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Rigid body dynamics modeling, experimental characterization, and performance analysis of a howitzer

Nachiketa TIWARI [a,*], Mukund PATIL [a], Ravi SHANKAR [a], Abhishek SARASWAT [a], Rituraj DWIVEDI [b]

[a] *Department of Mechanical Engineering, Indian Institute of Technology, Kanpur, India*
[b] *Ordnance Factory, Kanpur, India*

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Abstract

A large caliber howitzer is a complex and cumbersome assembly. Understanding its dynamics and performance attributes' sensitivity to changes in its design parameters can be a very time-consuming and expensive exercise, as such an effort requires highly sophisticated test rigs and platforms. However, the need of such an understanding is crucially important for system designers, users, and evaluators. Some of the key performance attributes of such a system are its vertical jump, forward motion, recoil displacement, and force transmitted to ground through tires and trail after the gun has been fired. In this work, we have developed a rigid body dynamics model for a representative howitzer system, and used relatively simple experimental procedures to estimate its principal design parameters. Such procedures can help in obviating the need of expensive experimental rigs, especially in early stages of the design cycle. These parameters were subsequently incorporated into our simulation model, which was then used to predict gun performance. Finally, we conducted several sensitivity studies to understand the influence of changes in various design parameters on system performance. Their results provide useful insights in our understanding of the functioning of the overall system.

Keywords: Howitzer gun; CAD modeling; Dynamic simulation; Recoil assembly parameters; Sensitivity analysis

1. Introduction

Performance prediction and analysis of artillery weapons have been going on across the world for a long time. Different approaches, analytical, experimental, and numerical, have been deployed to achieve these objectives. Walton et al. [1] have analyzed the performance of hydraulic gun buffers by building a test facility to simulate the reaction loads imposed on the recoil absorbers. They used these facilities to understand the sensitivity of the buffer performance with respect to changes in recoil mass, velocity, fluid viscosity and density. Eksergian's work [2] is a fairly well known reference used for study of recoil systems. Seah and Ooi [3] have performed FE simulations on an artillery system. They used their model to predict the recoil displacement, pressure and force as functions of time and angle of elevation. Ozmen et al. [4] have conducted static, dynamic and fatigue analyses for a semi-automatic gun locking device, with the aim to reduce recoil forces acting on the device. Letherwood and Gunter [5] have simulated the dynamic behavior of wheeled and tracked ground vehicles over at different points of time in their life cycle. To determine the stiffness and damping characteristics of shock absorbers, Rao and Gruenberg [6] developed an electrodynamic shaker based test rig. In this work, we have developed a detailed rigid body model for a typical howitzer gun. This included developing a 3D CAD model and incorporating it into the rigid body dynamics simulation model for the gun. Next, we developed experimental and analytical tools to estimate important design parameters affecting gun performance. Specifically, these tools determined stiffness and damping of recoil mechanism, tire stiffness, and friction coefficient between cradle and guide rails. The estimated design parameters were then incorporated into our simulation model, and the gun's performance was evaluated. The model was also used to conduct numerous sensitivity studies to understand the influence of variations in key design parameters on system's performance.

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* Corresponding author. Tel.: +919559270306.
E-mail address: ntiwari@iitk.ac.in (N. TIWARI).

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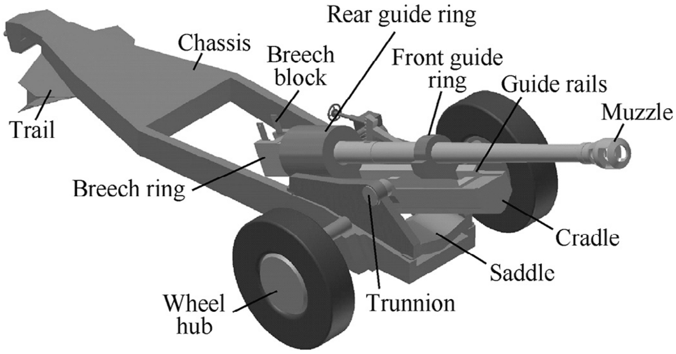

Fig. 1. Gun assembly.

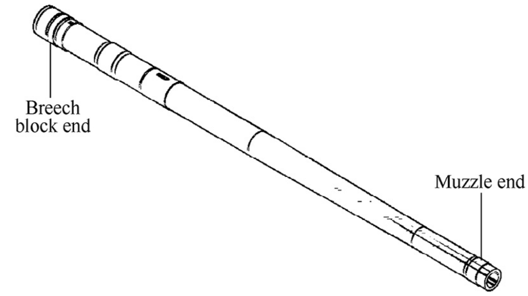

Fig. 3. Barrel.

1.1. Construction of a gun

Fig. 1 provides an overview of the gun assembly. The gun is assembled around a chassis, which is connected to the ground through two tires and a trail during the firing operation. Thus, all the reaction forces are transmitted to the ground through tires and trail. However, when the gun is moving, the trail no longer touches the ground, and instead two extra tires are attached to the chassis. The chassis is the "foundation" for all other important gun sub-assemblies. On top of it is where the saddle is mounted, which provides two supporting arms for placement of the cradle through two trunnion eyes. It is in these eyes that the trunnions of cradle are seated. The cradle is free to rotate around the axis of trunnions. Such an arrangement facilitates changing of the elevation angle (or azimuth) of the gun's firing direction with the help of an elevating gear mechanism, which is not shown in Fig. 1. The cradle houses the recoil system. On its upper side, there are two longish slots, one on each side, which run along its entire length. These slots provide a seat for guide-rail slide mechanism. The assembly is crafted in such a way that the slide mechanism can move back and forth in these slots.

Fig. 2 shows the details of guide rails and guide ring sub-assembly, which is mounted in the cradle. The sub-assembly has two guide rings, front and rear, used for seating the barrel which is shown in Fig. 3. The barrel is the most important part of the entire system. Its rear and front ends are termed as breech and muzzle ends. At the breech end, attached are a breech ring and a breech block. The latter component acts as a door, which is firmly shut once the projectile and charge are inserted in the barrel for firing. The muzzle end is connected to the muzzle break. The barrel with its breech assembly and the muzzle brake fits firmly into the guide rings.

The gun also has a recoil and counter-recoil mechanism, which serves two important functions. Firstly, such a system absorbs extremely high recoil forces which are generated during gun firing. Secondly, the system also ensures that the barrel gets back to its original position post firing of the projectile. Its details are shown in Fig. 4.

The recoil and counter-recoil mechanism is made up of a recoil brake assembly, and a recuperator assembly [7]. While the former element absorbs recoil energy so that only a small fraction of it is transmitted to the chassis, the latter element ensures that the gun barrel returns back to its original position after the recoil period. A system with an inefficient recoil system will require very heavy chassis. Similarly, a system with a suboptimal counter-recoil system will not bring back the barrel to its original position post firing of a projectile. Both these conditions are not desirable from a standpoint of operational efficiency. The recoil brake system is essentially a damper and has a hydraulic piston–cylinder arrangement. Its cylinder is bolted to the cradle while its piston is bolted to guide rails. The cylinder is filled with viscous oil, which is forced through a large number of orifices by compressive forces generated because of recoil motion of the piston. The recuperator is essentially a spring which is made up of one or two piston–cylinder arrangements. Similar to the recoil system, this assembly is connected on one side to the cradle, and on the other side

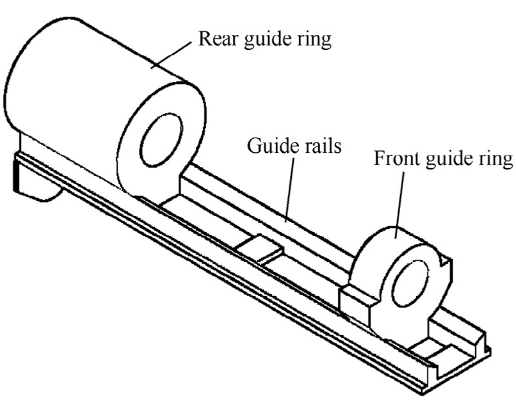

Fig. 2. Guide rails and guide rings.

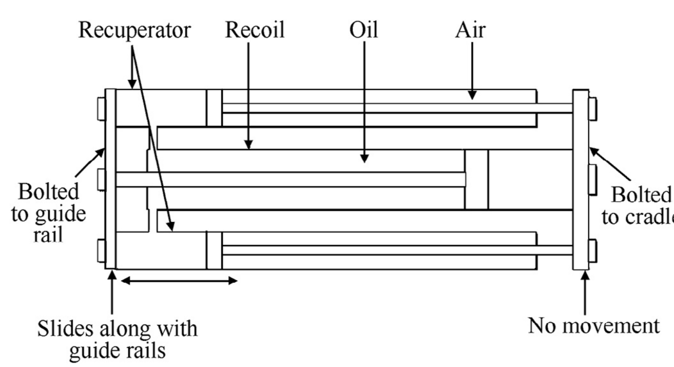

Fig. 4. Recoil and counter recoil mechanism.