Research on muzzle dynamic analysis of an overhead weapon station with the viscoelastic elastomer damper

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Abstract. Live firing tests are difficult to realize, thus it is not clear whether the viscoelastic elastomer damper can effectively reduce the recoil force and recoil displacement, which determines the firing accuracy of the overhead weapon station. This paper constructed a rigid-flexible coupling dynamics model of overhead weapon station with the viscoelastic elastomer damper. The dynamic simulation parameters of the damper were determined according to the static pressure test results. A characterization method of the firing dispersion of the overhead weapon station was then proposed. Additionally, the influences of the viscoelastic elastomer damper and the spring damper on the muzzle dynamic characteristics and firing dispersion of the overhead weapon station were studied. The results show that: the recoil displacement and the recoil-return time with the viscoelastic elastomer damper were respectively reduced by 69.83% and 33.50% compared to the spring damper; By contrast the spring damper, the horizontal and vertical dispersion standard deviations of the overhead weapon station with the viscoelastic elastomer damper at different firing conditions were respectively decreased an average of 39.48% and 43.68%, while the firing dispersion was increased by an average of 41.89%. These results prove that the viscoelastic elastomer damper can significantly reduce and shorten the recoil displacement and the recoil time of the machine gun overhead weapon station, effectively reduce the muzzle jump and improve the firing accuracy of the overhead weapon station.

1. Introduction

The overhead weapon station is a relatively independent modular weapon system that can be mounted on a variety of carriers [1] (see figure 1). The current overhead weapon stations in our country mainly rely on the spring damper to consume and absorb the energy when the machine gun recoils. However, the spring damper has a large stiffness and a small damping, it makes the energy dissipation be insufficient and recoil force be large in the recoil process, which will cause a high firing dispersion and lead to a poor reliability of the weapon station. The effects of absorbing energy and reducing vibration of the viscoelastic elastomer damper are significant, because it has both the high viscoelasticity and high damping properties [2], which is widely used in various fields [3-10]. Wang Z Q, Mao B Q et al. [11-14] developed a viscoelastic elastomer damper suitable for the weapon station, and through laboratory tests proved that this viscoelastic elastomer damper has good energy dissipation and can adapt to the firing load of the weapon station. The live firing test can be difficult to
realize, thus it is not clear whether the viscoelastic elastomer damper can effectively reduce the recoil force and recoil displacement, which affects the firing accuracy of the overhead weapon station.

![Image](https://example.com/image.png)

**Figure 1.** A photo of the first Chinese overhead weapon station of prototype.

Launching dynamics simulation analysis based on virtual prototype is an important method to study muzzle dynamic characteristics and firing dispersion of overhead weapon station. Compared with the live firing test, it has the advantages of short period, low cost, convenience and simplicity, and high visualization degree of transient process. The research team represented by Mao B Q [15-19] built a series of virtual prototypes of overhead weapon stations with different calibers, loads and working conditions, for improving the comprehensive performance of the weapon stations to provide a strong theoretical support.

Therefore, in order to study the effects of viscoelastic elastomer damper for firing dispersion of overhead weapon station, this paper constructs a rigid-flexible coupling dynamics model of overhead weapon station with viscoelastic elastomer damper. The dynamic simulation parameters of the damper are then determined according to the static pressure test results. The influence of the viscoelastic elastomer damper and the spring damper on the muzzle dynamic characteristics and firing dispersion of the overhead weapon station are studied in detail.

2. Rigid-flexible coupling dynamics modelling of overhead weapon station with viscoelastic elastomer damper

According to the actual movements on each part and the force conditions of the overhead weapon station at firing, the following assumptions are made for the dynamic model:

1. The coupling effects are extremely complex between vehicle body, road surface, underpan and overhead weapon station. Additionally, this model is mainly used to analyze the impact of the damper for the dynamic characteristics of weapon station. The influences of road surface and vehicle underpan are not considered, only is the fixed frame considered when firing;

2. The rest of the parts are considered as rigid bodies except the gun-body and the bracket are considered as flexible bodies;

3. The external force at shooting is mainly the resultant force of bore bottom, other factors are not considered;

4. The effect of belt feed mechanism on the overhead weapon station is not considered, and the bullet is assumed to be in firing position at each shot;

5. The firing situation of fixed firing angle of 0° is considered in overhead weapon station for simplifying the model.

The constraint relationships of the overhead weapon station are shown in figure 2. This paper only considers the firing situation of the horizontal firing angle in overhead weapon station. Therefore, the elevating mechanism and the traversing mechanism are considered as mass blocks in the form of the control box, which are fixed on the right bracket. The elevating mechanism is fixed with the right
bracket, the traversing mechanism is fixed with the inner race, and they are both fixed with the control box.

Figure 2. Schematic diagram of constraint relationship of overhead weapon station.

The constructed rigid-flexible coupling dynamics model of overhead weapon station with viscoelastic elastomer damper is shown in figure 3.
3. Determination dynamic parameters of the damper

3.1. Structure and composition of damper

A spring of spring damper for an overhead weapon station is shown in figure 4, and the basic parameters of this spring damper are shown in table 1. The viscoelastic elastomer damper is designed and processed without changing the size of the spring damper, the geometrical schematic and a photo of a viscoelastic elastomer damper prototype are respectively shown in figure 5 and figure 6. The dimension parameters of a viscoelastic damper prototype are shown in table 2.

![Image 1](image1.png)

**Figure 4.** Spring of a spring damper for an overhead weapon station.

| Table 1. Basic parameters of spring damper for a weapon station. |
|---------------------------------------------------------------|
| **The spring damper** | **The spring** |
| Diameter (mm) | Length (mm) | The initial length (mm) | Diameter (mm) | Material | Cross-section shape |
| 44 | 86.5 | 83.5 | 28 | 60Si2Mn steel | Rectangle |
Figure 5. The geometrical schematic of a viscoelastic elastomer damper:
(a) The viscoelastic elastomer inlet; (b) chamber; (c) gap; (d) piston; (e) piston rod; (f) orifice; (g) chamber wall; (h) stand.

Figure 6. A photo of a viscoelastic elastomer damper prototype.

Table 2. The dimension parameters of a viscoelastic elastomer damper prototype.

| The orifice diameter (mm) | The number of orifice | The gap width (mm) | The piston diameter (mm) | The diameter of piston rod (mm) |
|---------------------------|-----------------------|--------------------|--------------------------|-------------------------------|
| 1.0                       | 4                     | 0.9                | 20                       | 9                             |

3.2. Static pressure test and results

Static pressure tests were conducted by using the SUNS universal press (see figure 7) to collect force and displacement curves of dampers. During static pressure tests of a viscoelastic elastomer damper, the viscoelastic elastomer damper was installed vertically on the pressure machine, and the piston rod of the damper was compressed by evenly loading at the speed of 2 mm/s. When the compression was reached or approached the maximum designed stroke, it was unloaded slowly and evenly at a speed of 2 mm/s. When measuring the static pressure curves of the spring damper, the spring damper was vertically installed on the pressure machine and compressed by evenly loading at the speed of 2 mm/s. When it was entered yielding state, the loading force was withdrawn and the test was ended. The press was connected to the computer, and the force-displacement curves of dampers were recorded synchronously. Force-displacement curves of two dampers from static pressure tests are shown in figure 8.

Figure 7. SUNS universal press.
3.3. Determination of the equivalent stiffness and the equivalent damping

Based on the static pressure test results in figure 8, the parameters of equivalent stiffness and equivalent damping are calculated; these are defined as the stiffness and damping coefficients of the damper in the dynamic model of the overhead weapon station, and then compared and analysed by simulation. The parameter calculation methods of equivalent stiffness and equivalent damping are as follows:

3.3.1. The equivalent stiffness. The equivalent stiffness is an important representation of the elastic property of the damper. According to literature [20][21], the calculation formula of equivalent stiffness is:

\[
K_{eq} = \frac{F_{\text{max}} - F_{\text{min}}}{D_{\text{max}} - D_{\text{min}}}
\]

where, \( F_{\text{max}} \) and \( F_{\text{min}} \) represent the maximum output force and minimum output force in a single load and unload respectively, \( D_{\text{max}} \) and \( D_{\text{min}} \) represent the maximum output displacement and minimum output displacement in a single load and unload respectively.

According to the static pressure curves in figure 8, the equivalent stiffness of the spring is 0.235 kN/mm when it does not enter the yield state, while the equivalent stiffness of viscoelastic elastomer damper is 0.597 kN/mm.

3.3.2. The equivalent damping coefficient. The damping coefficient of a viscoelastic elastomer damper is nonlinear, which is difficult to obtain in either simulation or test. In actual structure, the equivalent damping is usually expressed the damping property [22]. In general, the equivalent damping refers to the equivalent damping ratio that can be obtained through the hysteresis curve from the static pressure test [23]:

\[
\xi_{eq} = \frac{W_d}{2\pi K_{eq} \left( \frac{D_{\text{max}}}{2} \right)^2}
\]

where \( \xi_{eq} \) is equivalent damping ratio; \( W_d \) is the area around the hysteretic curve, namely the energy consumption.
According to the static pressure curves in figure 8 (b), the equivalent damping ratio of the viscoelastic elastomer damper is 0.12. The equivalent damping ratio of spring steel is 0.02, so the equivalent damping ratio of the spring damper is also chosen 0.02. In ADAMS, the damping coefficient only can be defined, while the equivalent damping coefficient is a representation of the damping coefficient of real damper, both of these have the same unit. The damping coefficient can be obtained through the damping ratio [24]:

$$c_{eq} = 2 \pi \xi \sqrt{K_{eq} M}$$  \hspace{1cm} (3)

where $c_{eq}$ is the equivalent damping coefficient; $M$ is the recoiling mass, that is, the mass of the machine gun.

Thus, it can be obtained from equation 3 that the equivalent damping coefficient of the spring damper is 0.086 Ns/mm, while that of the viscoelastic elastomer damper is 0.83 Ns/mm.

4. Muzzle dynamic analysis of the overhead weapon station

4.1. A characterization method of the firing dispersion of the overhead weapon station

The machine gun overhead weapon station is a direct fire weapon with an effective range of 1500 m. The firing dispersion of weapon is one of the important indexes of tactics and techniques, and it is mainly related to the jump angle at close range when the secondary factors are ignored [25,26]. The jump angle is related to the muzzle vibration and can be divided into the vertical jump angle and the horizontal jump angle according to the coordinate axis. The component of vertical jump angle is shown in figure 9, the component of horizontal jump is similar to the vertical jump angle expect that the direction changes. In figure 9, $\varphi_0$ is the angle of firing; $b$ is a center point of the muzzle, and $a$ is a point that is $L_{ab}$ to the muzzle. A straight line connecting these two points can be regarded as the actual axis of rifling near the muzzle.

Figure 9. Jump angle component.
It can be seen from figure 9 that the jump angle $\theta$ is equal to sum of the included angle $\delta$ and the included angle $\gamma$. $\delta$ is an included angle between the muzzle normal and the bullet velocity vector, while $\gamma$ is an included angle between the actual axis of rifling and the line of sight. So $\theta$ can be written as:

$$\theta_{ij} = \gamma_{ij} + \delta_{ij}$$

where $i = x, y$ is coordinate axis, $j = 1, 2, \ldots, n$ means the sequence of bullets.

The included angle $\gamma$ can be written as:

$$\gamma_{ij} = \arcsin \frac{i_{iia} - i_{iib}}{L_{ab}}$$

The included angle $\delta$ can be written as:

$$\delta_{ij} = \arctan \frac{v_{ij}}{v_{i0}}$$

where $v_{i0}$ is the initial velocity of the bullet out from the muzzle, $v_{ij}$ is the velocity component in the direction $i$ at the moment when the $j$th bullet shoots out from the muzzle.

The vertical target dispersion deviation of the bullet can be written as [19]:

$$\Delta y_j = X \tan \theta_{ij} + y_j$$

where $\Delta x_j$ and $\Delta y_j$ are the horizontal and vertical dispersion deviations respectively at the moment when the $j$th bullet shoots out from the muzzle; $X$ represents the horizontal distance between the muzzle and the target; $x_j$ and $y_j$ are the horizontal and vertical linear displacements respectively at the moment when the $j$th bullet shoots out from the muzzle.

The first terms on the right of equations (7) and (8) are much larger than the horizontal and vertical displacements, so

$$\tan \theta_{ij} \approx \theta_{ij}$$

Therefore, equation (4) - (6) are substituted into equation (7) - (8), which can be expressed as by simplified:

$$\Delta x_j \approx X \cos \theta_{ij} \left( \gamma_{ij} + \frac{v_{ij}}{v_{i0}} \right) = X \cos \theta_{ij} \left( \arcsin \frac{i_{iia} - i_{iib}}{L_{ab}} + \frac{v_{ij}}{v_{i0}} \right)$$

$$\Delta y_j \approx X \left( \gamma_{ij} + \frac{v_{ij}}{v_{i0}} \right) = X \left( \arcsin \frac{i_{iia} - i_{iib}}{L_{ab}} + \frac{v_{ij}}{v_{i0}} \right)$$

The firing dispersion of the machine gun overhead weapon station is usually expressed by the half-dispersion circle radius index $R_{50}$, the calculation formula is as follows:
where \( \sigma_x \) and \( \sigma_y \) are the horizontal and vertical standard deviations respectively, and this expression is

\[
\sigma_i = \sqrt{\frac{1}{n-1} \sum_{j=1}^{n} (\Delta i_j - \Delta \bar{T})^2}
\]  

(13)

where, \( i = x, y \), \( n \) is the total number of bullets, \( j \) is the sequence of bullets, and \( \Delta \bar{T} \) is the expectation of \( \Delta i_j \).

4.2. Muzzle dynamic analysis of single shot

The single shot force (see figure 10) was used to load at the bottom of bullet, and the simulation results are shown in figure 11 - 14. Figure 11 and 12 respectively are machine gun recoil displacement and recoil force of the overhead weapon station with the viscoelastic elastomer damper and the spring damper as time increased. Since the range limit of the damper cannot be added in the computer simulation, the damper will exceed zero point after returning stroke, that is, these curves have positive values.

![Figure 10. The resultant force curve of bore bottom of single shot.](image-url)

In figure 11 and figure 12, OA segment and OB segment are respectively the changes of recoil displacement and recoil force of machine gun of the overhead weapon station with the viscoelastic elastomer damper and the spring damper in the first cycle of recoil and return. The machine gun maximum recoil displacement of the overhead weapon station with the viscoelastic elastomer damper is 3.87 mm and the maximum recoil force is 3978.60 N; while the maximum recoil displacement with the spring damper is 12.83 mm and the maximum recoil force is 3026.21 N. It can be seen that the recoil displacement with the viscoelastic elastomer damper is reduced by 69.83% compared to the spring damper, while the recoil force is increased by 31.47%. This is because the stiffness of the viscoelastic elastomer damper is larger than that of the spring damper. However, its maximum recoil force is far less than the design maximum recoil force 5 kN. Moreover, the simulation results are basically consistent with the static pressure test results of the two dampers (see figure 8), which proves the accuracy of the model. By comparing the time consumed of the viscoelastic elastomer damper and the spring damper during the cycle of recoil and return in figure 11 and figure 12, it can be seen that
the viscoelastic elastomer damper needs 0.0135 s per cycle, while the spring damper needs 0.0203 s. The recoil-return time of the former is decreased by 33.50% compared with that of the latter, which can effectively reduce the coupling strength between bullets and bullets in the process of continuous firing. Additionally, the viscoelastic elastomer damper has a large damping, we can find from the perspective of the changing trend of the whole curves that the recoil process is obviously more stable than that of the spring damper, and the oscillation amplitude is smaller, the oscillation period is shorter.

Figure 11. Recoil displacement changing curve of machine gun as time increased for different dampers.

Figure 12. Force changing curve of dampers as time increased.

Figure 13. Curves of the horizontal linear displacement and linear velocity of the muzzle of single shot as time increased for different dampers.
Figure 14. Curves of the vertical linear displacement and linear velocity of the muzzle of single shot as time increased for different dampers.

Figure 13 and 14 show the curves of the linear displacement and the linear velocity of the horizontal and the vertical of the muzzle of single shot as time increased for different dampers respectively. The simulation results of dynamic characteristics for different dampers are shown in table 3. Combined with figure 13 - 14 and table 3, it can be seen that the linear displacement and the linear velocity of the viscoelastic elastomer damper are far less than that of the spring damper in both the horizontal direction and vertical direction. By comparing the simulation results in table 3, it can be seen that the horizontal root mean square value of the muzzle linear displacement with the viscoelastic elastomer damper is decreased by 34.32% compared to that of the spring damper, while the vertical linear displacement is reduced by 41.77%. The horizontal and vertical linear velocities with the viscoelastic elastomer damper are reduced by 35.10% and 41.41% respectively relative to the spring damper.

Table 3. The simulation results of the muzzle dynamic characteristics of single shot for different dampers.

| Types                              | Parameters                        | The minimum value | The maximum value | The average value | The root-mean-square |
|------------------------------------|-----------------------------------|-------------------|-------------------|-------------------|----------------------|
| The viscoelastic elastomer damper  | The horizontal linear displacement (mm) | -4.0233           | 2.5696            | -0.3508           | 1.1949               |
|                                    | The horizontal linear velocity (m/s) | -466.9522         | 383.5564          | -1.2198           | 129.3122             |
|                                    | The vertical linear displacement (mm) | -3.3079           | 2.6443            | -0.2462           | 0.8193               |
|                                    | The vertical linear velocity (m/s)  | -566.3186         | 376.2302          | -0.7753           | 116.3752             |
| The spring damper                  | The horizontal linear displacement (mm) | -5.3766           | 5.2674            | -0.3485           | 1.8193               |
|                                    | The horizontal linear velocity (m/s) | -469.8652         | 716.1165          | -1.2863           | 199.2636             |
|                                    | The vertical linear displacement (mm) | -5.3249           | 4.3365            | -0.2484           | 1.4070               |
|                                    | The vertical linear velocity (m/s)  | -726.2833         | 783.2292          | -0.7501           | 199.6471             |
4.3. Muzzle dynamic analysis of continuous firing

In order to analyze and compare the effects of firing dispersion and the dynamic characteristics of the muzzle of the overhead weapon station with the viscoelastic elastomer damper and the spring damper in the continuous firing, the 6-continuous firing was loaded from figure 15. The load frequency was set according to the actual firing conditions of the overhead weapon station, i.e. 600 rounds/min. Figures 16 and 17 show the curves of the linear displacement and the linear velocity of the horizontal and the vertical of the muzzle in continuous firing as time increased for different dampers respectively. As can be seen from the figures 16 - 17, under the continuous firing load of 600 rounds/min, the linear displacements and the linear velocities of the viscoelastic elastomer damper in both the horizontal direction and vertical direction are always lower than that of the spring damper, which is similar to the results of single shot.

Figure 15. The resultant force curve of bore bottom of continuous firing.

Figure 16. Curves of the horizontal linear displacement and linear velocity of the muzzle of continuous firing as time increased for different dampers.
Table 4 and 5 respectively show the dynamic characteristics with the spring damper and the viscoelastic elastomer damper in the continuous firing at the moment of each bullet out from muzzle. As shown in figure 9, the point a was selected to be 100 mm away from the muzzle. The horizontal and vertical line displacements of point a and point b (at the muzzle) in the continuous firing process at the moment of each bullet out from muzzle were collected respectively, and the horizontal and vertical angular displacements in the table 4 and table 5 were obtained from equation (5). The horizontal and vertical dispersion deviations were calculated by equations (10) and (11). The horizontal and vertical dispersion standard deviations were obtained by equation (13). And then, the half-dispersion circle radius index $R_{50}$ (that was, the firing dispersion) of the weapon station with two different dampers on 6 consecutive firing were obtained by equation (12), where the horizontal distance between the muzzle and the target was $X=100$ m.

Table 4. The dynamic characteristics of the muzzle with the spring damper in the continuous firing.

| Sequence of bullets | Horizontal angular displacement $\gamma_x/^{\circ}$ | Vertical angular displacement $\gamma_y/^{\circ}$ | Horizontal linear displacement $x/mm$ | Vertical linear displacement $y/mm$ |
|---------------------|-----------------------------------------------|-----------------------------------------------|------------------------------------|------------------------------------|
| 1                   | -0.00004                                      | -0.00064                                      | 0.010                             | 0.106                              |
| 2                   | -0.00239                                      | -0.00394                                      | 1.150                             | 0.842                              |
| 3                   | -0.00157                                      | -0.00466                                      | -1.186                            | 1.933                              |
| 4                   | -0.00031                                      | -0.00383                                      | 0.702                             | 3.426                              |
| 5                   | -0.00222                                      | -0.00327                                      | -1.186                            | 3.580                              |
| 6                   | -0.00073                                      | -0.00218                                      | -0.446                            | 3.360                              |

| Sequence of bullets | Horizontal linear velocity $v_x/(mm/s)$ | Vertical linear velocity $v_y/(mm/s)$ | Horizontal dispersion deviations $\Delta x/mm$ | Vertical dispersion deviations $\Delta y/mm$ |
|---------------------|----------------------------------------|----------------------------------------|-----------------------------------------------|-----------------------------------------------|
| 1                   | -47.750                                 | 59.807                                 | -9.77                                         | -56.42                                        |
| 2                   | 211.441                                 | 360.768                                | -212.57                                       | -348.61                                       |
| 3                   | 113.867                                 | 416.401                                | -142.97                                       | -413.45                                       |
| 4                   | 16.764                                  | 332.696                                | -28.90                                        | -341.31                                       |
| 5                   | 197.656                                 | 282.519                                | -197.09                                       | -291.39                                       |
| 6                   | 67.321                                  | 185.996                                | -64.38                                        | -194.45                                       |
It is calculated that the horizontal dispersion standard deviation of the 100 m target of the overhead weapon station with the spring damper in the 6-continuous firing is 8.71 cm, while the vertical dispersion standard deviation is 12.92 cm. The half-dispersion circle radius index $R_{50}$ is 12.62 cm. However, at 100 m target in live firing, the $R_{50}$ of the test prototype of 12.7 mm machine gun overhead weapon station was between 12 cm and 13 cm, which was provided by the factory. The simulation result is not significantly different from this test result, which indirectly proved the accuracy of the rigid-flexible coupling dynamics model of the overhead weapon station.

**Table 5.** The dynamic characteristics of the muzzle with the viscoelastic elastomer damper in the continuous firing.

| Sequence of bullets | Horizontal angular displacement $\gamma_x/^\circ$ | Vertical angular displacement $\gamma_y/^\circ$ | Horizontal linear displacement $X/mm$ | Vertical linear displacement $Y/mm$ |
|---------------------|-----------------------------------------------|-----------------------------------------------|--------------------------------------|------------------------------------|
| 1                   | -0.00009                                      | -0.00128                                      | -0.021                               | 0.136                              |
| 2                   | -0.00124                                      | -0.00357                                      | 0.977                                | 1.416                              |
| 3                   | -0.00143                                      | -0.00333                                      | -1.012                               | 1.547                              |
| 4                   | -0.00151                                      | -0.00235                                      | 0.092                                | 1.464                              |
| 5                   | -0.00149                                      | -0.00248                                      | 0.149                                | 0.901                              |
| 6                   | -0.00190                                      | -0.00271                                      | -0.514                               | 0.588                              |

| Sequence of bullets | Horizontal linear velocity $V_x/mm/s$ | Vertical linear velocity $V_y/mm/s$ | Horizontal dispersion deviations $\Delta x/mm$ | Vertical dispersion deviations $\Delta y/mm$ |
|---------------------|-------------------------------------|-------------------------------------|-----------------------------------------------|-----------------------------------------------|
| 1                   | -32.681                             | 90.566                              | -12.99                                        | -116.98                                       |
| 2                   | 168.120                             | 322.979                             | -102.89                                       | -316.23                                       |
| 3                   | 195.415                             | 300.645                             | -118.27                                       | -295.12                                       |
| 4                   | 106.258                             | 215.608                             | -137.92                                       | -207.65                                       |
| 5                   | 239.252                             | 231.660                             | -119.29                                       | -218.64                                       |
| 6                   | 161.361                             | 254.413                             | -169.93                                       | -239.30                                       |

The horizontal dispersion standard deviation of the 100 m target of the overhead weapon station with the viscoelastic elastomer damper in the 6-continuous firing is 5.29 cm, while the vertical dispersion standard deviation is 7.08 cm. The half-dispersion circle radius index $R_{50}$ is 7.24 cm. Compared with the spring damper, the horizontal dispersion deviation of the overhead weapon station with the viscoelastic elastomer damper is reduced by 39.24%, and the vertical dispersion is reduced by 45.14%, while the firing dispersion is increased by 42.63%.

4.4. **Muzzle dynamic analysis of variable firing**

At present, China has not developed the overhead weapon station with variable firing, but it is the only way to adapt the diversified development of weapons that the machine gun overhead weapon station will realize the variable firing in the future. In order to simulate whether the viscoelastic elastomer damper can be suitable for the machine gun overhead weapon station in variable firing, the variable firing force was loaded at the bottom of bullets as shown in figure 18. The total number of bullets is 6, the firing frequency of the first 3 bullets is 300 rounds /min, while the last 3 bullets is 600 rounds /min.
Figures 18 and 20 show the curves of the linear displacement and the linear velocity of the horizontal and the vertical of the muzzle in variable firing as time increased for different dampers respectively. As can be seen from the figures 19 - 20, in the variable firing, the linear displacement and the linear velocity of the viscoelastic elastomer damper in both the horizontal direction and vertical direction are always lower than that of the spring damper, which is similar to the results of single shot and continuous firing.

(a) Linear displacement  
(b) Linear velocity

Figure 19. Curves of the horizontal linear displacement and linear velocity of the muzzle of variable firing as time increased for different dampers.
According to the calculation methods of muzzle dynamic characteristics and the firing dispersion of continuous firing in section 4.3., the firing dispersion of variable firing was obtained. The point \( a \) was selected to 100 mm away from the muzzle and the horizontal distance between the muzzle and the target was \( X = 100 \) m (see figure 9). Equation (5), equation (10) and equation (11) were used to calculate the horizontal and the vertical angular displacements and dispersion deviations of the overhead weapon station at the muzzle with the spring damper and the viscoelastic elastomer damper, and the results are shown in table 6 and table 7. Through equations (12) and (13), the horizontal and the vertical dispersion standard deviations and the half-dispersion circle radius indexes for variable firing were then obtained. It is calculated that the horizontal dispersion standard deviation of the 100 m target of the overhead weapon station with the spring damper in the variable firing is 10.16 cm, while the vertical dispersion standard deviation is 14.83 cm, and the half-dispersion circle radius index \( R_{50} \) is 14.58 cm.

**Table 6.** The dynamic characteristics of the muzzle with the spring damper in the variable firing.

| Sequence of bullets | Horizontal angular displacement \( \gamma_x^o \) | Vertical angular displacement \( \gamma_y^o \) | Horizontal linear displacement \( x/mm \) | Vertical linear displacement \( y/mm \) |
|---------------------|---------------------------------|---------------------------------|-------------------------------|-------------------------------|
| 1                   | -0.00004                        | -0.00064                        | 0.010                         | 0.106                         |
| 2                   | 0.00017                         | -0.00033                        | -2.853                        | 0.888                         |
| 3                   | 0.00008                         | -0.00083                        | -3.204                        | 1.099                         |
| 4                   | -0.00185                        | -0.00056                        | -1.757                        | 1.140                         |
| 5                   | -0.00101                        | -0.0032                         | 1.252                         | 1.581                         |
| 6                   | -0.00257                        | -0.00411                        | 0.207                         | 2.105                         |

| Sequence of bullets | Horizontal linear velocity \( v_x/mm/s \) | Vertical linear velocity \( v_y/mm/s \) | Horizontal dispersion deviations \( \Delta x/mm \) | Vertical dispersion deviations \( \Delta y/mm \) |
|---------------------|---------------------------------|---------------------------------|-------------------------------|-------------------------------|
| 1                   | -47.750                         | 59.807                          | -9.77                         | -56.42                        |
| 2                   | -79.785                         | 116.838                         | 6.63                          | -18.70                        |
| 3                   | 135.119                         | 70.979                          | 24.69                         | -73.93                        |
| 4                   | 166.690                         | 46.902                          | -164.16                       | -50.54                        |
| 5                   | -10.507                         | 201.310                         | -102.51                       | -294.59                       |
| 6                   | 268.725                         | 340.417                         | -223.71                       | -368.15                       |
The horizontal dispersion standard deviation of the 100 m target of the overhead weapon station with the viscoelastic elastomer damper in the variable firing is 6.13 cm, while the vertical dispersion standard deviation is 8.57 cm, and the half-dispersion circle radius index $R_{50}$ is 8.58 cm. Compared with the spring damper, the horizontal dispersion deviations of the overhead weapon station with the viscoelastic elastomer damper is reduced by 39.71%, and the vertical dispersion is reduced by 42.22%, while the firing dispersion is increased by 41.14%.

Table 7. The dynamic characteristics of the muzzle with the viscoelastic elastomer damper in the variable firing.

| Sequence of bullets | Horizontal angular displacement $\gamma_x/°$ | Vertical angular displacement $\gamma_y/°$ | Horizontal linear displacement $x/mm$ | Vertical linear displacement $y/mm$ |
|---------------------|-------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|
| 1                   | -0.00009                            | -0.00128                            | -0.021                              | 0.136                               |
| 2                   | -0.00039                            | -0.00052                            | -2.531                              | -0.174                              |
| 3                   | -0.00107                            | -0.00085                            | -2.212                              | -0.567                              |
| 4                   | -0.00083                            | -0.00111                            | -1.193                              | -0.219                              |
| 5                   | -0.00046                            | -0.00296                            | 0.726                               | 0.966                               |
| 6                   | -0.00217                            | -0.00258                            | 0.115                               | 1.453                               |

In conclusion, compared with the spring damper, the horizontal dispersion standard deviation of the 100 m target of the overhead weapon station with the viscoelastic elastomer damper at different firing conditions is decreased by an average of 39.48%, and the vertical dispersion standard deviation reduced by an average of 43.68%, while the firing dispersion is increased by an average of 41.89%.

5. Conclusions

In order to study the effects of the viscoelastic elastomer damper for the firing dispersion of the overhead weapon station, this paper constructed a rigid-flexible coupling dynamics model of overhead weapon station with viscoelastic elastomer damper. The dynamic simulation parameters of the damper were determined according to the static pressure test results. Then the influences of the viscoelastic elastomer damper and the spring damper on the muzzle dynamic characteristics and the firing dispersions of the overhead weapon station were studied.

Simulation results show that: (1) The recoil displacement and the recoil-return time of single shot with the viscoelastic elastomer damper are respectively reduced by 69.83% and 33.50% relative to the spring damper; (2) Compared with the spring damper, the horizontal and the vertical dispersion deviations of the overhead weapon station with the viscoelastic elastomer damper in the continuous firing are reduced by 39.24% and 45.14%, and the firing dispersion is increased by 42.63%; (3) By contrast with the spring damper, the horizontal and the vertical dispersion deviations of the viscoelastic elastomer damper in the variable firing are respectively decreased by 39.71% and 42.22%, while the firing dispersion is increased by 41.14%. (4) The horizontal and the vertical dispersion standard deviations of the 100 m target of the overhead weapon station with the viscoelastic elastomer
damper at different firing conditions are respectively reduced by an average of 39.48% and 43.68% compared with the spring damper, while the firing dispersion is increased by an average of 41.89%.

Therefore, the viscoelastic elastomer damper can significantly reduce the recoil displacement of the machine gun overhead weapon station and shorten the recoil-return time, effectively decrease the muzzle jump and improve the firing accuracy of the overhead weapon station, which has good military application value.

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