force $(M_s = m_s g x_s)$
e	Distance of centre of gravity of the recoiling parts from the barrel axis
S	Basic cross-section of the barrel bore
$P(t)$	Pressure in the barrel bore
F_b	Resistance force of recoil buffer
h_b	Distance between the axis of recoil buffer and centre of gravity of recoiling parts
F_v	Resistance force of recuperator
h_v	Distance between the axis of recuperator and centre of gravity of recoiling parts
m	Mass of recoiling parts
g	Gravitational acceleration
f_b	Friction coefficient in recoil buffer
f_v	Friction coefficient in recuperator
m_s	Mass of the shell
x_s	Trajectory of shell in the barrel bore

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1. INTRODUCTION

Main battle tanks provide one of the most effective power for the armoured land forces. The performance of main battle tanks is assessed under three basic categories; fire power, mobility and survivability[1].

Fire power effectiveness is directly related to the projectile, main gun effectiveness, second armament effectiveness, gun and turret drive system, fire control system, automatic target tracker, commander and gunner sight etc. Mobility of a tank is generally defined as the capability to move effectively in various kinds of road profiles for large ranges and the ability to change its position rapidly in a short response time. Mobility is directly related to the parameters like vertical obstacle crossing, maximum speed, cruising range, suspension system etc. On the other hand, the survivability of a tank is defined as the capability to avoid and withstand/protect against the enemy attack. Survivability is evaluated under some parameters like silhouette, active protection system, ballistic protection, NBC protection, radar and laser warning systems etc. In this study, the effects of the gun structural components are examined for fire power performance of a main battle tank thoroughly.

Higher fire power is achieved only by higher and repeatable first shot hit probability. First shot hit probability is the statistical measurement of fire power effectiveness. It is the cumulative effects of all weapon system errors. First shot hit probability depends on accuracy and consistency of the shot fired from the weapon system. Accuracy depends on gun droop, sighting calibration, gun wear, ammunition (finish, shape, weight, propellant, charge temperature), crew (laying and ramming), meteorological conditions (inadequate correction for space, time and measurement), survey (map, height and location of the gun and target) and prediction (inadequate theory (drag law and trajectory calculation) and limited data) whereas dispersion depends on gun (jump, throw off, wear, sighting system), ammunition (finish shape, weight, driving band, propellant and obturation), gun crew (laying and ramming), meteorological conditions (temperature, pressure, wind, precipitation and humidity).

In other words, first shot hit probability is affected by variations of the projectile parameters, the main gun structure uncertainties, fire control system errors, interaction between the projectile and the gun barrel and the unpredictable environmental variations.

Projectile related variations include the geometric tolerances, thermodynamic properties and weight which affect round-to-round dispersion. Gun and turret drive systems point the gun towards the desired aim point calculated by the fire control system as precisely as possible with minimum backlash and sensor errors. Fire control system error sources include target tracking, line of sight and weapon stabilisation/synchronisation accuracy, ballistic computation, range measurement and sensor accuracy errors and cumulative error of fire control system algorithms like fire inhibit algorithm, linear motion compensation, dynamic lead calculation, etc. The disturbance due to the motion of the combat vehicle, affects the weapon and sight stabilisation performance adversely and this results in reduced first shot hit probability of the weapon system. The performance of the suspension system influences the vibration level transmitted to the turret and barrel structures. The muzzle angular displacement can be significantly changed using active suspension system[2]. These errors cause variations in gun pointing accuracy. Commander's and gunner's periscopes affect the target detection, recognition and identification ranges as well as the line of sight stabilisation and boresight retention. The change in the chamber pressure, the misalignment of the projectile axis with respect to the gun bore axis, the clearance between the projectile and the gun bore inner diameter affect the interaction between the projectile and the gun barrel and cause variations in the impact point. Sudden environmental changes such as the change in the wind speed and direction affect the free flight trajectory of projectiles especially the projectiles with slower muzzle velocity like high explosive (HE) and high explosive anti-tank (HEAT) ammunitions. In addition to the above mentioned factors, the change in sabot discharge distance from the muzzle end, the clearance between the barrel and thrust bearings, the clearance inside the trunnion roller bearings, the variation on the preload of the trunnion bearings and the change in the recoil force may also cause the change in impact point on the target which results in the decrease of the first shot hit probability of the weapon system.

In this review study, main gun structure components which have effect on the first shot hit probability are discussed in detail considering all other error sources to some extent. First, weapon system related error sources are introduced. Next, tank gun components which have effect on the firing effectiveness and accuracy are described, and analytical description of tank gun dynamics is given. In the last section, design recommendations for the gun structure components to minimise the system errors and maximise the first shot hit probability are discussed.

2. WEAPON SYSTEM ERROR SOURCES

Weapon system is composed of two main subsystems. These are fire control system and gun system. Fire control system consists of sensors, gunner's and commander's sight, fire control computer and gunner's and commander's handles. Gun system consists of gun controller, main gun, elevation and azimuth drives and recoil system. In Fig. 1, a simplified flowchart shows the operation of the weapon system.

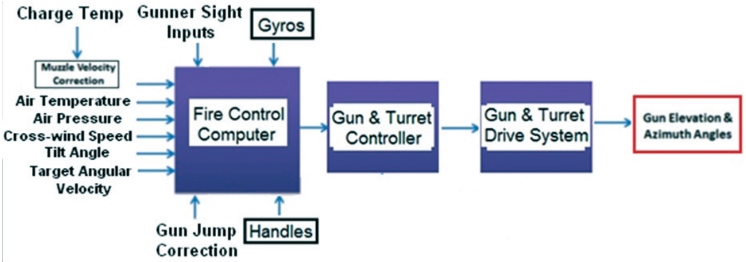

Figure 1. Weapon system's operation flowchart.

All the sensors, mechanisms and calculations have some degree of accuracy and the corresponding errors form the weapon system errors.

Total gun jump error is the angular deviation of the shot target impact point relative to the aiming point. The total jump of a projectile includes the gun components, the aerodynamic components and the windage components as shown in Fig. 2.

Transverse motion of a projectile in the gun tube can be caused by any one or more of the following conditions are listed in Table 1.

Table 1. Causes of projectile transverse motion in the gun tube

Offset of projectile centre of gravity and principal axis from the bore centreline
Eccentric manufacturing of projectiles
Gaps (clearances) between the projectile bourrelet surfaces and the gun bore due to wear
Occurrence of irregular pressures at the projectile base due to gas dynamics
Projectile/gun tube clearances due to manufacturing tolerances
Insufficient stiffness of the projectile / gun tube interface
Gun tube curvature (including bore irregularities)

Error sources may be categorised in three groups; fixed-bias errors, variable bias errors (occasion-to-occasion) and random errors (round-to-round)[4].

Fixed-bias errors are constant for a range and for all firings. Gravity drop-off, drift of spin-stabilised projectiles, and parallax error are the typical examples for fixed-bias errors.

On the other hand, variable bias errors change slowly so

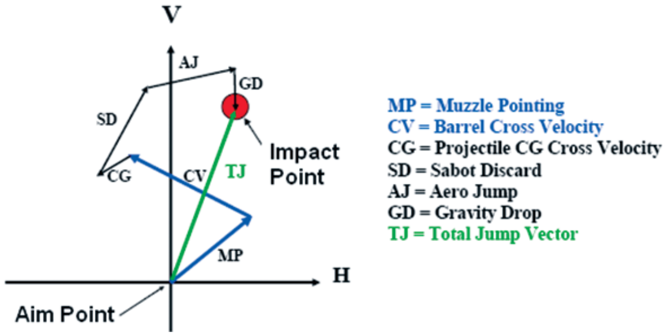

Figure 2. Gun jump error components[3].

that they can be assumed to be constant or corrected easily through the use of high accuracy sensors with high sampling rates. Vehicle tilt angle (not moving or on smooth road), wind velocity and direction, air density and temperature changes (both for air and ammunition) are some examples for variable bias[5].

Random errors generally cannot be reduced or controlled during firing. The magnitude of random errors is inherent to the weapon system design and to the manufacturing processes used to produce the system. Uncertainties in gun and turret bearings, radial clearance between the projectile and gun barrel, vibrations due to the motion of the vehicle (ground-induced vehicle disturbances), axial position of the projectile inside the chamber and ammunition dispersion and thermal droop of barrel due to changes in sunlight and successive firings are some examples of random errors[5]. Muzzle end deviations due to thermal droop can be controlled to some degree using muzzle reference systems. Gun barrel vibrations due to the motion of the vehicle may be controlled using dynamic muzzle reference systems, muzzle end estimation algorithms or fire inhibit algorithms[6]. The magnitude of random errors changes from firing-to-firing and reduction of random errors implies radical improvements in the weapon system design.

Other weapon system related error sources are barrel-to-barrel variations and occasion-to-occasion variations. In addition, disassembly and reinstallation of shroud and bore evacuator may change the centreline or shape of the gun barrel[7].

Boresighting and zeroing processes help to determine the fixed bias errors and minimise its effects. In boresighting, the offset between the tank's line of sight and its gun (line of fire) is measured and corrected at a known distance from the tank. Although boresighting allows accurate alignment of the gun, the gun barrel can bend, vibrate, and rotate during the firing. Additional mechanical interactions and aerodynamics change the trajectory of the projectile. Therefore, correction for the fixed bias errors is done by performing several firings and obtaining the impact centre called zeroing firings and determining the offset[8].

3. TANK GUN DYNAMICS

In this section first, the components of the tank gun system and recoil mechanism are introduced briefly. Next, the equation of motion of projectile/gun barrel system during the firing event is described.

The major components of the tank gun system that may have effect on the dynamic characteristics of the gun are (1) barrel with thermal jacket, (2) cradle, (3) cradle tube, (4) bore evacuator, (5) Muzzle reference sensor, (6) breech mechanism, (7) elevation mechanism (elevation gear) and (8) recuperator as shown in Fig. 3.

The recoil mechanism is comprised of a recoil buffer, a recuperator and a counter recoil buffer (located inside the recoil buffer). Recoil buffer operates hydraulically and consists of a cylinder (cradle) and piston assembly. The variable orifice, between the piston and the varying internal diameter of the buffer cylinder retards the moving part of the recoil mechanism during and after firing. There are two main types of recuperator mechanisms. These are spring and pneumatic. In the pneumatic type, compressed gas is used instead of spring. The recuperator drives the counter recoil to before firing (initial) position. The recoil system has effect on the accuracy, stability and the rate of fire of the gun system. In order to achieve high accuracy, it is important for the recoiling parts to move the gun forward and backward preserving its same axial and rotational positions for every firing event[9].

Analytical modelling is an useful technique to understand the dynamics of the firing event and to determine the effects of parameters on the dynamic behaviour including the projectile-barrel interaction.

The total kinetic energy (T) of the projectile/gun barrel system is[10]:

$$\begin{aligned} T &= T_{gun} + T_{projectile} \\ T &= \frac{1}{2}m_g(\dot{x}_g^2 + \dot{y}_g^2) + \frac{1}{2}I_g\dot{\theta}^2 \\ &\quad + \frac{1}{2}m_p(\dot{x}_p^2 + \dot{y}_p^2) + \frac{1}{2}I_p\dot{\alpha}^2 \end{aligned} \tag{1}$$

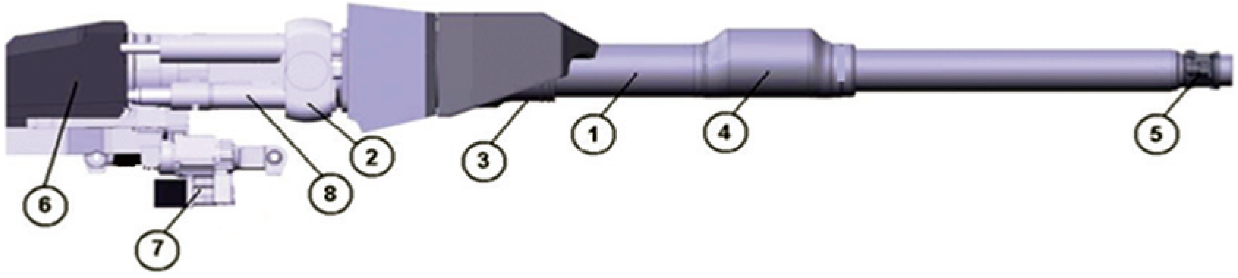

Figure 3. A typical tank gun system: (1) barrel with thermal jacket, (2) cradle, (3) cradle tube, (4) bore evacuator, (5) Muzzle reference sensor, (6) breech mechanism, (7) elevation mechanism (elevation gear) and (8) recuperator[6].

where m_g, m_p are the masses of the gun and the projectile and I_g, I_p are the mass moments of inertia about the centres of gravity of the gun and the projectile. $\dot{x}_g$ and $\dot{y}_g$ are the translational velocity of the centre of gravity of gun, and $\dot{x}_p$ and $\dot{y}_p$ are the translational velocity of the centre of gravity of projectile. Angles θ and α are shown in Fig. 4. $\dot{\theta}$ and $\dot{\alpha}$ are the respective angular velocities of angles θ and α .

The total potential energy (V) of the projectile/gun system is[10]: I_p

$$V = V_{gun} + V_{projectile} + V_{bourrelet\_contact} + V_{obturator} + V_{foundation\_moment}$$

$$V = m_g g y_g + m_p g y_p + \frac{1}{2}k_{bc}\delta_{bc}^2 + \frac{1}{2}k_0\delta_0^2 + \frac{1}{2}k_0'(\delta_0 - R_{c1,0})^2 + \sum_n \frac{1}{n}a^n\alpha^n \tag{2}$$

where k_{bc} is the stiffness of the bourrelet, δ_{bc} is the displacement of the projectile into the gun bore, δ_o is the projectile displacement at the obturator, k_o and k_0' represent the stiffness of the plastic band and metallic part of the obturator respectively and, $R_{c1,o}$ is the radial clearance between the obturator and the bore. The last term of the equation (2) is a power series due to the foundation moment that occurs as the projectile moves down the gun barrel.

By applying Hamilton principle using equation 1 and 2, jump angle of projectile at the muzzle end can be determined which is input to free flight trajectory analysis.

In another way, the equation of motion or the interaction between a moving projectile of a mass m_p and a gun barrel (modelled as an Euler-Bernoulli cantilever beam) can be written as[11]:

$$\frac{d^2}{dx^2}\left\{EJ(x)\frac{d^2w(x)}{dx^2}\right\} - w^2 m(x)w(x) = p\left[(x-x_p,t)\right] - m_p(x-x_p)\left(\frac{d^2w(x_p,t)}{dt^2}\right) \tag{3}$$

here x_p is the time-dependent projectile location, E is the elasticity module, J is the inertia moment of the cross-sectional area, $m(x)$ is the mass of the barrel's unit length, x is the central coordinate of the barrel system with respect to the global coordinate plane, t is the time, $w(x,t)$ is the vertical deflection of the barrel with respect to the global coordinate, w is the frequency of the barrel, $p(x,t)$ is the force applied to the unit length of the barrel by the projectile and $d^2w(x_p,t)/dt^2$ represents the barrel acceleration in vertical direction with respect to the global coordinate system. Modelling the accelerating mass as a finite element, longitudinal and transverse vibrations of the barrel including the inertia, Coriolis and damping effect of the accelerating projectile are determined.

The equation of motion for the gun barrel-projectile system is defined as:

$$\left[\bar{M}(t)\right]\left\{\ddot{\bar{Z}}\right\} + \left[\bar{C}(t)\left\{\dot{\bar{Z}}(t)\right\}\right] + \left[\bar{K}(t)\left\{\bar{z}(t)\right\}\right] = \left\{\bar{F}(t)\right\} \tag{4}$$

where $\left[\bar{M}\right]$, $\left[\bar{C}\right]$ and $\left[\bar{K}\right]$ are the instantaneous mass, damping and stiffness matrices of the system in global coordinate plane respectively. These matrices are time dependent and they consist of constant mass and stiffness matrices of the barrel and time-dependent characteristic matrices of the projectile. $\left\{\ddot{\bar{z}}(t)\right\}$, $\left\{\dot{\bar{z}}(t)\right\}$ and $\left\{\bar{z}(t)\right\}$ are the acceleration, velocity and displacement vectors of the barrel nodal points on the global coordinate axis, respectively.

Mass, stiffness and damping matrices of the equivalent mass element are determined using finite element method. The element where the projectile is located, has 3 equivalent nodal forces and displacements at each nodal point.

The force as a result of the motion of the projectile through the deformed barrel can be determined as[11]:

$$f_z(x,t) = \left[m_p g - m_p\frac{d^2w_x(x_p,t)}{dt^2}\right]\delta(x-x_p) \tag{5}$$

where, $x_p = x_0 + v_0 t + (1/2)a_m t^2$ is the time dependent location of the projectile inside the barrel, $\delta(x-x_p)$ and g are

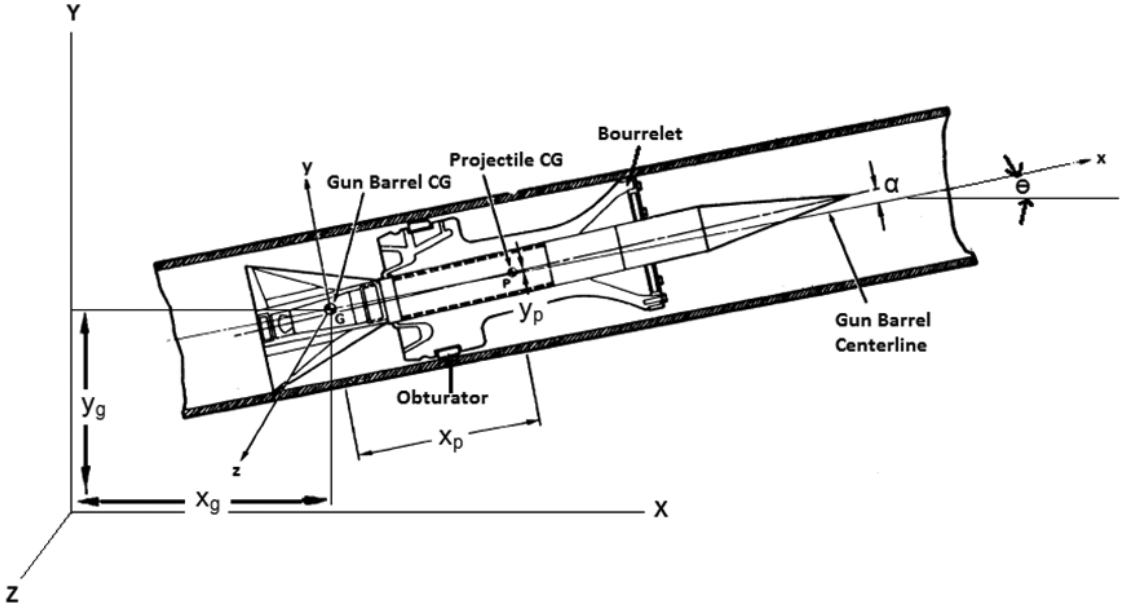

Figure 4. Gun and projectile displacements[10].

the Dirac-delta function and the gravitational acceleration, respectively.

By solving equation 4, vertical deflection of the barrel can be determined. In addition, the effects of projectile's muzzle velocity, barrel inclination angle, projectile mass, serial firings on the forced and free vibrations of the gun barrel can also be determined. The details of the solution of the problem are given in[11,12,13]. By the addition of the support flexibility, recoil motion, implementation of the more realistic barrel boundary conditions, the firing instant can be simulated more accurately.

Dynamic analysis using the proposed method expressed in references[11,12,13] show that inclination angle of the barrel increases the axial vibration of the barrel, the increase in the projectile mass and velocity increases the barrel muzzle end deflection. The analyses also show that the vertical vibration of the barrel muzzle end increases due to the increase of the projectile's inertia force and the serial firings affect the barrel vibration characteristics.

The barrel motion in the elevation axis during firing, can be also written as[14]:

$$j\ddot{\varphi} = M_e + M_b + M_v + M_{tb} + M_{tv} + M_s \qquad (6)$$

The distances of moment arms, the resultant moment, the location and number of recuperators and recoil buffer, length of barrel guidance in the cradle and the moment of inertia of recoiling parts play important roles on the muzzle oscillation and firing accuracy[14].

Ballistic gun codes which include interior ballistic analysis module and balloting (projectile motion inside the barrel) analysis module can be used to determine the barrel/projectile interaction. In balloting analysis modules, finite element based analysis is performed to determine the gun barrel-projectile interactions and gun barrel deflections as a function of projectile position and time are determined. Gun barrel and projectile models used in Prodas ballistic software are as shown in Fig. 5 as an example.

With this sort of analysis, muzzle exit sensitivity analysis, sabot design analysis for APFSDS projectiles, production tolerance effects, the effect of barrel curvature on the impact point and dispersion analysis can be performed.

Finite element 3D modelling techniques are useful in understanding the gun motion and barrel-interaction during the firing events[16,17,18]. Using these techniques, the effects of barrel curvature, off-axis masses attached to the barrel and off-axis forces due to recoil mechanism on the dynamic response of the gun system and the muzzle exit conditions (pointing direction of the muzzle, muzzle velocity, transverse velocity and angular velocity of the projectile) of the shot can be easily determined. Therefore, accuracy and consistency of the gun system can be improved in a cost effective way.

4. EFFECTS OF GUN STRUCTURAL COMPONENTS ON THE FIRING ACCURACY

In this section the effect of gun structural components such as trunnion bearings, cradle design, breech design, recuperator locations and bearing clearances are discussed.

According to the modernisation program in T72 tanks[14], the first shot hit probability was increased by 23 per cent and muzzle oscillation was decreased to half with respect to the original gun by reducing the muzzle oscillations and the cumulative effect of moment on the barrel during the motion of the projectile inside the barrel. This was accomplished by making changes in the recoil system and placing the recoil buffer and recuperator in the breech ring symmetrically. Breech ring was constructed symmetrical in the elevation plane crossing the barrel axis and the number of recuperators were increased twofold and symmetrically located in the upper section of breech ring. Recoil buffer was symmetrically located in the bottom side of the breech ring. Finally cradle tube which guides the barrel was extended to reduce the muzzle oscillation.

In the Arjun main battle tank the recoil system includes diagonally placed two hydro-spring mechanisms. The design of taper control rod provides uniform recoil and run-out, which results in increased accuracy and life of the system and the high rate of fire[19].

Long gun barrels like 55 calibre 120 mm tank guns are generally needed due to range and armour penetration requirements as a result of advances in composite armour systems. However, long gun barrels (~1.3 m longer than L44 calibre 120 mm calibre guns) are more flexible with respect to the short gun barrels. This results in the increase of the vibration amplitude of muzzle end. According to the firing

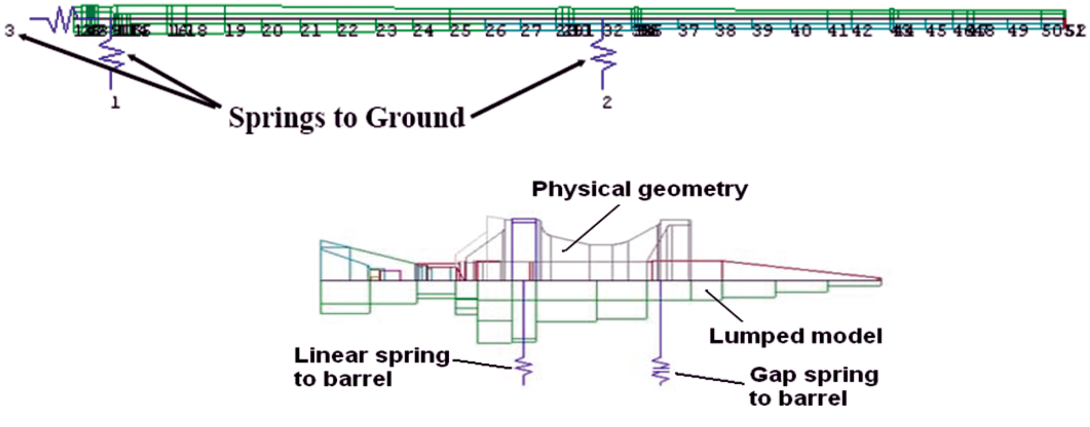

Figure 5. Prodas gun/projectile model[15]: (a) Barrel finite element model, and (b) Projectile finite element model.

tests[20] performed with 55 and 44 calibre guns from the same tank platform, hit accuracy was observed to be lower in 55 calibre guns especially when shooting from the moving tank. Suggested solutions to the reduction of this flexibility of longer barrels include decreasing the length of the cantilevered length of the gun barrel, increasing the cradle tube guidance, changing the cross-sectional profile of the barrel or changing the barrel material thereby increasing the bending stiffness of the barrel.

Small differences in the projectile initial positioning (seating) inside the gun chamber due to clearances between the front and rear rider of the sabot and barrel as shown in Fig. 6 could result in important changes in the projectile lateral velocity at the muzzle exit.

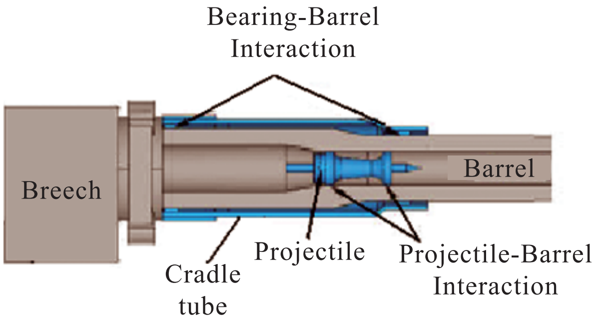

Figure 6. Gun components interaction[17].

In addition, there exist small clearances among the parts within the gun recoil system due to manufacturing tolerances such as the clearances between the sliding contacts at thrust bearing-barrel. As a result of clearances in the recoiling parts of the gun coupled with an unbalanced breech, the gun movement changes from firing to firing and occasion to occasion, leading to perturbations in the projectile exit conditions. These disturbances affect the motion of the gun system and jump angle and cause deviations in the projectile trajectory path resulting an increase in dispersion.

In some gun systems like M256, there are kick blocks that engage the breech block as it returns into battery, constrain the breech motion in the elevation axis and guides it to sit in the cradle the same position after every firing. Because the breech motion directly influences the shape of the gun barrel, a reduction in the amplitude of the breech motion could provide a straighter gun barrel while projectile is moving inside the gun barrel. This results in repeatable and consistent firing performance[21,,22,23].

Balancing of breech has a positive effect on the overall performance of the gun system. In an unbalanced breech system, the gun has an asymmetrical breech block causing the centre of gravity of the recoiling mass to be shifted from the gun tube axis. After firing, the pressure from the burning propellant exerted on the breech face, results in an offset between the centre of gravity and the centre of pressure. As a result of this torque, gun barrel movement occurs in both axis. An increase in breech eccentricity results in an increase in muzzle transverse deflection and the velocity. By balancing the breech, this source of gun motion could be reduced in both elevation and azimuth axes[17,21,23].

Furthermore, the results of the experimental work[24] show that, the accuracy of tank gun can be improved as a result of reduction of the occasion-to-occasion error due to the decreased dynamic response to the recoil force.

Cradle bearing position and cradle bearing stiffness affect the muzzle transverse velocity, muzzle slope and cradle rotation[25]. To shoot accurately it is important that the gun barrel not move relative to the cradle in the horizontal and elevation axes upon firing. Therefore bearing play should be compensated for in axial and radial directions[26].

One of the methods to compensate for bearing play, is the use of adjusting rings (nuts) as seen in Figs. 7 and 8.

These rings are screwed on two bearing rings or at least on one of the two bearing rings. The adjusting rings can be fastened after the insertion of the gun in the direction against the sidewalls of the turret and compensate for axial play of the axial needle bearings or the radial roller bearings. These rings keep the axial bearings under axial compression so that the play is eliminated[26,27].

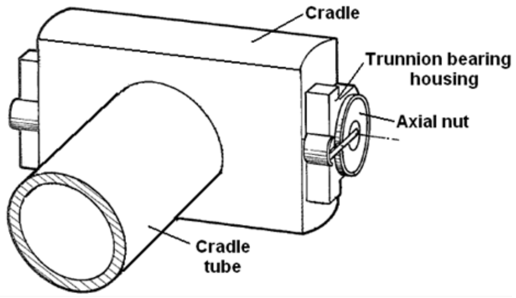

Figure 7. Presentation of trunnion bearing housing[26].

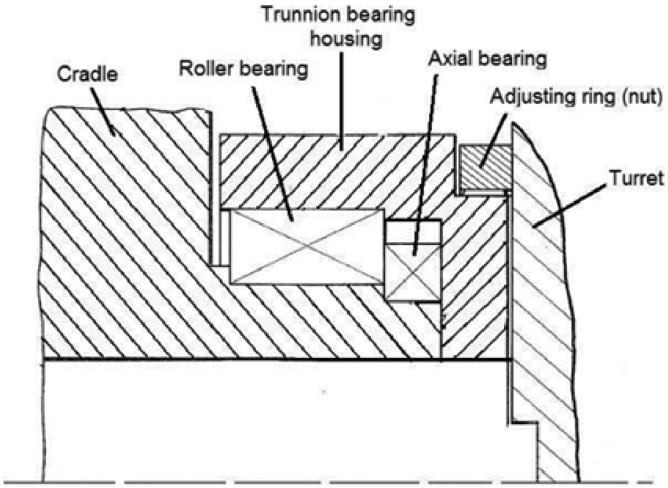

Figure 8. Cross-section of trunnion bearing and its housing[27].

As radial bearings, toroidal roller bearings can be used in order to compensate for alignment errors in the trunnions or their receiving components without exerting additional stresses on the cradle frame[28].

Other parameters that affect the amplitude of the barrel oscillation and firing accuracy while the projectile is moving inside the barrel are the mass moment of inertia and the location of the centre of gravity of the recoiling mass. Increasing the mass moment of inertia decreases the barrel oscillations while the projectile is travelling inside the gun tube. For the ratio of the gun barrel length to bore diameter L/D> 52, a relatively short support width of 6D to 7D is required. This way, the centre of gravity moves forwardly towards the muzzle end of the gun barrel. With this change, the angular motion of the barrel due to gun firing is reduced and the jump angle becomes more uniform in each successive firing[29].

Another way of prevention of the barrel vibration and strong change in jump angle is through the change in barrel guidance design. In conventional designs, the barrel is seated in two slide-bushing bearings, which are positioned at the muzzle- and breech-side ends of the cradle barrel. In slide-bushing bearing designs, the gun barrel rests on the lower inside edge of the bearing, as stipulated by its mass, and lifts due to the expansion of the barrel during firing. This phenomenon causes the barrel to oscillate, and has an adverse effect (i.e. increase or change the jump angle) on the jump error of the projectile[30,31]. Lift-effect-free bearings may reduce the negative effects caused by conventional slide-bushing bearings. Lift-effect-free bearings fit in the cradle-tube such that there is the smallest possible amount of play. Lift-effect-free bearing type barrel bushings have at least three segment-like support ribs, which are uniformly distributed around the circumference of the bushing. This barrel bushing has recesses on the outer surface, and segment-like recesses on its inner wall opposite the support ribs[31].

5. CONCLUSIONS

A tank weapon system including the projectile inherently owns errors. These errors can be categorised as fixed-bias errors, variable bias errors and random errors. Fixed-bias and variable bias errors are generally easily controlled errors. On the other hand, random errors generally cannot be reduced or controlled during firing. So they should be eliminated in design and production phases.

In this study, the tank gun components which cause random errors and have important effects on the first shot hit probability are discussed and studies covering the design recommendations to reduce the random errors are reviewed.

Higher first shot hit probability is achieved by almost constant gun dynamics response under every shot. In order to achieve higher first shot hit probability under all battlefield conditions, all types of error sources should be controlled as much as possible.

Thrust and trunnion bearing elasticity, bearing types, bearing clearance, bearing and barrel damping, barrel expansion on the barrel response during firing, recoiling system, cradle design, balancing of the breech, the spacing between the thrust bearings, the shape of thrust bearings (barrel bushings) are the most important gun structure related parameters which affect the gun jump characteristic. These structures should be designed such that, gun motion and gun jump angle are almost similar and constant after every shot.

Although hydro-pneumatic type of recoil mechanisms are widely used in combat vehicles due to their consistent performance, but the performance of these system are affected by terrain/weather conditions. Curvilinear recoil system and adaptive recoil systems are the two candidates that can be used in place of existing systems which depend on soft recoil mechanism and non-Newtonian fluid (Electro-rheological and Magneto-rheological fluid). These systems increase both the stability, accuracy and fire power of the gun[9].

Furthermore, the results of the experimental and numerical studies show that, the reduction of asymmetry in all parts of the gun/projectile system has beneficial effect on the reduction of both the random and the regular bias content of jump.

The vibrations and/or relative motions between the moving gun components which occur during firing instant should be minimised, so that the jump angle becomes more uniform and consistent in every firing.

In-bore and free-flight simulations give an important idea about the variation of the gun jump angle and dispersion of the gun system. Numerical simulation of gun dynamics is an important effort to have a deep insight about the effects of the gun system components during firing instant and for the sensitivity analyses. In finite element dynamic analyses, the real firing event is simulated including the detailed interaction between the moving components of the tank gun system, clearances, friction, damping and flexibility of the necessary components.

By performing extensive and detailed firing tests and obtaining data using strain gauges, laser autocollimators, high speed cameras, x-ray equipment and radars etc., the dynamic behaviour of the gun system such as gun motion, barrel shape, projectile motion, jump angle, muzzle velocity components etc. should be determined and the data acquired from these tests should be used to verify both the numerical simulations and gun component designs in order to reach the desired first shot hit probability.

For a future combat scenario, requirements for the main battle tanks may considerably vary than the traditional main battle tanks. The revolutionary configuration may require higher fire power but a lighter platform[32]. Therefore, the gun system design may change accordingly in order to achieve higher accuracy and consistency.

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