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Design and Performance Analysis of Smart Fluid Damper for Gun Recoil System

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ABSTRACT

When a gun is fired, the burning propellant charge generates a blast of pressurized gases that impose enormous loads on the projectile as well as on the gun structure. Although the firing event has a short duration, the pressure forces impart a strong impulse load to the gun structure. To mitigate such a strong impulse and to maintain the displacement of recoil mass within specified limit the passive absorbers are not suitable. Also the passive system is unable to deal the changes in firing forces once it designed for particular load. To deal such variations in loads the smart fluid damper is designed. For designing the damper thorough study of smart fluid and gun recoil dynamics is carried out, as the MR fluids have higher yield strength than that of ER they are selected for this applications. During designing of damper the effect of various parameters on damping force and dynamic range are studied. The trade-off between number of coils and dynamic range has been found out.

Once the damper is designed the mathematical modelling of gun recoil system is formulated. The response analysis of system is carried out by MATLAB software with known charging forces and at different angles for 155 mm howitzer. Recoil mass displacement, velocity, acceleration and force transmitted to structure are the performance parameters. After the performance analysis the result are compared with passive system.

Keywords: Smart Fluid, MR damper, Mathematical modelling, MATLAB.

INTRODUCTION

The gun fire imparts strong impulse load on structure, it is necessary to put control on these loads appropriately. Traditionally, heavy guns minimize recoil load transmissions by employing recoil absorbers that control the recoil force by absorbing the propellant gas impulse. Generally, the recoil mechanisms utilize passive components such as a stiff spring, a viscous damper, or muzzle brakes. This passive system leads to [1] following limitations;

- The areas of flow orifices are designed for a particular angle and cannot be applicable when firing angle changes.
- When the impact load changes, the passive recoil system cannot change the force accordingly.
- The change of areas of orifices is the nonlinear function of piston displacement but due to manufacturing constraints they are manufactured as the approximate linear function.

The above limitation can be overcome by using semi-active system consisting of smart fluid damper. This smart fluid absorber has advantages that it produces adjustable damping force, not require designing the variable orifices, also it suitable for different shooting angles.

Smart fluids are the fluids whose [5] physical attributes can be changed by the external stimulus. Basically there are three types of smart fluids; magnetorheological (MR), electrorheological (ER) and ferro fluids. All of these smart fluids become more viscous when activated; they can be converted from a gel into a liquid (or vice versa) almost immediately. For gun recoil application the damper should produce higher damping force which mostly depends on the dynamic yield strength of fluid. The table 1 explains comparison of smart fluids. From table 1 it is clear that the MR fluid has higher yield strength hence MR fluid is selected as working fluid for our application.

Table 1 Comparison of Smart Fluids

	MR Fluid	ER Fluid	Ferro Fluid
Yield strength	~130 kPa	~ 10 kPa	No change
Device Excitation	Electromagnets or permanent magnets	High voltage	Permanent magnet
Required field	150-250 kA/m	3kV/mm	~1 kOe

MR DAMPER

For analytical evaluation of MR damper it is assumed that the fluid follows the typical Bingham plastic model. And hence the linear stroke MR damper can be analyzed [3] using Bingham plastic model incorporating minor losses (BPM). For gun recoil application double ended configuration is considered. The double-ended configuration had piston rods on both ends of the piston and resulted in simplified analyses because there was no change of volume inside the hydraulic cylinder by the piston displacement.

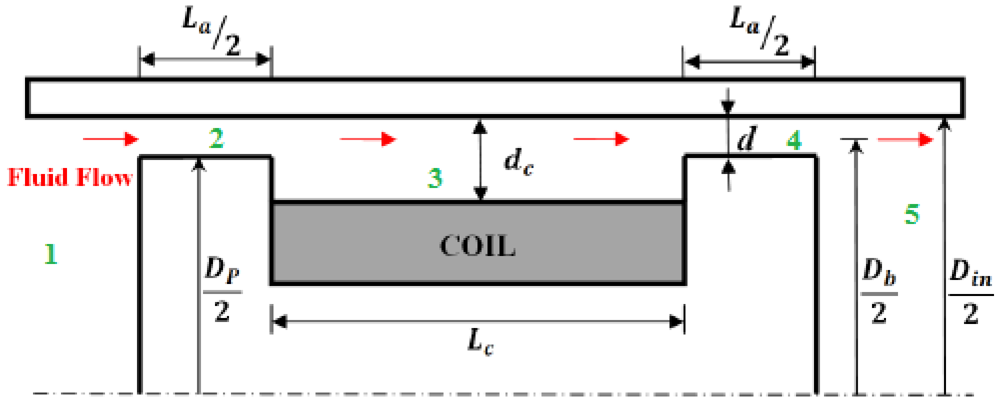

Figure 1 Geometric fluid circuit of single stage electromagnetic coil [3]

As MR damper in gun recoil works under high fluid velocities hence the pressure drops due to change in orifice size cannot be neglected [1]. The damper forces can be evaluated by estimating the pressure drops occurring inside the hydraulic cylinder because of piston motion. The schematic of geometric fluid circuit with the regions of pressure drop for single stage damper is shown in Figure 1. The pressure drops originated because the fluid [3] experienced the following phenomena:

- Entrance effect from region 1-2.
- Sudden expansion from region 2-3.
- Sudden contraction from region 3-4.
- Exit effect from region 4-5.
- Viscous Darcy friction losses in coil gap 3.
- Viscous Darcy friction losses in MR valves 2 and 4.
- MR effect in MR valves 2 and 4.

The total force produced by an MR damper is sum of passive viscous force (F_{OFF}) and controllable MR force (F_{MR}). Therefore the total damping force produced by damper F_D is given by;

$$F_D = (F_{MR} + F_{OFF}).\text{sign}\,(V_P)$$

Where, V_P is the velocity of piston. The total damping force produced by the damper is affected by the coil length L_c, active length L_a and number of coils.

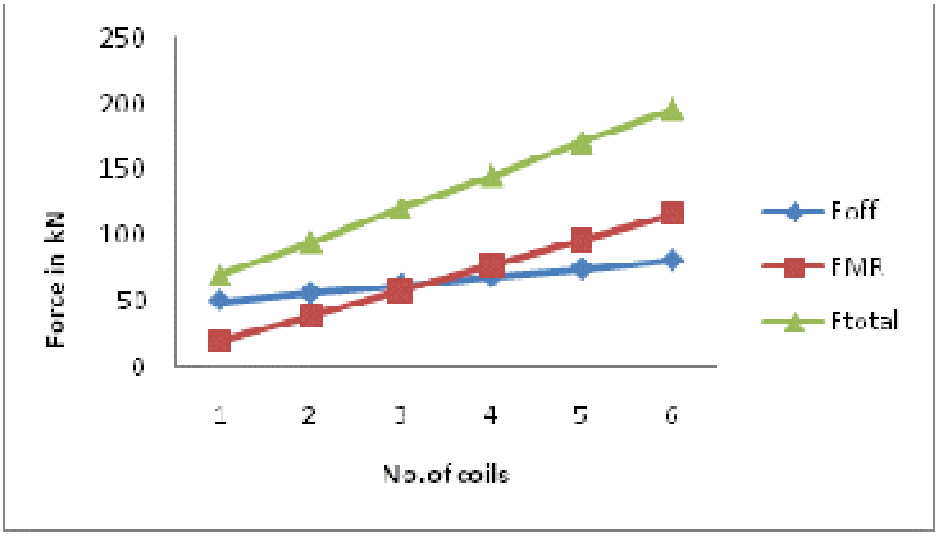

Figure 2 Force verses number of coils

The dynamic range (DR) is the most important concerned term regarding MR damper. The dynamic range of MR damper is given by;

$$DR = \frac{F_{total}}{F_{OFF}} = \frac{F_{MR} + F_{OFF}}{F_{OFF}} = 1 + \frac{F_{MR}}{F_{OFF}}$$

The dynamic range indicates the controllability of MR damper. In the design of MR damper, some key geometrical parameters are restricted by the geometrical constrains and installation requirements like cylinder inner diameter D_{in} then the optimum gap width has to be obtained for particular load and dynamic range requirements. The figure 2 shows the trade off between dynamic range and number of coils. By imposing the condition of minimum force requirement of 20 tonne and minimum dynamic range as 2 the following damper parameters are obtained.

Table 2 MR Damper parameters

Parameter	Value
MR fluid Density	3080 Kg/m3
MR fluid viscosity	0.096 Pa-s
MR yield stress	≈ 130 kPa
Hydraulic cylinder inner diameter	150 mm
MR valve thickness	6 mm
Coil gap thickness	6 mm
Active length of MR valve	44.45 mm
Length of coil	8.467 mm
Number of coils	6

MATHEMATICAL AND MATLAB MODEL

For deriving the mathematical model of gun recoil system, it is considered as a single degree of freedom system as shown in figure 3. By using equilibrium method its governing equations will be;

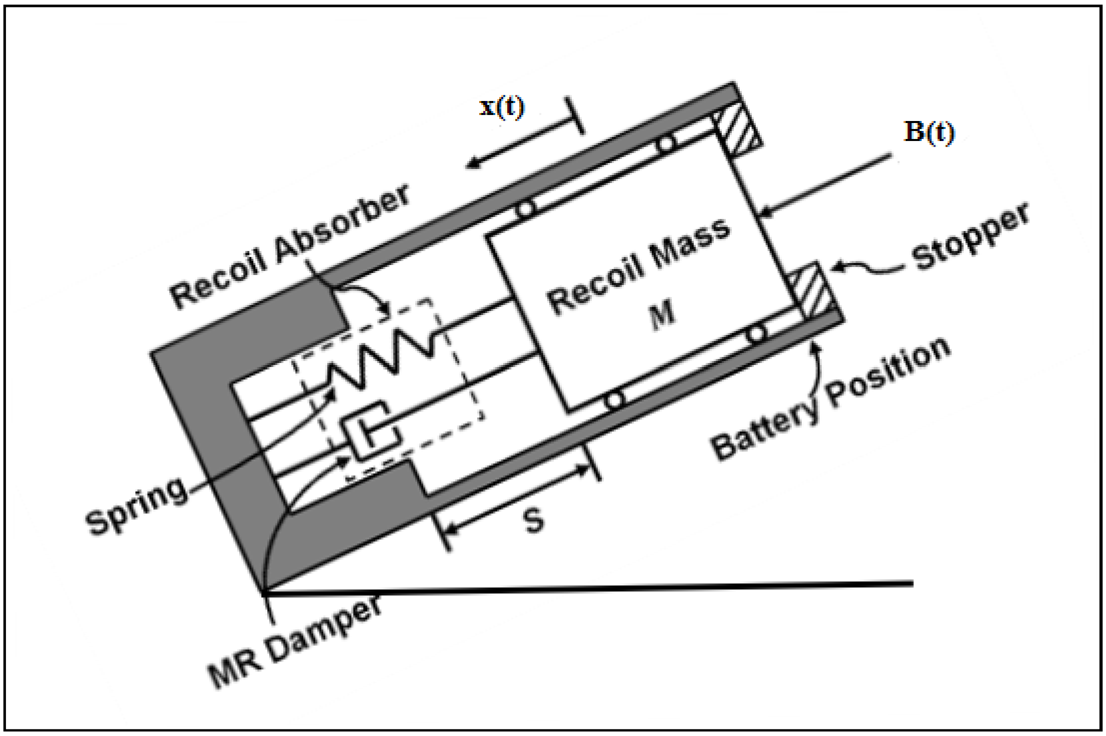

Figure 3 Model of gun recoil system

$$m\ddot{x} = B(t) - kx + W\sin\theta - F_{d}(\dot{x}) \quad \text{……..During recoil phase}$$

$$m\ddot{x} = -kx + W\sin\theta - F_{d}(\dot{x}) \quad \text{……..During rebound phase}$$

Where, B (t), W, m, k are the britch force, recoil weight, recoil mass, spring stiffness respectively. Figure 4 shows the MATLAB model of above equations.

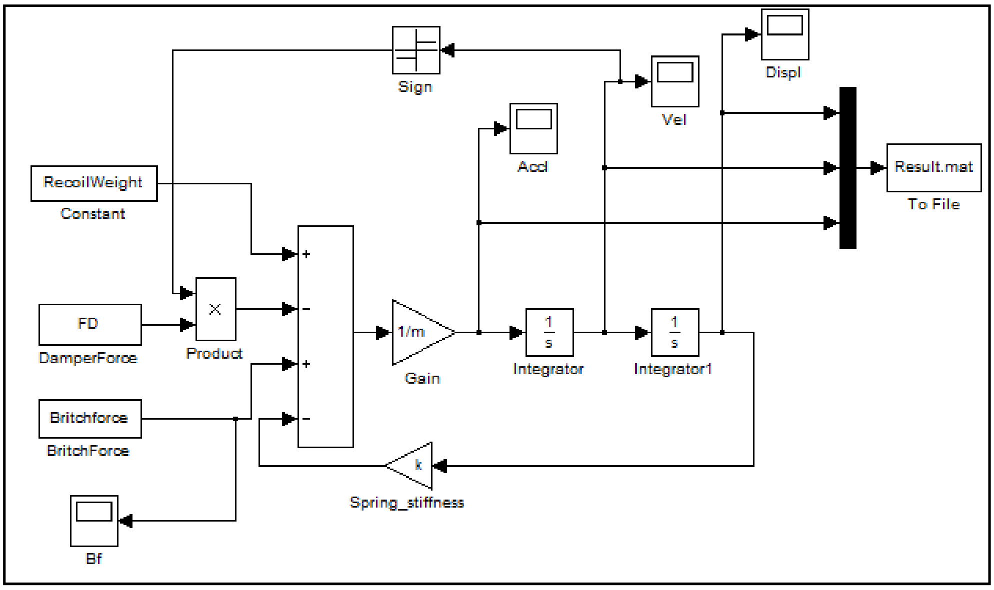

Figure 4 MATLAB model of gun recoil system

RESULTS AND CONCLUSION

Results:

In actual different types of charging [6] forces are used for different ranges and applications with 155 mm recoil system. MACS C1, MACS C2, MACS C3, MACS C3max are the types of charges used in 155 mm recoil system. The force verses time variation for different charging forces are as shown in figure 5.

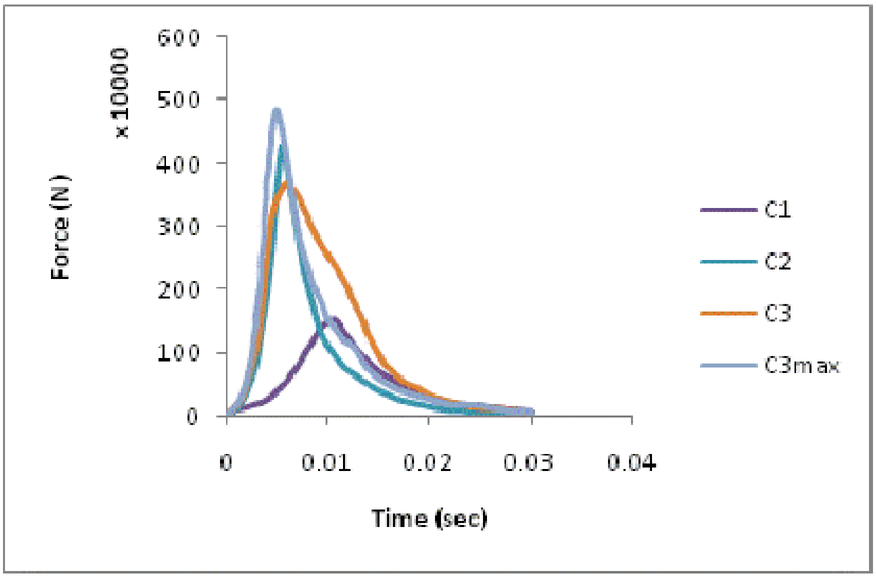

Figure 5 Force verses Time for various charges

These charging forces are given as input to MATLAB model and the results are obtained for different firing angles. Now the combination of damping force and spring stiffness should be selected such that there will not be any chaotic vibrations. Also the spring stiffness should be selected such that the recoil mass should be returned to battery position with minimum force transmitted to structure. Now for the designed semi-active system with damper force of 12 tonne and spring stiffness of 2100 kN/m for charge C1 gives following results as shown in figure 6. As the curve is closed at vertical axis there will not be force transmitted to structure by recoil mass during rebound. Similarly, the results for different charging forces and firing angles are found out. These results are compared with the results from technical report as shown in tables 3 and 4.

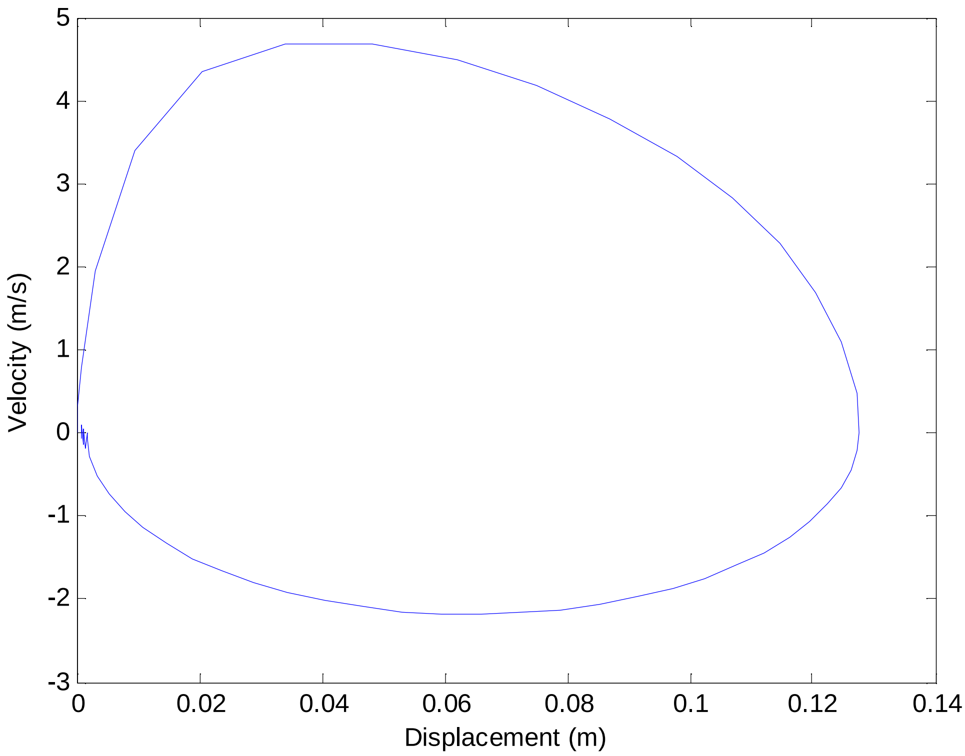

Figure 6 Recoil velocity verses displacement

Table 3 Recoil mass displacement for zero degree firing angle

Charge	Technical Report displacement (m)	Obtained recoil mass displacement (m)	Percentage Reduction in displacement
C1	0.762	0.1225	83.92
C2	1.194	0.1247	89.55
C3	1.397	0.1225	91.23
C3 max	1.219	0.1225	89.95

Table 4 Recoil mass displacement for 63 degree firing angle

Charge	Technical Report displacement (m)	Obtained recoil mass displacement (m)	Percentage Reduction in displacement
C1	0.635	0.1296	79.59
C2	0.9398	0.1321	85.94
C3	0.9652	0.1296	86.57
C3 max	0.9525	0.1296	86.39

4.2 Conclusion:

Designing a semi-active system for a load of around 20 tonne require a designing of special MR damper. To have a higher damping force, the higher yield strength smart fluid is required.

The total damping force produced by a damper is affected by the various parameters of damper like active length, coil length, MR valve thickness, number of coils etc.

In semi-active system the designed damper should have sufficient dynamic range to achieve the good controllability.

By using semi-active system there is more than 80 % reduction in recoil displacement which leads to reduction in duration of firing cycle. Hence the number of fires per minute will be increased.

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