

Building and simulation-analysis of the friction loop on the movement period control*

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Abstract. This paper presents a study on the movement period control of the friction buffer using finite element methods and theoretical methods. The emphasis is on the prediction of the relationship between the number of the friction loops and the movement period control. The mathematical-physical model and a finite element model of a kind of friction buffer that includes several friction loops and a buffer spring are developed. The experimental study on some friction buffers that are different in material and half cone angle is conducted. The experimental results agree well with the theoretical results and the simulation results. The obtained results are of great importance to improve the design quality of the automatic weapons, especially for those that have particular request for firing rate. The simulation results suggest that the number of the friction loops has its limits for controlling the movement period.

Keywords: friction loop, simulation, FEA, friction loops, movement period control

1 Introduction

The firing rate, the reciprocal of firing period, is an important technical specification, because the firing stability, the durability of the movement part and even the firing accuracy are influenced by it in automatic weapons^[5].

The movement period can be controlled by many methods, among which the friction buffer is an effective way. At the same time, the cushioning device can reduce the recoil force. Furthermore, the impacts and vibrations derived from firing that are not good to the stabilization of the firing position do not act on the firer directly. The degree of conditional reflection exciting on the firer is lower and the change of the automatic rifle attitude is smaller^[6]. The accuracy of continuous fire is enhanced.

It is very important to control the movement period in designing the automatic weapons in some cases, especially when the veracity and reliability of the mechanism depend on the movement period of a moving part^[9].

The friction buffers using in the automatic weapons usually includes: a. Hydraulic spring buffer. The energy of the moving part is dissipated by the drag generated by fluid passing the regulating valve. But it is heavy when used in the hand-held automatic weapons^[3]. b. Outer cylinder shock absorber. When the moving part is moving in the weave of the outer cylinder, its velocity is reduced. The decelerating force is always negative direction to the motion direction. But its sustainability and reliability need to be improved. c. Magnetic fluid buffer. It consists of a magnetic fluid damping shock absorber that is wined by the coil of wire. When the current passes the coil, a magnetic field that is perpendicular to the moving direction of the moving part is produced. The magnetic field changes the microstructure of the magnetic fluid. When the moving part moves in this magnetic field, it endures the damping force opposite to its motion direction. But the application of the

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magnetic fluid buffer in the automatic weapons is not mature. d. Friction buffer. It consists of some friction pairs (a friction pair includes a friction loop and an outer cylinder) and a buffer spring that supports the first or the end buffer pair. Fig. 1 gives out a simple description of the friction loops structure^[9].

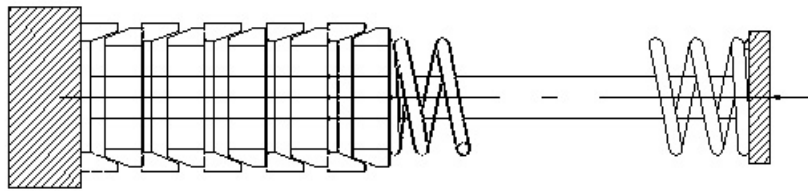


Fig. 1. structure of the friction loop

2 FEA simulation model and theoretical simulation model

2.1 FEA simulation model

The DYNA3D program is a finite element analysis code for non-linear dynamic analysis of structures in three dimensions. The code utilizes of an explicit time integr5ation scheme with a diagonal mass matrix. Element stiffness is assembled as an internal force vector so that the program does not require the assembly of a system matrix nor the solving of any matrix equation^[7]. The material parameters are as follows: Young’s modulus $E = 208GPa$, Poisson’s ratio $\nu = 0.30$, initial yield stress $\sigma_y = 0.33GPa$ and density $\rho = 7800kg/m^3$. This paper presents the simulation results of movement period affected by 2, 3, 4 friction loops respectively.

In this paper, the finite element model of the friction buffer that includes several friction loops(20half cone angle, 50 steel) and a buffer string ($\phi 2.0mm$ steel wire, 60mm pre-compression). The elements of the buffer spring and the friction loop are COMBI165 and SOLID164^[4] respectively. The type of contact among the friction loop, the dabber and the outer cylinder is face- face contact^[1].

2.2 Theoretical simulation model

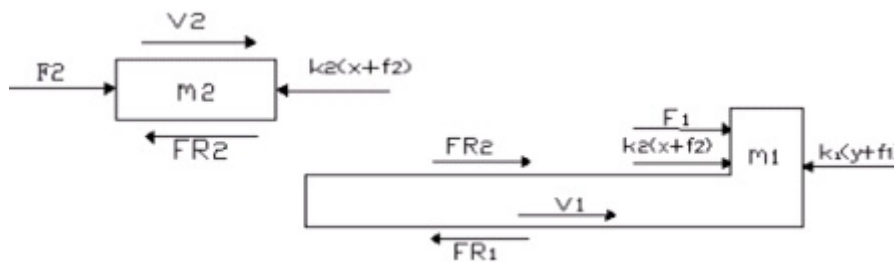


Fig. 2. mechanics analysis of the two degree system

Fig. 2 gives out the simple description of the movement of the moving parts acted by the friction loops. The m_1 and m_2 are the mass of the moving parts. The k_1 and f_1 are the stiffness and preloading of the friction loops respectively. F_1 and F_2 are the force of the moving parts. FR_1 and R_2 are the constant resistance of the moving parts. The differential equation of the two degree system is given by [2]:

$$\begin{cases} m_2(\ddot{x} + \ddot{y}) = F_2 - k_2(x + f_2) - FR_1, \\ m_1\ddot{y} = F_1 - k_1(y + f_1) + k_2(y + f_2) + FR_2 - FR_1, \end{cases} \quad (1)$$

When the moving component moves going with the orientation component in a surface, the differential equation of the two degree system in this kind of situation is given by [2]:

$$\left(m + \sum_{i=1}^n m_i \frac{k_i^2}{\eta_i}\right) \ddot{X} + \sum_{i=1}^n m_i \frac{k_i \ddot{k}_i}{\eta_i} \dot{X} = F + \sum_{i=1}^n F_i \frac{k_i}{\eta_i} - \left(m + \sum_{i=1}^n m_i \alpha_i \frac{k_i}{\eta_i}\right) \ddot{Y} \quad (2)$$

$$\left(M + \sum_{i=1}^n m_i y_i - \sum_{i=1}^n m_i \alpha_i \beta_i\right) \ddot{Y} = \Phi + \sum_{i=1}^n m_i \beta_i (k_i \ddot{X} + \dot{X}^2 \dot{k}_i) - \sum_{i=1}^n \beta_i F_i \quad (3)$$

When the moving component moves going with the basic component in a surface, the differential equation of the two degree system in this kind of situation is given by [2]:

$$\left[m + \sum_{i=1}^n J_i \frac{k_i^2}{\eta_i} + \sum_{i=1}^n m_i \left(\lambda_i \frac{k_i}{k_i} + \mu_i + \zeta_i k_i\right)\right] \ddot{X} + \left[\sum_{i=1}^n J_i \frac{k_i k_i'}{\eta_i} + \sum_{i=1}^n m_i (k_i' \zeta_i + k_i^2 \xi_i)\right] \dot{X}^2 \quad (4)$$

$$= F + \sum_{i=1}^n F_i \frac{k_i}{\eta_i} - \left[m + \sum_{i=1}^n m_i \left(\lambda_i \frac{k_i}{\eta_i} + \mu_i\right)\right] \ddot{Y}$$

$$\left(M - \sum_{i=1}^n m_i \lambda_i \omega_i\right) \ddot{Y} = \Phi + \sum_{i=1}^n (J_i \omega_i k_i + m_i \omega_i \lambda_i) \ddot{X} + \sum_{i=1}^n J_i \omega_i k_i' \dot{X}^2 - \sum_{i=1}^n \omega_i F_i \quad (5)$$

where:

m is the mass of basic active component;

m_i is the mass of the working component i ;

M is the mass of the orientation component;

F is the active force on the displacement point of the basic active component;

F_i is the resistance of the working component i displacement point;

ϕ is the active force of the orientation component displacement point;

α, β, γ are the influence coefficient between the basic active component and orientation component i ;

k_i is the ratio transmission velocity between the active component and the slave component;

η_i is the ratio transmission velocity between the slave component and the working component i ;

$\lambda_i, \mu_i, \zeta_i, \xi_i$ and ω_i are the influence coefficient between the basic active component and the working components respectively.

In order to get the stiffness of the friction loops, k_1 , the mechanics analysis of the friction loop during the phase of recoil may be found in the following equations^[8]:

$$Q_{i+1} = Q_i + F_i \quad (6)$$

$$F_i = f \pi d H P_i \quad (7)$$

$$Q_i = \pi D H n_i (f \cos(\beta) + \sin(\beta)) \quad (8)$$

$$\pi d H P_i = \pi D H n_i (\cos(\beta) - \sin(\beta)) - f Q_{i+1} \quad (9)$$

where n_i is the surface normal pressure of the friction loop, p_i is the surface pressure of the friction loop's inner hole, is half cone angle of the friction loop, β is friction coefficient, H is width of the friction loop, d is the diameter of the friction loop's inner hole, D is external diameter of the friction pair. Fig. 3 gives out the mechanics analysis of n friction pairs during the phase of recoil stroke. The solution is:

$$k_1 = \frac{2f \cos(\beta) + \sin(\beta) - f \sin(\beta)}{(1 + f^2)(f \cos(\beta) + \sin(\beta))} \quad (10)$$

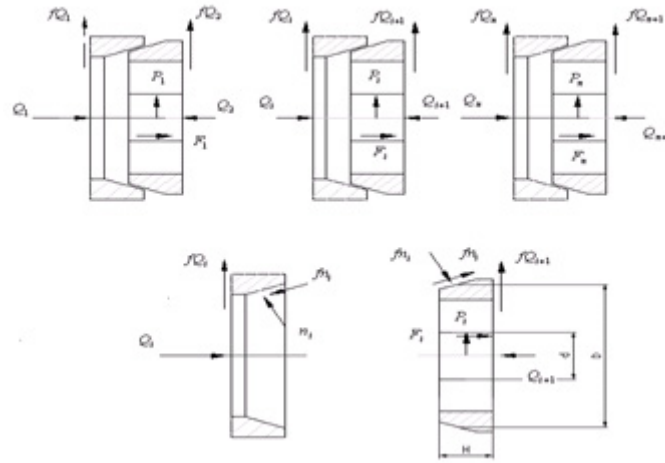


Fig. 3. the mechanics analysis of friction pairs during the phase of recoil stroke

3 Experimental principle and experimental facilities

3.1 Experimental principle

The firing rate is inspected and the state of prototype is debugged with applying the optical screen testing system. Motion pictures of the moving part acted by the friction buffer in the firing process are shot by the high-speed photography testing system. The displacement-time curves and the velocity-time curves of the moving part are obtained by post processing. The buffering effect of the different configuration's friction buffers is studied by analyzing the curves.

There are two emission modules and two receiving modules in an infrared optical screen of the optical screen testing system. The bullet passes the optical screen and shuts off the light that irradiates on the infrared receiving diodes in the test. At the same time the photoelectric couple circuit exports a high level and the counter records the shutting-off time. The reciprocal of span between two shutting-off time is the firing rate.

When getting the displacement-time curves and the velocity-time curves of the moving part with the shooting results of the high-speed photography, the displacement is obtained by the value of coordinates. The velocity and the acceleration are obtained with the displacement-time curves. So a point is marked on the moving part as the reference point for coordinates measuring and two points are marked on the fixed part and the distance between the two points is divided by the distance between the same two points in the picture as the transition rate.

3.2 Experimental facilities

High-speed photography testing system, friction buffer, optical screen testing system, fixed machine rest, a new type automatic rifle, test cartridge.

4 Results and discussion

Fig. 4, Fig. 5 and Fig. 6 give out the experiment, FEA and theoretical results of the moving parts acted by 2, 3 and 4 friction loops respectively. Tab. 1 gives out the period of the moving part acted by 2, 3 and 4 friction loops. T_2 , T_3 and T_4 denote the period of the moving part acted by 2, 3 and 4 friction loops respectively in Tab. 1.

When one buffer spring ($\Phi 2.0mm$ steel wire) works, the motion period of the moving part is 107ms. But besides one buffer spring, if two buffer loops whose cone angle are 20° and material are 50 steel are used, the motion period of the moving part is 144ms. So we can find the friction buffer has better buffer effect. When there are three or four buffer loops in the friction buffer, the period is 115ms and 109ms respectively. When

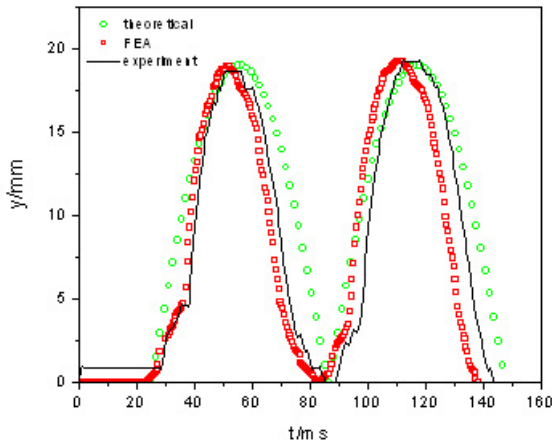


Fig. 4. Displacement-time curve of the moving part acted by 2 friction loops in 2-continuous-fire period

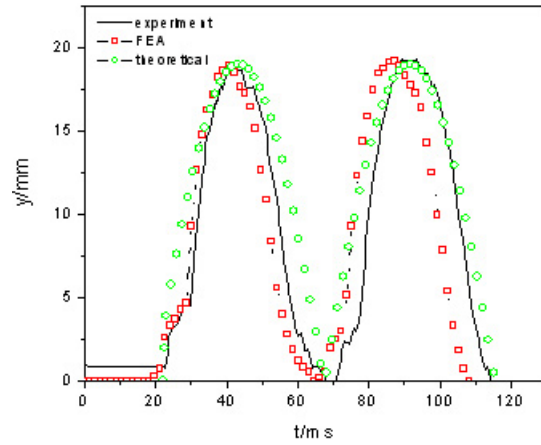


Fig. 5. Displacement-time curve of the moving part acted by 3 friction loops in 2-continuous-fire period

Table 1. the period of the moving part

| | T2/ms | T3/ms | T4/ms |
|-------------|-------|-------|-------|
| Experiment | 144 | 115 | 109 |
| FEA | 138 | 108 | 108 |
| Theoretical | 147 | 116 | 110 |

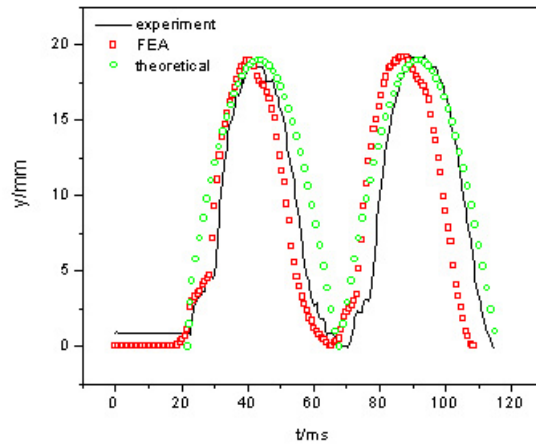


Fig. 6. Displacement-time curve of the moving part acted by 4 friction loops in 2-continuous-fire period

the number of the friction loop gets a limit, adding the number of the friction loop does not change the buffer effect evidently.

5 Conclusions

The buffer effect is better, when the material of the friction loop is spring steel. Because the elasticity of the spring steel is better, the uniform radial pressure can be generated easily when the buffer loop deforms. In this paper the experimental study to a kind of friction buffer is conducted and the mathematical-physical model is established. The experimental results verify the theoretical results. The obtained results are of great importance to improve the design quality of the machine which needs controlling the moving period.

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