Defence Technology 13 (2017) 353–359

Contents lists available at ScienceDirect

Defence Technology

journal homepage: www.elsevier.com/locate/dt

# A review on the gun barrel vibrations and control for a main battle tank

Tolga Dursun*, Fırat Büyükcivelek, Çağrıhan Utlu

*Aselsan Inc MGEO Division, CankiriYolu 7.km Akyurt, Ankara 06750, Turkey*

ARTICLE INFO

*Article history:*
Received 1 December 2016
Received in revised form
7 April 2017
Accepted 19 May 2017
Available online 25 May 2017

*Keywords:*
Gun dynamics
Vibration control
Muzzle reference system
Vibration absorber

ABSTRACT

Achieving high hitting accuracy for a main battle tank is challenging while the tank is on the move. This can be reached by proper design of a weapon control and gun system. In order to design an effective gun system while the tank is moving, better understanding of the dynamic behavior of the gun system is required. In this study, the dynamic behaviour of a gun system is discussed in this respect. Both experimental and numerical applications for the determination of the dynamic behaviour of a tank gun system are investigated. Methods such as the use of muzzle reference system (MRS) and vibration absorbers, and active vibration control technology for the control and the reduction of the muzzle tip deflections are also reviewed. For the existing gun systems without making substantial modifications, MRS could be useful in controlling the deflections of gun barrels with estimation/prediction algorithms. The vibration levels could be cut into half by the use of optimised vibration absorbers for an existing gun. A new gun system with a longer barrel can be as accurate as the one with a short barrel with the appropriate structural modifications.


## 1. Introduction

Main battle tanks require effective weapon control system and gun system in order to achieve the highest hit probability under all battlefield conditions, in the shortest possible reaction time from a stationary or moving tank to a stationary or moving target. Weapon control system is composed of two main parts. These are fire control system (FCS) and gun control system (GCS).Weapon control systems used in main battle tanks (MBTs) stabilise the line of sight (LOS) and line of fire (LOF) in order to increase the firing accuracy while the MBT is on the move.FCS determines the necessary motions of the gun and the conditions that will achieve the highest first shot hit probability. These are realised by ballistic computation of data obtained from sensors (laser range finder, meteorological sensor, gun and vehicle encoder and inertial measurement units etc.) and the application of fire inhibit algorithms. On the other hand, gun control system implements the gun and turret motion by the help of elevation and azimuth drivers and stabilization algorithms. Controller algorithm designs which are important in achieving higher stabilisation performance have been studied in Refs. [1–5]. An efficient control strategy must be employed to ensure precision pointing of the gun according to the gunner's or commander's sighting system. It is important that the gun control system satisfies this performance under the harsh ground vibrations induced due to the movement of the main battle tank along the rough terrain. The main source of vibration in a main battle tank is the running gear system. This system includes tracks, sprockets, idler wheels and support rollers. Most vibrations are generated by the constant impact of the driving sprockets on the moving tracks when the vehicle is in motion. Interactions between the tracks and the ground, the idler wheels as well as the support rollers also cause vibration. In addition the running engine and transmission are the other sources of vibration in the main battle tanks [6–8].

The performance objective of the classical gun control system is to maintain minimum trunnion-pointing error as measured by the gun-trunnion angular measurement sensor. Since the gun barrel is a long flexible tube, during the MBT is on the move, the gun barrel deflects. Therefore muzzle end points deflected LOF with respect to the trunnion axis (stabilised point). This deflection, caused by the terrain induced vibration of the gun barrel; results in the dispersion of shots on the target leading to the decrease of the effectiveness of the weapon system and reduced first shot hit probability (FSHP). The gun flexibility is not generally considered in gun systems which

* Corresponding author.
*E-mail address:* tdursun@aselsan.com.tr (T. Dursun).
Peer review under responsibility of China Ordnance Society.

http://dx.doi.org/10.1016/j.dt.2017.05.010

use L44 calibre gun or similar. Since 1990s, the L44 calibre gun was not considered powerful enough to defeat the new generation armours, which led to the development of advanced 120 mm L55 calibre gun. The L55 gun is approximately 1.3 m longer, giving an increased muzzle velocity (from 1600 m/s to 1750 m/s) to the ammunition fired through it. Longer gun barrels, however, are more susceptible to ground induced vibration. This modification in the gun barrel should not decrease the FSHP of the tank while the tank is on the move.

Since the introduction of the L55 calibre guns, researchers have performed many experimental and numerical studies in order to investigate the effect of the longer gun barrel on the firing accuracy of the tank gun and increase the availability of this gun system. Studies on the vibrations of gun barrel can be grouped in five classes such as the determination of the dynamic characteristics of the gun/projectile system, control of the muzzle end deflection using muzzle reference systems, reduction of the muzzle end vibration using vibration absorbers, reduction of the muzzle end vibration with structural modifications in the gun, and last but not least, studies on the muzzle end deflection estimation/prediction using fire control algorithms (coincidence algorithms, which calculate the right time to allow firing) in conjunction with the sensors such as the gun gyros and accelerometers. In this review paper the first four classes of studies are discussed in detail. The last issue will be discussed in detail in future work.

## 2. Dynamic characteristics of a tank gun/projectile system

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) MRS, (6) breech mechanism, (7) elevation mechanism (elevation gear) and (8) recuperator as shown in Fig. 1.

Vibration of a gun barrel is composed of two dynamic events. These are the interaction of the projectile with the barrel during firing instant and the vibration of gun barrel due to the motion of the tank over the rough terrain. The last event is discussed in the next section. The motion of the projectile inside the gun tube is affected by the gun/projectile stiffness, clearance between the barrel and the projectile, the gun barrel centerline curvature, the velocity of the projectile, asymmetric gas pressure etc. The

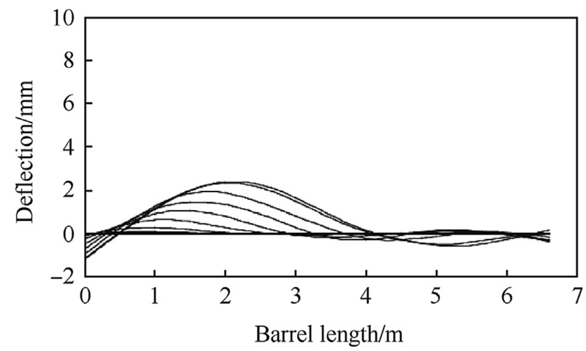


**Fig. 2.** Centre line of the deflected gun barrel [9].

centerline of the deflected gun barrel during the motion of the projectile inside the gun barrel evaluated using finite element analysis [9] is shown in Fig. 2. In Fig. 2 each curve represents the centerline of the deflected shape of the gun barrel at 1 msec intervals during firing instant.

Dynamics of a moving projectile in a gun barrel can be described by the following equations [10]. The total kinetic energy ($T$) of the projectile/gun barrel system is

$$T = T_{\text{gun}} + T_{\text{projectile}}$$
$$T = \frac{1}{2}m_{\text{g}}\left(\dot{x}_{\text{g}}^2 + \dot{y}_{\text{g}}^2\right) + \frac{1}{2}I_{\text{g}}\dot{\theta}^2 + \frac{1}{2}m_{\text{p}}\left(\dot{x}_{\text{p}}^2 + \dot{y}_{\text{p}}^2\right) + \frac{1}{2}I_{\text{p}}\dot{\alpha}^2 \quad (1)$$

where $m_{\text{g}}$, $m_{\text{p}}$ are the masses of the gun and the projectile and $I_{\text{g}}$, $I_{\text{p}}$ are the mass moments of inertia about the centers of gravity of the gun and the projectile. $\dot{x}_{\text{g}}$ and $\dot{y}_{\text{g}}$ are the translational velocity of the center of gravity of gun, and $\dot{x}_{\text{p}}$ and $\dot{y}_{\text{p}}$ are the translational velocity of the center of gravity of projectile respectively. Angles $\theta$ and $\alpha$ are shown in Fig. 3 $\dot{\theta}$ and $\dot{\alpha}$ are the respective angular velocities of angles $\theta$ and $\alpha$.

The total potential energy (V) of the projectile/gun system is

$$\text{V} = \text{V}_{\text{gun}} + \text{V}_{\text{projectile}} + \text{V}_{\text{bourrelet\_contact}} + \text{V}_{\text{obturator}} + \text{V}_{\text{foundation\_moment}}$$
$$\text{V} = m_{\text{g}}gy_{\text{g}} + m_{\text{p}}gy_{\text{p}} + \frac{1}{2}k_{\text{bc}}\delta_{\text{bc}}^2 + \frac{1}{2}k_{\text{o}}\delta_{\text{o}}^2 + \frac{1}{2}k'_{\text{o}}(\delta_{\text{o}} - R_{\text{c1,o}})^2 + \sum_n \frac{1}{n}a^n\alpha^n \quad (2)$$

Where $k_{\text{bc}}$ is the stiffness of the bourrelet, $\delta_{\text{bc}}$ is the displacement of the projectile into the gun bore, $\delta_{\text{o}}$ is the projectile displacement at the obturator, $k_{\text{o}}$ and $k'_o$ represent the stiffness of the plastic band

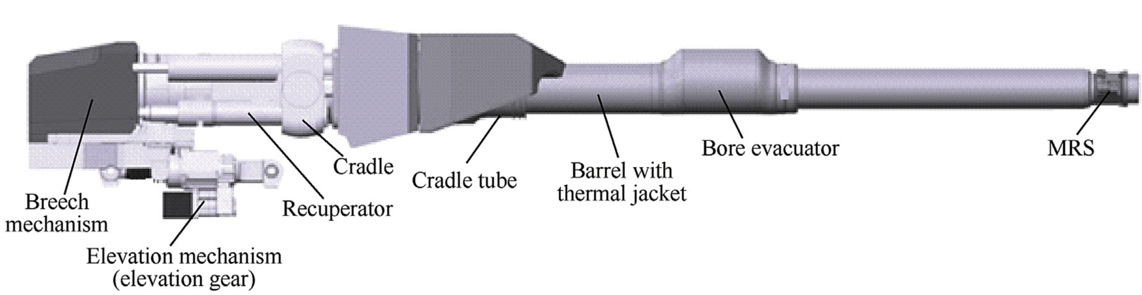


**Fig. 1.** A typical tank gun system.