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Dynamic simulation of the recoil mechanism on artillery weapons

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Summary

The artillery weapons have been developed from the thirteenth century to the present. Generally, it contains a gun body and a gun mount. The gun body consists of a barrel, a breech, a breechblock, and a muzzle brake. In addition, the gun mount is composed of recoil mechanisms, elevating mechanisms, traversing mechanisms, and supporting parts. Among these parts, the muzzle brake and recoil mechanism can reduce the mass recoil force during firing, and push the gun body back to the original position after firing. Before the mid-nineteenth century, general guns did not assemble any device having the cushioning effect. For this reason, people had to design bulky guns to avoid the powerful recoil force. It took much time to return the gun tube to the original position and aim again. In order to solve this problem, the designers tried to install a buffer in the base which could generate a retarding force to stop the recoil motion. Finally, the recoil mechanism was invented in the ninth decade of the nineteenth century.

The recoil mechanism is mainly used to absorb the recoil force during firing, and furthermore it can make use of compressed gas or mechanical spring to return the gun tube to its original position. In other words, the recoil is the rearward movement of the gun and connected parts during and after firing. It is caused by the reaction to the forward motion of the projectile and propellant gases. After recoil, the gun and connecting parts return to the in-battery, or firing position. This forward movement is called "counter recoil". If the gun were mounted rigidly without any recoil system, it would be practically impossible to build a carriage to withstand the load imposed upon it without rupturing, overturning, or moving. To bring the carriage stresses down to a reasonable value and to ensure the stability, a recoil system is interposed between the gun and the carriage. In recent years, the development trends of artillery weapons with recoil mechanisms focus on the vehicular integration. It can increase the mobility of artillery weapons. Therefore, a small volume, high recoil efficiency, small recoil length, and low cost of the recoil mechanism which can be easily installed on vehicles is very important.

The system of the recoil mechanism usually consists of eleven components: recoil piston rod, recoil piston, cushion, dish spring, recoil cylinder, recuperating cylinder, counterrecoil buffer, floating piston, recoil throttling valve, regulator, and regulator valve. All of these components have their own respective functions,

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which will be introduced in this paper. Because the recoil mechanism was developing for a long time, there are many available devices using in different kinds of guns. There is a general classification, hydrospring and hydropneumatic types as shown in Figure 1 proposed by Horm(1982). The classification of the recoil mechanism is often seen in the national defense industry. These two types of the recoil mechanism principally differ from their action components, one is the spring and the other is compressed gas.

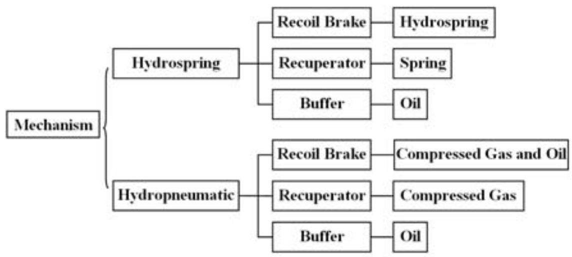

Figure 1: Classification of the recoil mechanism

The innovation of the recoil mechanism is not easy because there are so many problems which need to be solved. According to the above reasons, the purpose of this paper is to find a mathematical model for the recoil force during firing. In addition, it can be implemented by the computer program for simulation. The results which are presented and constructed by this paper can provide a clear understanding for designing the mechanism or improving the performance of recoil ability in the future.

All kinds of recoil mechanisms operate according to same basic principles. The apparatus can control forces, through the specific recoil movement. In other words, it makes use of the force to retard the gun tube, and return the gun tube to original position. When firing, owing to the action of the gas recoil force and the recoil braking force, the load on the gun body often varies from time to time. The forces generated from the components of the recoil mechanism are listed in Figure 2.

Two main methods are used for the dynamic model creation. First, the free body analysis is applied on the system components because the required forces can be found easily. Forces can be treated as the internal or external ones according to the free body setup. If the component is too complex to find its physical or mathematical model, it can be treated as a “black box” in the second stage. In such black boxes, experience data and curve fitting methods are used to create the relation that supports for dynamic system. Only input data and output responses are used for analysis, such as the equivalent orifice, the situation of sliding surface, the affect of all packing, and etc. The dynamic models are similarly built in Matlab Simulink according to these equations. The model is shown in Figure 3 and its

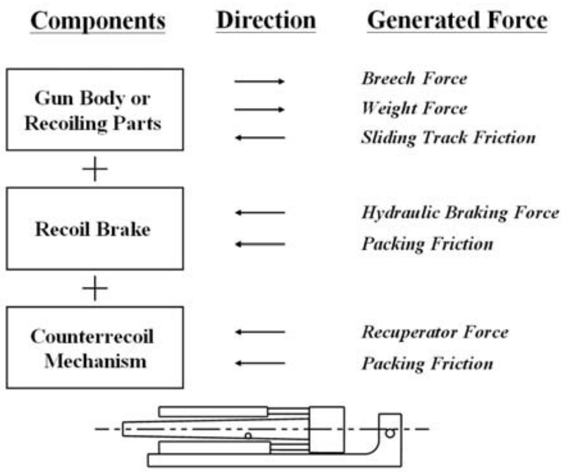

Figure 2: Forces generated from the components

flowchart is shown in Figure 4.

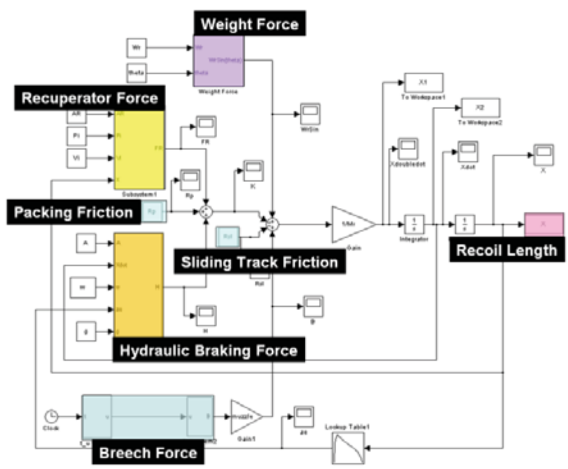

Figure 3: Dynamic model of the recoil mechanism

In order to simplify the models, some assumptions are supposed in the free body analyses.

The boundary condition is free release and free recoil (Ma, 2004). The analysis focuses on the motion of the recoil mechanism only. It uses systematic view to analyze the force behavior, and isn't affected by external force of other components.

The supporting structure is immovable. The supporting structure of the gun body is a rigid body. Its quantity of motion is very small. Thus, the motion of the supporting structure is neglected. It means that the analysis only focus on the first

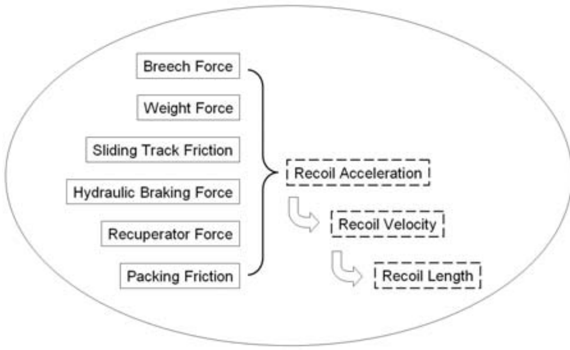

Figure 4: Flowchart of the model

recoil effect.

The effect on the muzzle brake is ignored (Lou, 2005). The recoil force is balanced by the muzzle brake and the recoil mechanism. The forces of these two parts are with a proportional relation, such as thirty percent for the muzzle brake and seventy percent for the recoil mechanism. Therefore, the effect on the muzzle brake could be ignored.

The analysis focuses on the bore period during firing. The bore period means that a projectile moves along the bore of barrel until exiting the muzzle. After a projectile exits the muzzle, the bore pressure would drop to atmospheric pressure gradually. And the influence on recoil force is very small. For this reason, the analysis only focuses on the bore period.

The parameters of the M178 recoil mechanism on the M109 155mm self-propelled howitzer are used. The simulation results are shown in Figure

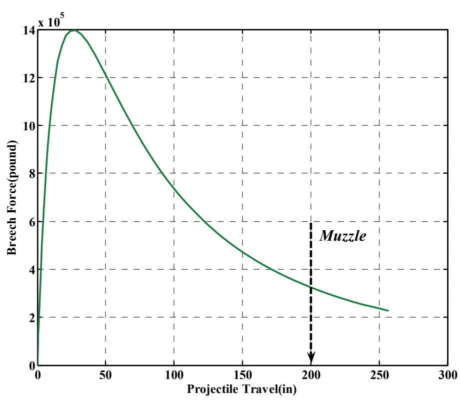

Figure 5: Breech force versus projectile travel

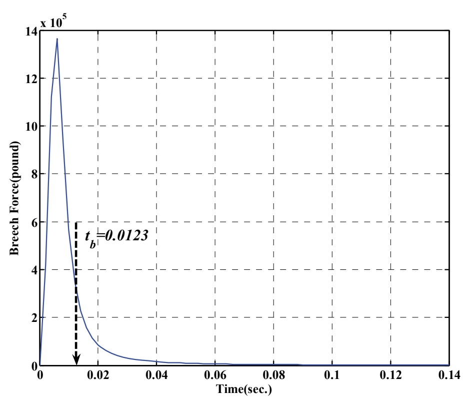

Figure 6: Breech force versus time

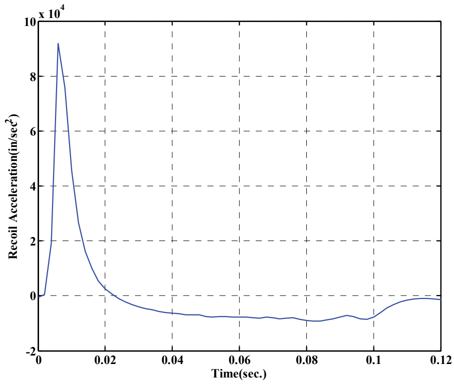

Figure 7: Recoil acceleration versus time

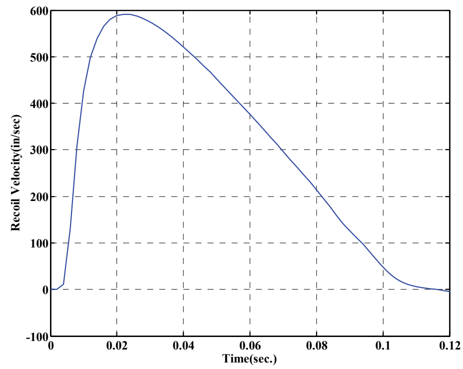

Figure 8: Recoil velocity versus time

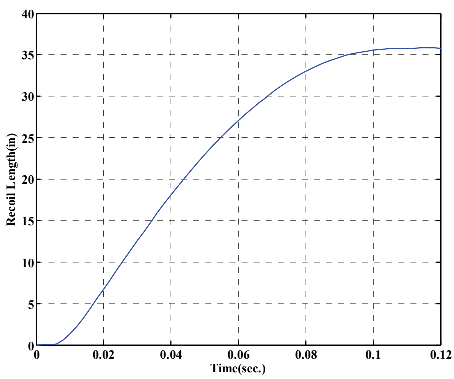

Figure 9: Recoil length versus time

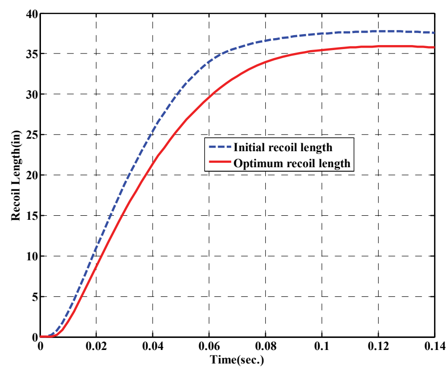

Figure 10: Optimization result

The simulation of the dynamic model shows that the maximum recoil length can be computed specifically. Under different conditions, there are changes on the recoil length. It means that the simulation result predicts the changes of recoil length. It can save the cost to do many real experiments. Furthermore, the maximum recoil length is improved by adjusting the simple design variables. And it makes the space of the artillery use effectively.

The model proposed in this paper can also be used to predict the braking force in order to control the recoil travel. The mechanical parameters, such as bore area, barrel length, projectile weight, fluid density, cylinder or piston dimension, and etc., are treated as the input factors to the model. Then, the optimum braking force during firing can be obtained according to the gun tube elevation and the limited recoil length. Also, the optimization analysis for the parameters in the dynamic model can be performed. Large recoil distance is the most important problem that hinders from designing the space requirement of other mechanisms.

Therefore, optimization will focus on how to reduce the maximum recoil length. Therefore, the maximum recoil length of the recoil mechanism which is needed to be minimized is defined as the cost function of the optimization problem.

Cost function:
After the model construction of the recoil mechanism, this section uses this model to perform optimization. Large recoil distance is the most important problem that hinders from designing the space requirement of other mechanisms. Therefore, optimization will focus on how to reduce the maximum recoil length. Therefore, the maximum recoil length of the recoil mechanism which is needed to be minimized is defined as the cost function of the optimization problem.

Design variables:
There are four design variables: the barrel length, the projectile weight force, the effective area of the recoil piston, and the effective area of the recuperating cylinder. The barrel length is the geometrical parameter from the recoiling parts. The barrel length affects the value of the breech force. Since the artillery has different length of barrel, adjustment of barrel length most modifies the required breech force. The projectile weight force is the weight of the projectile. It also affects the value of breech force. Since the artillery has different weight of projectile, adjustment of the projectile weight can control the required breech force. The design value can be adjusted as long as the gunshot is still satisfied. The effective area of the recoil piston is the geometrical parameter from the recoil brake. Effective area of the recoil piston affects the value of hydraulic braking force. It affects the total braking force indirectly. And it provides negative relation of recoil length. Finally, the effective area of the recuperating cylinder is the geometrical parameter from the recuperator. Effective area of the recoil piston affects the value of recuperator force. Although it doesn't affect the recoil length too much, it is still improved to find a better design on the recoil length.

Constraints:
In order to avoid unimplemented optimization result, some constraints are defined in this subsection. First, since the cost function of the optimization is to minimize the maximum recoil length, improper parameter setting may cause the optimization results impracticable. Thus, it needs some suitable range to constraint the geometrical parameters in the mechanism.

According to the definitions in previous subsections, optimization of the mechanical structure of the recoil mechanism is executed by using Matlab. In this study, optimization Toolbox Matlab is used to solve the problem. Since the optimization problem is defined as a nonlinear constrained multivariable problem, "fmincon", which is used to find a minimum of a constrained multivariable function, is chosen to solve the problem.

After optimization, it is obviously that the maximum recoil distance is reduced from 37.7573*in* to 35.9117*in*. It decreases 1.8456*in* (about 5%) from the original length as shown in Figure 10.

From the design viewpoint, designers can adjust these parameters and the mechanism can complete the recoil motion in the pre-determined space. The proposed model improves the fixed recoil length on the current artillery, and the artillerist can operate the system easily and automatically without complex instructions.

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