THREE-DIMENSIONAL MOTION SIMULATION MODULE DEVELOPMENT OF A LARGE CALIBER GUN RECOIL MECHANISM

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In order to improve the design efficiency and realize the teaching demonstration of large caliber gun recoil mechanism , the three-dimensional motion simulation module of large caliber gun recoil mechanism was developed. The module is composed of parametric design and motion simulation. Based on the structure analysis and motion law of recoil mechanism, the structure template and motion mathematic model of recoil mechanism are established, and the man-machine interactive interface is designed. After the design parameters are input into the interface, the design parameters are calculated by the integrated calculation program, and the recuperator-recoil motion law curve is obtained. The curve is optimized by changing the design parameters, and the 3D solid model is generated by using parameter driven template.With the help of Unity3D software, the movement simulation visualization of gun recoil mechanisim is realized by combining the recuperator-recoil motion curve and 3D solid model.The feasibility and validity of the module are verified by an example of a gun recoil mechanisim. The mathematical calculation model and the motion simulation module design method of gun recoil mechanism can provide a reference for gun designers and teaching staff.

Key words: Large caliber gun, Recoil mechanism, Parametric design, Motion simulation, Unity3D.

1. Introduction

The recoil mechanism is an important part of artillery [1,2]. In order to design a recoil mechanism, designers need to design, calculate repeatedly and modify models in accordance with the inherent design process. The workload is

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large and the efficiency is low. For shortening the research and development cycle and improve the work performance of recoil mechanisim, He et al. [3] made use of Simulink software to simulate the recoil mechanism of gun. Sun et al. [4] used the ADAMS software to simulate the working principle and process of gun recoil mechanism, and established the design scheme of gun recoil mechanism. Du and Di [5] and Du and Wu [6], based on the MATLAB language, compiled its inverse problem simulation program, and simulated the operation characteristics of a complex gun recoil mechanism in order to deeply understand the structure and working process of the recoil mechanism. There are few reports on the design of recoil mechanism and the visualization of motion simulation combined with design parameters. In this paper, a motion simulation module of a large caliber gun recoil mechanism is developed based on the structural design parameters. By optimizing the design parameters, the 3D solid model of recoil mechanism is obtained to realize parametric design. Motion simulation and visualization are realized according to the motion curve and a 3D solid model, which solves the problem of repeated design and modifications, improves design efficiency and meets the requirements of teaching demonstration of artillery design related courses.

2. Development of three-dimensional motion simulation software

The operational simulation module of gun recoil mechanism developed in this paper is mainly composed of parametric design module and motion simulation module. The parametric design module includes two parts: the parametric template construction and the judgment of the recuperator-recoil motion law. The parametric template construction provides the input template of model parameters and the motion model of recoil mechanism. And man-machine interaction interface is designed, the input and display of design parameters are realized. The submodule of judging the law of the recuperator-recoil motion takes the information input by the user into the mathematical model and solves it, and obtains the curve diagram of the law of recuperator-recoil motion. The designer judges the quality of the law curve according to the design requirements, and generates the 3D model of the recoil mechanism according to the parameters that meet the design requirements to realize the parametric design. In the motion simulation module, the recuperator-recoil motion law curve is obtained based on the parameters and calculation, and combined with 3D model of the recoil mechanism, the motion simulation is realized. The flow chart is shown in Fig. 1.

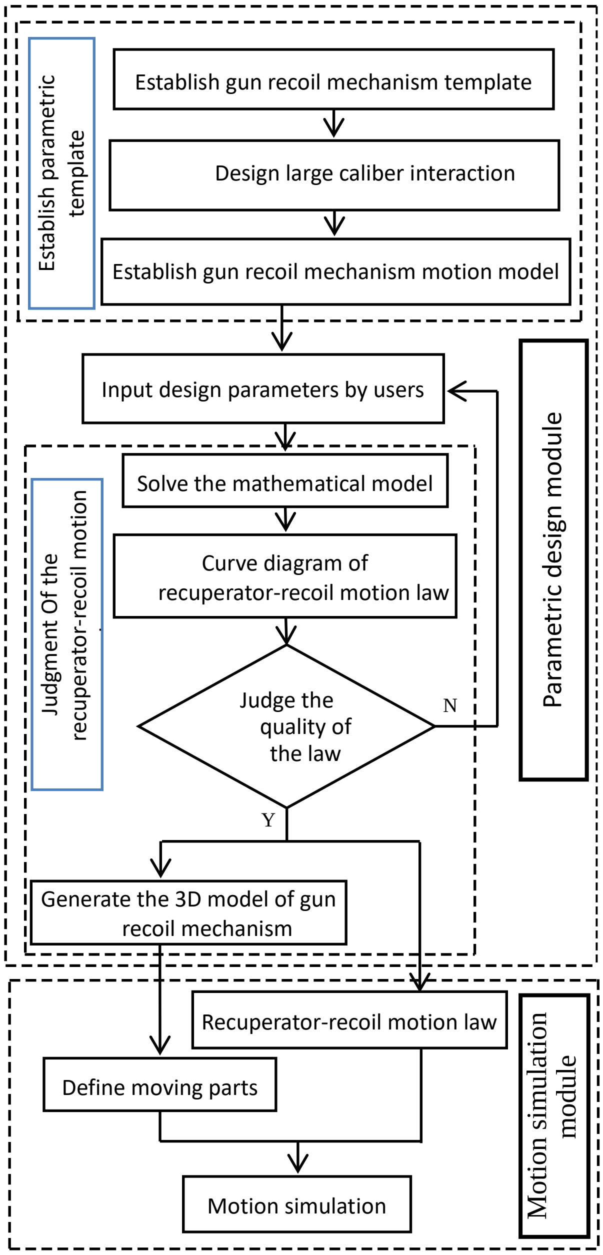


Fig. 1 Flow chart of motion simulation module for large caliber gun recoil mechanism

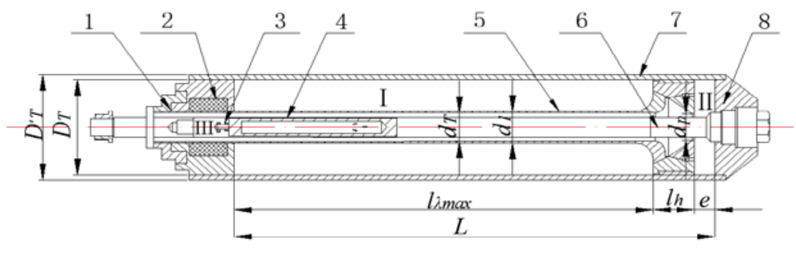
According to the partition of each functional sub-module, the main work of the module development is as follows: a) constructing the model template of recoil mechanism and establishing the motion model; b) using the standard "Winform" program interface style to design the man-machine interaction interface, thus making the module interface simple and clear; c) programming in Visual Studio to receive input parameters and bring them into the mathematical model to be solved by Runge-Kutta method; d) the result of calculation is expressed by the "Chart" control in the form of curve, that is to say, the recuperator-recoil motion curve is made; e) the designer can judge the quality of the curve - if not satisfied, the input parameters can be modified and the curve can be regenerated; f) sending messages to Unity 3D software through TCP communication mechanism; g) with the help of UG modeling software, the 3D model of moving parts is displayed in the model display area, and the parametric design module is completed; at the same time, the new recuperator-recoil motion curve is calculated and assigned to the moving parts, which realizes the motion simulation module function of gun recoil mechanism and completes the module development.

3. Parametric design module

3.1 Establish gun recoil mechanism template

The model of recoil mechanism adopts the structure of liquid-air recuperator and rod recoil mechanism. Combining with the structure of recoil mechanism, force condition and movement law, the parametric formwork is constructed.

The template for the rod recoil mechanism is shown in Figure 2. The main structural parameters include: inner diameter of recoil cylinder is D_T, outer diameter of recoil cylinder is D'_T, outer diameter of recoil rod is d_T , inner diameter of recoil rod is d_1, the recoil limit length is $l_{\lambda max}$, the working length of the rod recoil mechanism is L, length of rod recoil mechanism's rod piston is l_h [7].



1-front cover; 2-sealing means; 3-flapper; 4-speed control cylinder; 5-recoil rod; 6-control rod; 7-recoil cylinder; 8-back cover

Fig. 2 Template diagram of rod recoil mechanism structure

The area of the liquid pore is a_x, which is decided by the outer diameter of the control rod dx_i and the inner diameter of the control ring d_p. The calculation formula of a_x is shown in relation (1). At the same time, the shape of control rod can be made up of 10 cylindrical segments, as shown in Figure 3. Each segment is dx_i and the length is Lx_i as the design parameters to determine the control rod dimension [8,9].

$$a_x = \frac{\pi}{4}\left(d_p^2 - d_{x_i}^2\right) \tag{1}$$

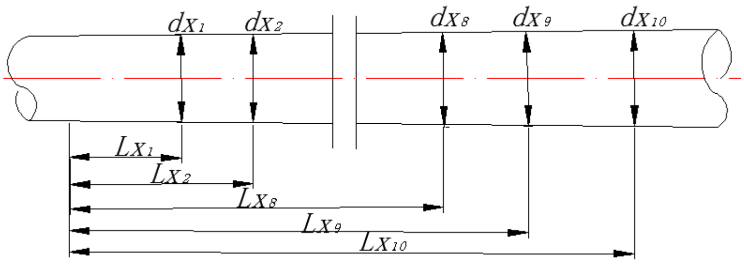
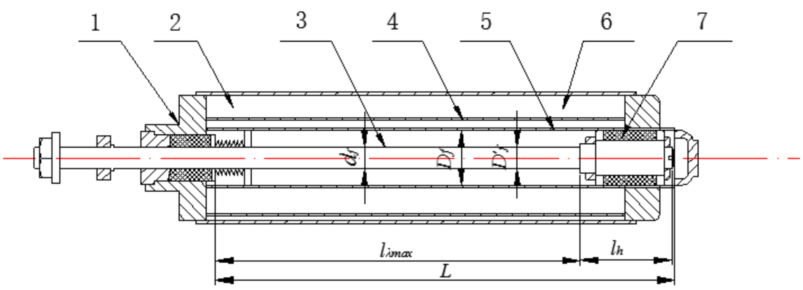


Fig. 3 Structure diagram of recoil mechanism control rod

The template for the liquid-air recuperator is shown in Figure 4. The main structural parameters include: outer diameter of recuperator inside cylinder is D'_f. Inner diameter of recuperator outside cylinder is D_f .The diameter of recuperator piston rod is d_f .The length of recuperator piston is l_h. The working length of the recuperator is L [7,10].



1-front cover; 2-compressed gas; 3-recuperator piston rod; 4-recuperator middle cylinder; 5-recuperator inside cylinder; 6-recuperator outside cylinder; 7-recuperator piston

Fig. 4 Template diagram of liquid-air recuperator structure

3.2 Design man-machine interaction interface

The man-machine interaction interface includes two parts: the structure parameters design of rod recoil mechanism and liquid-air recuperator.The structure parameters design of the rod mechanism includes the structure parameters and the control rod shape design. The input parameters correspond to the template representation parameters by clicking the View Rod Recoil Mechanism /Liquid-air Recuperator Template Diagram button to view the template. Using the standard “Winform” program interface style to develop the interactive interface as shown in Figure 5 below. Taking the design parameters of a gun recoil mechanism as an example, after inputting the parameters, the parameters are received by the program and applied to calculation.

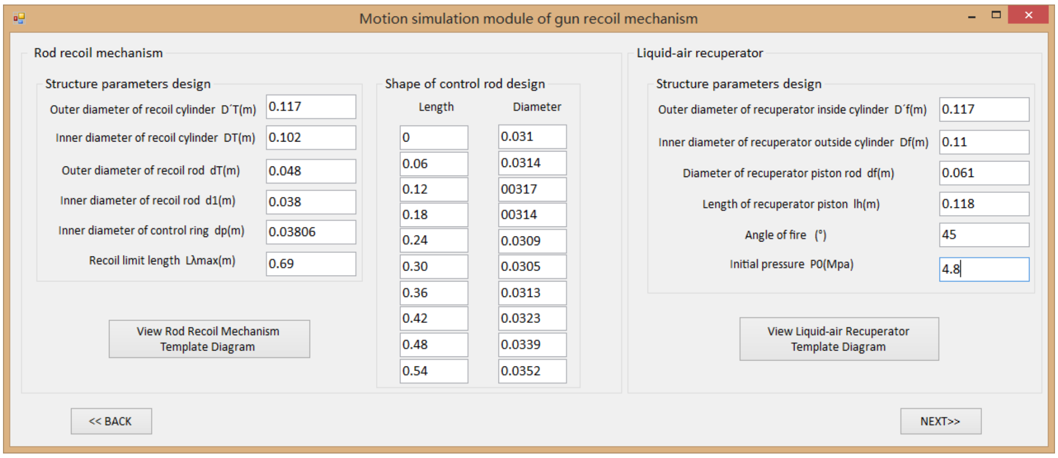


Fig. 5 man-machine interaction interface

3.3 Establish recoil mechanism motion model

After the internal trajectory parameters and gun firing conditions are known, the structural parameters are transformed into the parameters that can be solved on the basis of mathematical relationship. According to the force and motion law of gun recoil mechanism, the motion model of recoil mechanism is established as relation (2), [1,2]:

$$
\begin{cases}
m_h \frac{d^2x}{dt^2} = F_{pt} - F_R \\
F_R = F_{\phi h} + F_f + F + F_T - m_h g \sin\theta \\
F_f = \frac{\pi}{4}\left(D_f^2 - d_f^2\right) p_{f0} \left(\frac{V_0}{V_0 - A_f x}\right)^n \\
F_{\phi h} = f(a_x) v^2 \\
F_{pt} = \begin{cases} \frac{1}{\psi}\left(1 + \frac{\omega}{2m}\right) Ap & \left(0 \le t < t_g\right) \\ X F_g e^{-\frac{t - t_g}{b}} & \left(t_g < t \le t_k\right) \end{cases} \\
m_h \frac{d^2\bar{x}}{dt^2} = F_r \\
F_r = \begin{cases} F_{f0} + K(l_\lambda - \bar{x}) & 0 \le \bar{x} \le l_p \\ F_{sh} - F_{\emptyset fz} & l_p \le \bar{x} \le l_1 \\ F_{sh} - F_{\emptyset fz} - F_{\emptyset fj} & l_1 \le \bar{x} \le l_\lambda \end{cases}
\end{cases}
\quad (2)
$$

In the formula, F_{pt} is the resultant force in bore, F_R is the recoil resistance, $F_{\phi h}$ is the hydraulic resistance, F is the friction of sealing device, F_T is the friction of cradle guide rail, F_f is the recoil force, $m_h g \sin\theta$ is the gravity component of recoil part, θ is the angle of fire, A_f is the working area of recoil piston, v is the recoil velocity, ψ is the secondary work calculation coefficient, w is the charge quantity, m is the mass of the projectile, A is the cross-sectional area of the guided part, b is the attenuation coefficient of the resultant force in bore. X is the characteristic quantity of the muzzle brake, p is the average pressure in the bore, t_g is the end of the movement in the bore, t_k is the end time of the gunpowder gas aftereffect, F_{sh} is the recuperate remaining force and F_r is the recuperate resultant force.

3.4 The curve and optimization of recuperator-recoil motion

In order to improve the performance of gun recoil mechanism and increase the stability and accuracy of gun design, it can be achieved by changing the magnitude and flatness of gun recoil resistance [11], at the same time the design parameters directly affect the recoil resistance. Therefore, the more ideal gun recoil resistance curve can be obtained by adjusting the design parameters. The adjustment of recoil resistance is realized by adjusting the control rod's shape of the recoil machine. The change of the control rod's shape can change the area of the fluid hole and cause the change of the recoil machine force. At last, the recoil resistance force can be changed [12,13]. In this paper, the shape parameters of the control rod are optimized to obtain a more ideal recoil resistance force curve. The curve before and after optimization is shown in Figure 6.

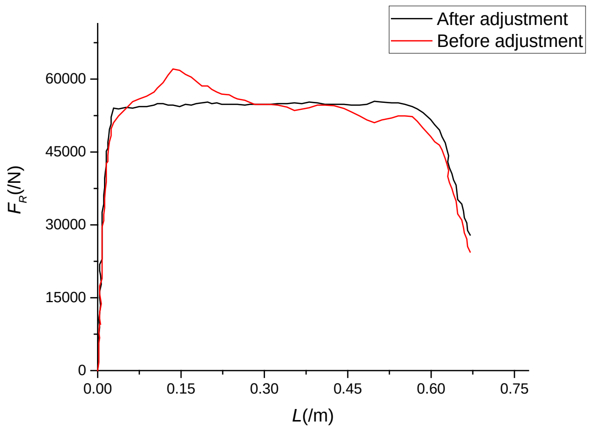


Fig. 6 F_R vs L for recuperator-recoil motion law

From the figure 6, it can be seen that the peak of the optimized curve decreases, the curve changes gently, and the fluctuation is small. The design results are in accordance with the design requirements of the gun recoil mechanism.

3.5 Establish gun recoil mechanism model

Apply the program to get optimized design parameters and send them to the established parameterized template. According to the design parameters, the 3D model of gun recoil mechanism is established to realize the display of 3D model. If modify the design parameters, the 3D model can be updated. As shown in Figures 7 and 8 [14,15], the whole part name is displayed on the left side of the display area. One has to click on the part name to display the corresponding parts in the display area.

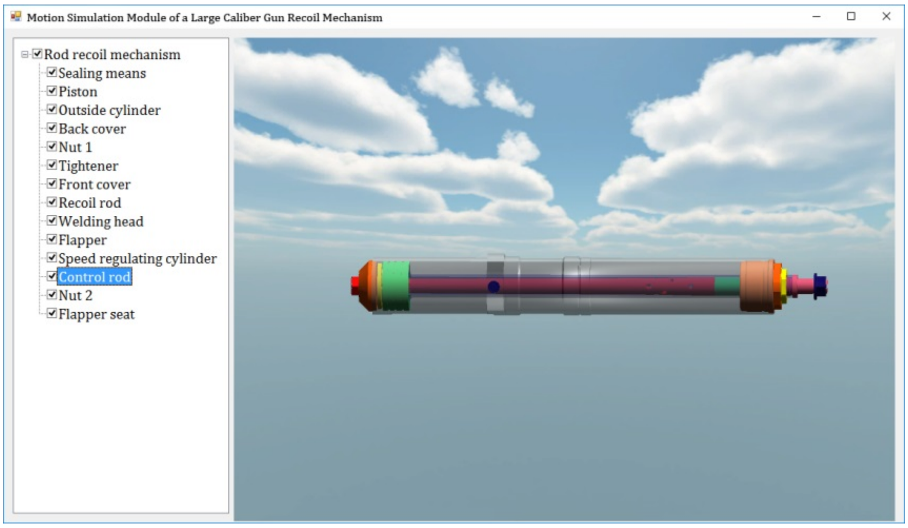


Fig. 7 Rod recoil mechanism 3D solid model

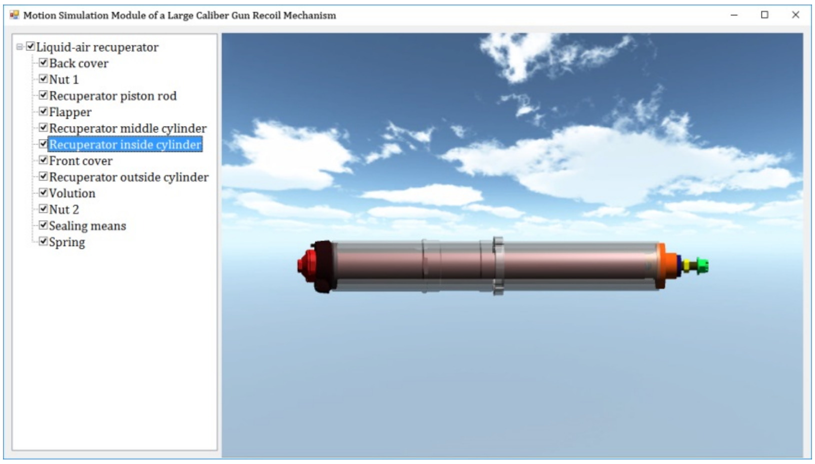


Fig. 8 Liquid-air recuperator 3D solid model

4. Three-dimensional motion simulation module

In order to more intuitively observe the movement process of gun recoil mechanism and the changes of force and motion parameters in the movement phase, a motion simulation module is designed. According to the motion law and force condition of recoil mechanism, combined with the optimized design parameters, the motion law is calculated by mathematical model and the recuperator-recoil motion curve is obtained, as shown in Figure 9-12.

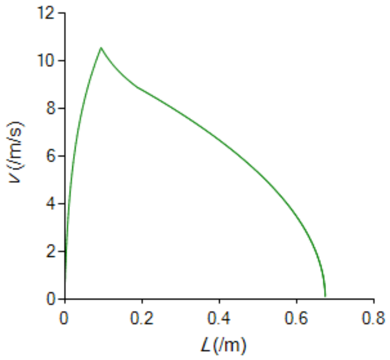


Fig. 9 *V* vs *L* during recoil process

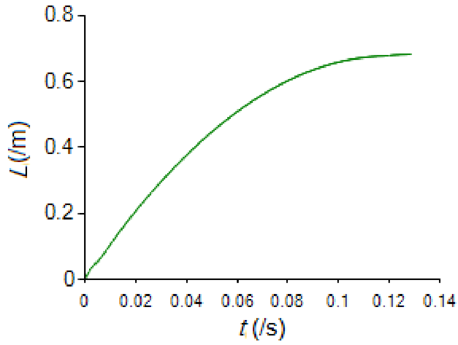


Fig. 10 *L* vs *t* during recoil process

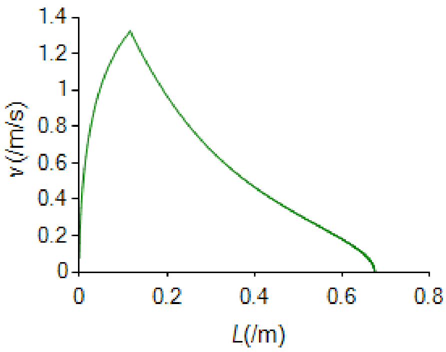


Fig. 11 *V* vs *L* during recuperator process

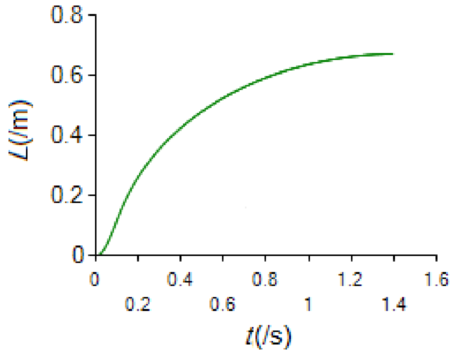
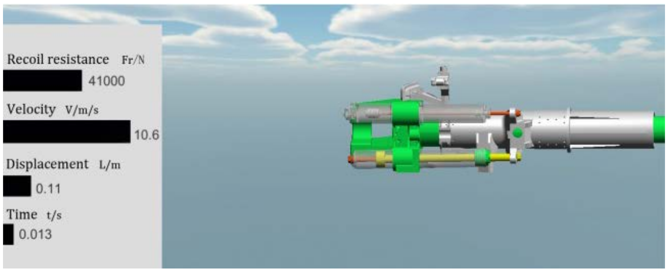
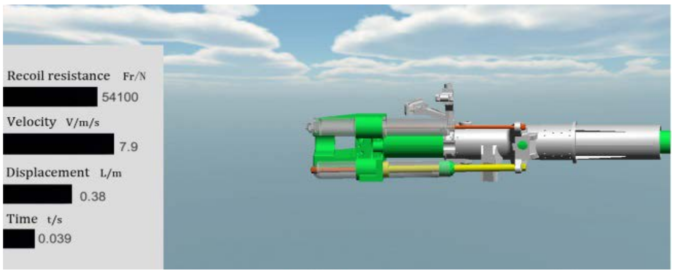


Fig. 12 *L* vs *t* during recuperator process

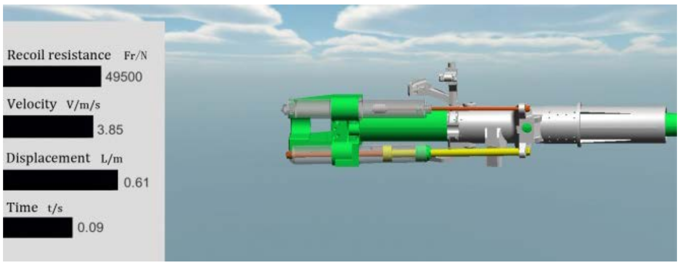
In the working process of gun recoil mechanism, the recuperator piston rod/recoil rod and piston are fixed on the gun frame body, and other parts moving with the gun barrel are moving parts. Motion simulation reflects the motion process by the corresponding relationship between the position and time of the moving parts of the gun recoil mechanism. Therefore, it is necessary to calculate the position of gun recoil mechanism moving parts corresponding to each frame. The motion rules are sent to each moving part, and finally the motion simulation visualization is realized through the Unity3D platform as shown in Figure 13-14, [16]. Users can repeatedly watch the movement process of the gun recoil mechanism, and pause to start in any movement process, inquire about the movement and mechanical parameters of a recoil mechanism [17].



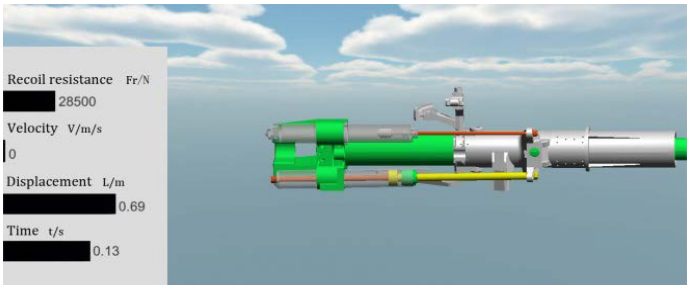
a *t*= 0.013 during recoil process



b *t*= 0.039 during recoil process



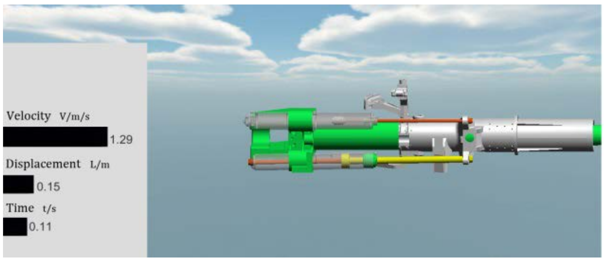
c *t*=0.09 during recoil process



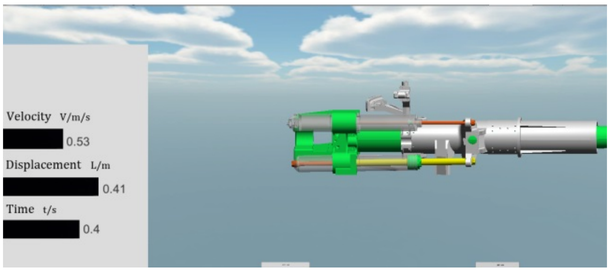
d *t*=0.13 during recoil process

Fig. 13 Motion simulation diagram of recoil

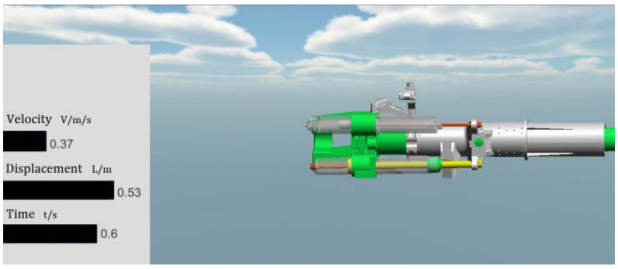
From Figures 9 and 10, it can be seen that the recoil process accelerates the recoil until the maximum recoil speed is reached, then slows down gradually until the recoil speed is zero, and the recoil displacement increases gradually with time until it returns to its original position. The simulation process is shown in Figure 13, which coincides with the law of gun recoil motion.



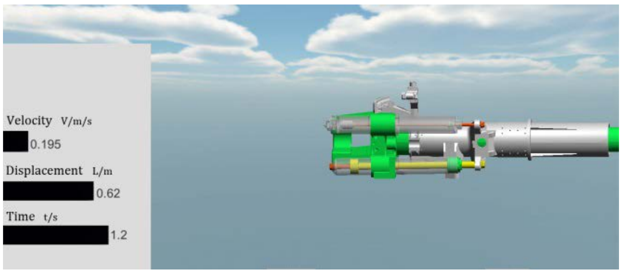
a *t*= 0.11 during recuperator process



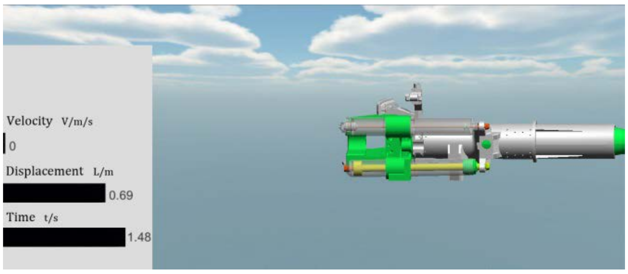
b *t*= 0.4 during recuperator process



c *t*= 0.6 during recuperator process



d *t*= 1.2 during recuperator process



e *t*= 1.48 during recuperator process

Fig. 14 Motion simulation diagram of recuperator

As shown in Figures 13 and 14, with the increase of time, the recuperator speed decreases, and the recuperator displacement increases slowly until the recuperator limit position is reached and the recuperator process ends. In the process of recuperator, the movement time is relatively long, the velocity changes a little, and keeps a steady return to the original position, which conforms to the movement law of gun recoil mechanism, and achieves the purpose of motion simulation of gun recoil mechanism .

5. Conclusions

Based on the structural analysis of gun recoil mechanism, a parametric recoil mechanism template is established through the force analysis of the whole movement process of recoil mechanism and the motion model of recoil mechanism is established. The relationship between recoil resistance and displacement can be determined by the motion model. A three-dimensional motion simulation module of recoil mechanism for large caliber gun is developed as including two parts: parametric design and motion simulation. In the parametric design part, the recoil resistance curve is optimized by adjusting the structural parameters and the 3D model of recoil mechanism is generated according to the determined structural parameters to realize the parametric design of gun recoil mechanism. The motion simulation part uses Unity3D software to realize the motion simulation and visualization of the recoil mechanism. The motion simulation example of recoil mechanism shows that the dynamic characteristics of virtual simulation are consistent with the motion law of recoil mechanism. The mathematical calculation model and module design method of gun recoil mechanism by using three-dimensional motion simulation can provide a reference for gun designers and teaching staff.

REFERENCES

[1]. *S.Z.Gao, Y.S.Chen, Y.L.Zhang*, Gun recoil mechanism, National Defense Industry Press, Beijing, 1995.
[2]. *Y.F.Gao*, Design of gun recoil mechanism, National Defense Industry Press, Beijing, 2010.
[3]. *W.G.He, L.B.Tan, X.B.Pan*, "Simulation of Gun Recoil Devices Based on Simulink", in Ordnance Industry Automation, **vol. 31**, no.11, Nov. 2012, pp.41-43,55.
[4]. *Y.Z.Sun, J.Q.Qin, C.C.Di, K.B.Cui and Y.L.Yang*, "Design and Simulation Research on Experimental Equipment of Gun Recoil", in Journal of Machine Design, **vol. 30**, no.8, Aug. 2013, pp.30-33.
[5]. *Z.H.Du, C.C.Di*, "Working Characteristic Simulation Analysis of a Gun with Complex Recoil System", in Mechanical Engineer, **vol .42** , no.2, Feb. 2011, pp.96-99.
[6]. *Z.H.Du, S.Wu*, "Numerical Simulation Analysis on Hydraulic Resistance of Certain Gun Recoil Mechanism", in Mechanical Engineer, **vol. 45** , no.12, Dec. 2014 , pp.28-31.
[7]. *S.Z.Zong, L.F.Qian, Y.D.Xu*, "Dynamic Coupling Analysis and Optimization of Gun Recoil Mechanism", in Acta Armamentarill, **vol. 28** , no.3, Mar. 2007, pp. 272-275.
[8]. *Z.C.Cao, Z Yao, Y.Z.Wang*, "Rapid Design Module Development of a Large Caliber Naval Gun Recoil Mechanism", in Journal of Gun Launch and Control, **vol. 37**, no.2, Jun. 2016, pp.57-59.
[9]. *L.B.Tan, X.Y.Zhang, X.B.Pan and H.G.Guan*, Introduction to artillery, Beijing Institute of Technology University Press, Beijing, 2014.
[10]. *G.Q.Cao, H.Y.Yao, S.H.Liu and Y.F.Gao*, "Parametric Design of Hydropneumatic Recuperator Based on the Redevelopment", in Journal of North University of China: Natural Science Edition, **vol.30**, no.1, Feb. 2009, pp. 46-49.
[11]. *C.Z.Jia, R.X.Hu, H.P.Liu*, "Research on Simulation and Quantitative Evaluation of Performance of Recoil System Nased on Virtual Prototyping of Guns" in Journal of System Simulation, **vol.19**, no.2, Jan. 2007, pp.322-325.
[12]. *Q.H.Liu*, Parameterized Design and Optimization of Gun Recoil Mechanism, MD Thesis, Nanjing University of Science and Technology, 2014.
[13]. *Q.H.Liu, Y.D.Xiu, L.Yang*, "Parameterization Design and Optimization of Throttling Bar Recoil Mechanism", in Jouranal of Gun Launch&Control, **vol. 34**, no.4, Dec. 2013, pp.49-53.
[14]. *L.Y.Shi, X.J.Zhu, J.Z.Ma*, "A UG-Based Parametric Design System", in Journal of Graphics, **vol.34**, no.2, Mar. 2013, pp.108-112.
[15]. *K.Y.Zhang, H.W.Tian*, "Research of Product Level Three-dimensional Parametric Design Based on UG", in Machinery, **vol.38**, no.2, Feb. 2011, pp.36-40.
[16]. *Y.F.Wu, Y.N.Suo*, Unity5.X 3D game development techniques and typical cases, Posts and Telecom Press, Beijing, 2016.
[17]. *Z.C.Li,J.Wang*, "A GunRecoil System Employing a Magnetorhelolgical Fluid Damper", in Smart Materials&Structures,**vol.21**, no.10, Jul. 2012, pp.31-41.