



Material and Kinematic Analysis of Recoil and Gas-operated Mechanical Systems: A Comparative Study of Glock 17 and AK- 47 with Experimental Validation

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Abstract :

This paper examines the behavior of recoil-operated and gas-operated mechanical systems using simplified engineering models. A spring–mass–damper approach is used to study force variation and motion response. The recoil-driven system produces a short-duration, high-intensity force, whereas the gas-operated system shows a gradual force pattern due to controlled pressure release. Material characteristics such as stiffness, strength, and resistance to wear are considered to understand durability. A basic experimental setup is used to observe system response under different force inputs. The results indicate that gradual force application leads to improved stability and reduced stress concentration. The study provides a simple and clear framework for understanding mechanical system behavior.

Keywords : Kinematic analysis, Mechanical systems, Material behavior, Dynamic response



1. INTRODUCTION:

Mechanical systems subjected to dynamic loading require proper evaluation of both motion behavior and material response. Recoil-operated and gas-operated mechanisms represent two distinct approaches of force transmission, resulting in different operational characteristics [1,2].

In this work, recoil-driven behavior is associated with Glock 17, while gas-operated behavior is represented using AK-47. These systems are used purely as engineering references to understand impulsive and gradual force mechanisms.

In recoil-operated systems, force is applied suddenly, leading to rapid movement and higher stress levels. On the other hand, gas-operated systems rely on controlled pressure release, resulting in smoother motion and comparatively lower peak forces [3,4]. These differences directly influence system stability and durability.

Material properties such as stiffness, strength, wear resistance, and corrosion resistance significantly affect performance under dynamic conditions [5,11]. This study combines motion analysis, material evaluation, and basic validation to provide a broader understanding.

2. LITERATURE REVIEW:

Existing studies suggest that gas-operated systems offer improved stability due to smoother force variation [1,7]. In contrast, recoil-operated systems tend to produce higher stress due to sudden loading conditions [3,8].

Research in motion dynamics indicates that velocity plays a major role in determining trajectory and stability [6,16]. Additionally, material-based investigations highlight that wear resistance, fatigue strength, and corrosion resistance are critical for long-term performance [12–14,17].

However, only limited attempts have been made to combine motion characteristics with material behavior and validation. This work aims to bridge that gap.

3. METHODOLOGY:

3.1 Modeling Approach

A simplified spring-mass-damper model is used to analyze the response of the system under different force conditions. The model consists of a mass, spring and a damper subjected to an external force input. The complete modeling framework is illustrated in Figure 1.

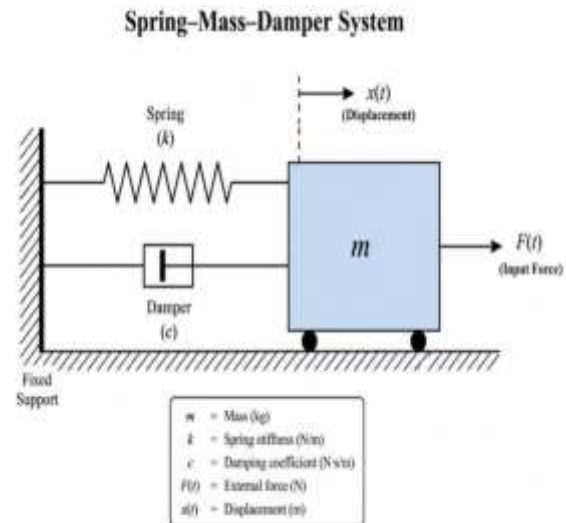


Figure 1 : Spring-Mass-Damper Model used for System Analysis

In this figure, m = Mass(Kg)

k = Spring Stiffness(Nm)

c = Damping coefficient (Ns/m)

$F(t)$ = External force(N)

$x(t)$ = Displacement(m)

3.2 Mathematical Modeling :

The recoil force is expressed as:

$$F(t) = 5000 e^{\left\{-\left(t-\frac{0.005}{0.001}\right)^2\right\}} \quad (1)$$

Where , $F(t)$ = Recoil force at time t (N)

t = Time(Seconds, s)

5000 = Peak recoil force(N)

0.005 = Time at which peak force occurs(s)

0.001 = Duration/spread of recoil impulse(s)

e = Exponential constant(approximately 2.718).



This equation is used to represent the short duration, high intensity impulsive recoil force acting in recoil-operated systems. This equation is adapted from[4].

The gas-operated force is given by:

$$F(t) = 3000 e^{\left\{\left(-\frac{t}{0.005}\right)\right\}} - (2)$$

Where, F(t) = Gas force at time t (N)

t = Time (s)

3000 = Initial force due to gas pressure (N)

0.005 = Time constant (s)

e = Exponential constant

This equation is used to represent the gradual decrease of gas pressure producing a smooth and distributed force over time. It was adapted from[1].

The motion of the system is governed by the Newton's Second Law of Motion,

$$F = ma - (3)$$

The Projectile Trajectory is described by :

$$y = x \tan \theta - \left(\frac{gx^2}{2v^2 \cos^2(\theta)} \right) - (4)$$

Where, y = Vertical height of bullet(m)

x = Horizontal distance travelled by bullet(m)

v = Initial velocity of bullet(m/s)

θ = Angle of projection in degrees

g = Acceleration due to gravity($9.81 \frac{m}{s^2}$)

This equation is adapted from research paper [9].

3.3 Graph Plotation :

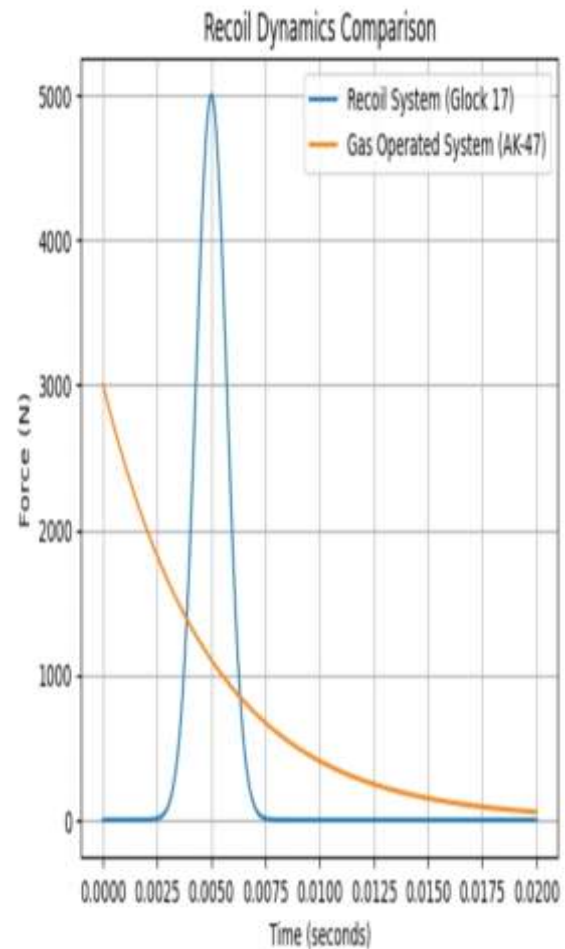


Figure 2 : Recoil dynamics comparison of Glock 17 and AK-47

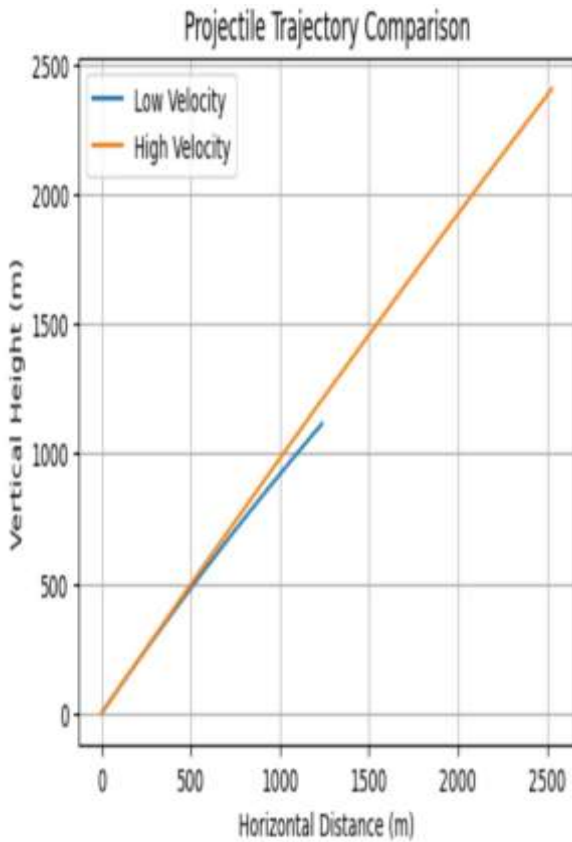
This graph is plotted with the help of Google Colab software from matplotlib. The reference used is equation(1) and (2).

The necessary assumptions considered for the figure 2 are :-

- 1 All moving parts(slide,bolt,piston) are considered rigid with no deformation.
- 2 . Friction between moving components is ignored to simplify motion.
- 3 . Mass of moving parts do not change during operation.
- 4 . Gas pressure decreases smoothly and follows a simplified decay pattern.
- 5 . Recoil force acts over a very short time and can be treated as a spike.



The research paper[4] is referred for considering assumptions for Glock 17 and [1],[5] for assumptions for AK-47.



- 1 . Bullet moves only under gravity.
- 2 . The constant gravity $g=9.81 \text{ m/s}^2$ is considered throughout the motion.
- 3 . Same firing angle for both systems is considered throughout the motion.
- 4 . Bullet is treated as a particle(no rotation or size effects).
- 5 . No elevation difference between firing and landing.

The research papers [9],[8] and [2] are referred for the consideration of assumptions for bullet trajectory graph plotation.

3.4 Tabular Data :

Table 1 : Comparative Kinematic Performance

Parameter	Recoil System	Gas System	Observation
Force Profile	Impulsive -ve	Gradual	Gas smoother
Peak force	High	Moderate	Recoil Higher stress
Motion	Rapid	Controlled	Gas stable
Oscillations	High	Low	Recoil unstable
Stability	Lower	Higher	Gas preferred

The Table 1 data is from the observation of Figure 2

Table 2 : Typical Material Properties of High Strength Engineering Steel used for Analysis

Property	Typical Value	Role in system	Effect in performance
Density(kg/m ³)	7850	Mass contribution	Affects Inertia
Young's Modulus(GPa)	200	Stiffness	Reduces deformation
Yield Strength(MPa)	250	Load Capacity	Prevents failure
Hardness	High	Wear Resistance	Increases life
Corrosion Resistance	Moderate-High	Environmental Stability	Improves durability

The Table 2 is adapted from research papers [11-15].



3.5 Material Considerations :

High-strength steel is considered for analysis due to its:

High rigidity

Good load-bearing capacity

Resistance to wear

Ability to withstand environmental effects [11–14]

These properties are summarized in Table 2

4. EXPERIMENTAL VALIDATION :

A basic experimental arrangement was considered to support the analytical model. A spring-based setup was used to simulate sudden force application, while a controlled release mechanism represented gradual force input.

The system subjected to impulsive force showed rapid displacement followed by oscillatory motion. In contrast, the gradual system exhibited smoother and more stable behavior. These observations are summarized in Table 3.

The experimental trends are consistent with the analytical force profiles shown in Figure 2. The experimental behavior observed is consistent with the theoretical force variation shown in Figure 2, where impulsive and gradual force profiles are compared. The figure 1 represents the spring-mass-damper system from the course of Control Systems Engineering applied in the analysis.

5. RESULTS :

The variation of applied force with time is illustrated in Figure 2, obtained using Eq. (1) and Eq. (2). The recoil-operated system exhibits a sharp peak due to impulsive loading, whereas the gas-operated system shows a smoother and gradually decaying force profile. This trend is consistent with previously reported studies on dynamic force behavior [3,7].

The motion response derived from Newton's second law (Eq. (3)) indicates that the recoil-based system undergoes rapid acceleration, which may result in higher oscillations. In contrast, the gas-operated system demonstrates a more controlled response, improving system stability [8,9].

The projectile trajectory calculated using Eq. (4) is shown in Figure 3, where increased velocity leads to greater range and improved trajectory consistency. These findings align with established research in motion dynamics [6,16].

A comparative summary of system performance is provided in Table 1, highlighting differences in force characteristics, oscillations, and stability. The material properties influencing system behavior are listed in Table 2, which represent generalized engineering material parameters used for analysis.

Overall, the results indicate that gradual force application leads to reduced stress concentration and enhanced stability.

6. DISCUSSION :

The results show that impulsive force (Eq. (1)) produces higher stress and instability, whereas gradual force (Eq. (2)) improves stability, as seen in Figure 2 [1,7,8]. The motion response from Eq. (3) confirms reduced oscillations for smoother force input, while trajectory analysis in Figure 3 using Eq. (4) highlights the effect of velocity on range [6,16]. Material properties in Table 2 enhance durability, and comparison in Table 1 indicates that controlled force distribution leads to better overall performance [12–14].

7. CONCLUSION :

This study shows that gradual force application improves system stability compared to impulsive loading, based on Eq. (1)–(4). Results from Figure 2, Figure 3, Table 1, and Table 2 confirm that controlled force distribution and suitable material properties enhance performance and durability [12–14]. The simplified model provides a useful basis for understanding dynamic mechanical systems.



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