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Simulation and Application of Automatic Weapon Transmission Mechanism Concept Design

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Keywords： automatic weapon, transmission mechanism, mechanism simulation and analysis, ADAMS.

ABSTRACT

This study presents a theoretical concept design analysis and verification of the new automatic weapon transmission mechanism based and improved on the Italy BELLINI shotgun transmission mechanism. An inertia-driven system is used in the Italian BELLINI shotgun to transmit the recoil energy generated by propellant burning and a high-pressure gas to make the shotgun fire semi-automatically. This study combined the principle of this inertia-driven system with that of a barrel short recoil-operated system to create a new type of transmission mechanism for an automatic weapon to transfer the recoil energy and shoot full-automatically. In this study, computer-aided design, mechanism simulation, and the analysis software ADAMS (Automatic Dynamic Analysis of Mechanical System) were used to design and analyze the new type of transmission mechanism to observe the movement of the new mechanism in the simulation and analyze the performance parameters of its action. Finally, the feasibility of the new transmission mechanism theory for automatic weapons was verified by shooting a sniper gun acting with barrel short recoil fully automatically.

INTRODUCTION

An Italy BELLINI shotgun applying the inertia-driven system transmission mechanism can shoot semi-automatically (Benelli, 2023). Its inertia-driven system utilizes the inertia of the bolt carrier itself, staying in place at the moment of shooting to make the recoil force generated by a high-pressure gas push the bolt within a very short time period and compress the side-by-side spring with a high coefficient of elasticity (called “inertia spring”). The inertia spring is released immediately after being compressed a short free distance by the bolt, and the spring energy is transferred to push the bolt carrier back and pull the cartridge shell and eject the shell automatically. The inertia-driven system used in the bolt assembly of the Italian Bellini shotgun is shown in Fig. 1. In this study, we combined the principles of the inertia-driven system and a barrel short recoil-operated system to create a new type of transmission mechanism such that the new mechanism could shoot fully automatically instead of semi-automatically in order to increase the power of gun firing. This new innovative mechanism could be applied to all high-chamber-pressure guns, e.g., rifles and machine guns.

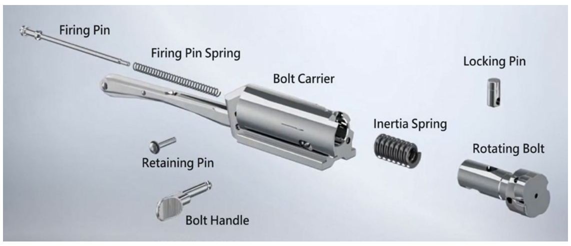

Fig. 1. Inertia-driven system used in the bolt assembly of an Italian Bellini shotgun (Robert Sutherland, 2016)

LITERATURE REVIEW

Traditional automatic weapons usually obtain all of their transmission and operation energy from the propellant to make gun fire semi-automatic or fully automatic. There are three general classes of automatic weapons, defined according to their transmission and operation system, namely blowback systems, gas-operated systems, and recoil-operated systems. First, a blowback system is a system of operating a gun mechanism that uses the propellant gas pressure to force the bolt to recoil, while the barrel and the receiver remain relatively fixed. The chamber pressure force is transmitted directly by the cartridge case base to the bolt. The blowback system includes two main types, simple blowback system and delayed blowback system (Mateusz and Mirosław, 2021). The main distinguish between them is the time to open firearm's bolt. A simple blowback firearm opens the

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bolt quickly and is only used usually with low-chamber-pressure ammunition, otherwise a delayed blowback firearm opens the bolt more slowly and is used generally with high-chamber-pressure ammunition, as rifles and machine guns. Second, a gas-operated system is a system that uses propellant gases that vent from the bore to drive a piston to push and unlock the bolt and then drives it in the rear direction. Third, a recoil-operated system is a system that utilizes the energy of the recoiling parts, including the barrel and the bolt to operate the gun (Army Materiel Command, 1970). The recoil-operated system can be realized with two kinds, a barrel short recoil-operated system and a barrel long recoil-operated system. The action principles of many types of automatic weapons, such as rifles, machine guns, and submachine guns, are of the above-mentioned types, and the action principle of using an inertia-driven system is very rare and uncommon.

The first practical use of the inertia-operated system was the Sjögren shotgun, developed by the Swedish engineer Carl Axel Theodor Sjögren in the early 1900s. In contrast to the other action principles, the inertia-operated system uses nearly the entire firearm as the recoiling component, with only the bolt remaining stationary during firing. Because of this, the inertia-operated system is only applicable to heavily recoiling firearms, particularly shotguns until this study. Paolo Benelli and his company developed the M1 super 90 shotgun with the original inertia-driven system in the early 1980s. Then, the Browning Arms Company introduced the Auto-5 shotgun with the kinematic drive inertia-operated system. The kinematic drive inertia-operated system is less maintenance and cleanliness, less cost of production and a more economical part due to less component (O. Beyaz and F. Erzincanli, 2018). The XADO Sniper "Rhino hunter" is a type of the 50-caliber sniper rifle applying with the inertia-driven system, shooting with a single shot semi-automatically. All of the abovementioned shotguns made by Sjögren, Benelli, and Browning and the XADO sniper rifle using the inertial action principle are semi-automatic firing models, and not fully automatic ones. This research focused on combining the inertia-driven system and the barrel short recoil-operated system to develop a new type of weapon transmission mechanism to shoot fully automatically.

In addition, if both the center of mass of the barrel and that of the bolt carrier deviate obviously from the bore axis, the action line of the recoil force of gun shooting will not pass through the center of mass of the barrel and the bolt carrier. The barrel and the bolt carrier have a tendency to rotate by the influence of the moment force, but its tracks restrict them from flipping and the friction resistance will increase. The result will be a reduction in the recoil velocities of the barrel and the bolt carrier and an aggravation of the track rail wear. In order to reduce the impact of the moment forces on the movement of the barrel and the bolt carrier, the centers of mass of the barrel and the bolt carrier, the action line of the barrel spring and the recoil spring should be designed to be as close to the axis of the barrel as possible. Furthermore, the joints between the mechanism parts constrain their movements. The constraint and friction forces between the mechanism parts make the transmission between the moving parts of the mechanism not ideal and lead to a transmission energy consumption loss (Gaocai Gan, 1990). The transmission mechanism includes active parts and the corresponding followers. The active parts in the barrel short recoil-operated system gun are the barrel and the bolt. The follower parts are the bolt carrier and its sub-follower parts. Therefore, the transmission efficiency is inversely proportional to the number of series connection parts; the smaller the number of series connection parts of the gun transmission mechanism is, the better is the transmission efficiency and the lower is the energy loss. Therefore, the transmission efficiency theory was integrated with the compound system including the inertia-driven system and the barrel short recoil-operated system in this study.

The study found there are few studies presenting theoretical design analysis and verification of the new automatic weapon transmission mechanism have been published. Huai-Ku Sun etc. analyzed the dynamic behavior of a machine gun mounted on a four-wheeled vehicle. The study combined a computer-aided analysis of rigid-body mechanisms with finite element analysis of a flexible structure. The total equations of motion were solved with numerical integration to simulate the transient response of the whole system (Huai-Ku Sun. et al., 2009). Mengfei Pan etc. presented three-dimension modeling and dynamic simulation conducted by using Unigraphics and Automatic Dynamic Analysis of Mechanical System based on the conversion mechanism design drawing to investigate the rationality and stability of the conversion mechanism. The analysis results show that the gunlock designed can work smoothly in open bolt firing mode (Mengfei Pan. et al., 2021). Huang Xianghong etc. developed the dynamics simulation software of individual soldier automatic weapon based on ADAMS. Parameter modification, remodeling, dynamics simulation, simulation replay, obtain and save of results of individual soldier automatic weapon model were completed (Zhao Yan-jin. et al., 2012).

For this study, it studied about firearms' dynamic behavior, mechanism designs, simulations and analyses, focused on the improvement of the inertia-driven system by combining it with a barrel short recoil-operated system to investigate the compound action of automatic weapons.

This study used the ADAMS mechanism movement simulation software based on the multibody dynamics theory and a numerical analysis method to calculate and simulate the movement behavior of the transmission parts of compound automatic weapons, including the displacement, velocity, acceleration, and the action force situation versus time. Then, we used ADAMS 3D visualization patterns and a post-processing analysis to analyze the mechanism simulation performance according to the automatic weapon design theory and judge its actual situation. Finally, a sniper gun was be took to reform its bolt assembly as a new type of transmission mechanism and shot with real ammunition to verify the performance of the fully automatic fire.

RESEARCH THEORIES AND METHODS

Principle of Barrel Short Recoil-Operated System

The main parts of a barrel short recoil-operated automatic weapon are the barrel, bolt, barrel spring, and the recoil spring, as shown in Fig. 2 (The mechanism of Fig. 2 is of the general and hint type). After the ammunition is fired, a high-pressure gas is generated, which pushes the bullet out of the shell and moves it in the barrel, rotating it with the rifling grooves. The high-pressure gas pushes the bullet forward and pushes the cartridge case backward. Because the cartridge case is closed and covered by the barrel and the bolt, the barrel and the bolt are pushed together by the high-pressure gas to push the cartridge case to move backward and transmit energy. The barrel moves back a short distance limited by the barrel latch to stop. When the barrel stops the recoil, the bolt lock is unlocked by the unlocking cam and the bolt separates from the barrel to move backward until the stop position is reached. The recoil of the barrel and the bolt compresses the barrel spring. When the recoiling bolt presses the unlatching cams, the barrel is released and returned to the initial position by the stored energy released by the barrel spring. The recoil spring is compressed when the bolt moves backward. When the bolt recoils and the recoil spring begins to store the energy, then the recoil spring is released to push the bolt forward when the bolt arrives at the rear stop position. When the bolt is returned to the initial position by the recoil spring, it is locked with the barrel again.

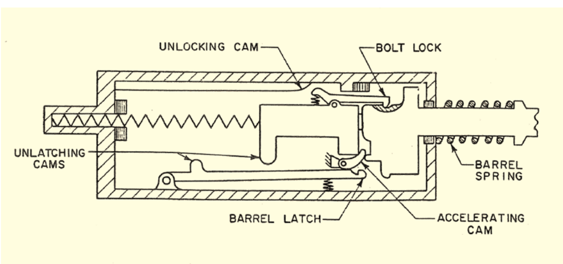

Fig. 2. Schematic representation of a barrel recoil-operated automatic weapon (Army Materiel Command, 1970)

Principle of Automatic Weapon Rotation Locking

As the high-pressure chamber gas is generated to push the bullet forward after the ammunition is fired, there must be a locking device to protect the ammunition's cartridge case. The barrel short recoil-operated automatic weapon locking method usually uses a type of rotary rigid locking device (Sheng Yao Yi and Jing Zhang, 2009) shown in Fig. 3. This rotary rigid locking device can make the barrel and the bolt firmly buckled and locked to prevent the cartridge case from being broken by the impact of the high-pressure gas. There are usually some lugs on the bolt and the corresponding grooves on the barrel extension. After the bolt pushes an ammunition into the chamber, the bolt rotates and locks with the barrel through a cylinder joint between the bolt and the bolt carrier. Then, the ammunition is sealed in the chamber and is ready to fire. After the ammunition is fired for approximately 2-3 ms, the gas pressure drops to a safe value gradually. When the gas pressure decreases to under the safe value, the bolt is rotated in the reverse direction to unlock from the barrel and the ammunition's cartridge case is pulled out of the barrel.

Fig. 3. Schematic representation of the rotary locking device (45Snipers, 2017)

Empirical Formula of Chamber Pressure Curve (Zürich Oerlikon, 1958)(Gaocai Gan, 1990)

In this study, Heydenreich's chamber pressure empirical formula was used to establish the chamber pressure generated by ammunition firing, which was used as the external force input setting value. When the caliber of the weapon (D), the weight of the bullet (m_D), the weight of the propellant (m_Y), the muzzle velocity (v_0), the maximum chamber pressure ($p_{\max}$), and the length of the bore (x_m) were known, then according to the Heydenreich empirical formula, the position, velocity, and time of the maximum chamber pressure in the bore; and the chamber pressure, bullet velocity, and time at any point in the bore could be calculated.

Using the cross-sectional area formula of the bore $S = 0.82D^2$, mean chamber pressure formula $P_{mean} = \dfrac{\left(m_D + \dfrac{m_Y}{2}\right)}{2gSx_m} v_0^2$, and chamber pressure efficiency $\eta = \dfrac{P_{mean}}{P_{\max}}$, we determined the following value. At the highest chamber pressure: $x_p = x_m \sum(\eta)$, $t_p = \dfrac{2x_m}{v_0}\theta(\eta)$, and $v_p = v_0\Phi(\eta)$, at the muzzle: $p_m = p_{mean}H(\eta)$, $t_m = \dfrac{2x_m}{v_0}T(\eta)$. In these formulas, x_p, t_p, and v_p respectively denote the projectile distance, time, and projectile velocity at the highest chamber pressure in the bore. p_m and t_m respectively indicate the muzzle pressure and the muzzle time. p_{mean} is the mean chamber pressure. $\sum(\eta)$, $\theta(\eta)$, $\Phi(\eta)$, $H(\eta)$, and $T(\eta)$ are a function of the chamber pressure efficiency η, and their values were obtained by checking the value in the corresponding table (Zürich Oerlikon, 1958).

In addition, the chamber pressure, bullet velocity, and time at any position in the bore were determined by using $p = p_{\max}\psi(\lambda)$, $v = v_p\phi(\lambda)$, and $t = t_p\delta(\lambda)$. In these formulas, $\lambda = \dfrac{x}{x_p}$ and $\psi(\lambda)$, $\phi(\lambda)$, and $\delta(\lambda)$ are a function of the value of λ, and their values can be obtained by checking the value in the corresponding table (Zürich Oerlikon, 1958).

After the bullet exit the muzzle, the pressure change in the barrel entered the "after-effect period," which could be determined using Bravin's empirical formula (Gaocai Gan, 1990). The relationship between the residual chamber pressure in the barrel versus time during this period could be described by an exponential function as follows:

$$P(t) = P_k e^{-\alpha(t-t_k)} \tag{1}$$

$$\alpha = \frac{SP_k}{(\beta - 0.5)m_Y V_0} \tag{2}$$

$$\beta = 1.35\frac{D}{V_0}\sqrt{\frac{P_k L'}{m_Y}} \tag{3}$$

$$L' = x_m + \frac{V_0}{S} \tag{4}$$

where P_k is the average chamber pressure in the barrel when the projectile exits the muzzle, t_k is the duration time after the projectile exits the muzzle, and V_0 is the chamber volume.

DYNAMIC MODEL SIMULATION OF NEW TRANSMISSION MECHANISM

Draw Chamber Pressure Curve

We calculated the relationship between the mean chamber pressure in the bore versus time, as shown in Fig. 4, by entering the parameters of the ammunition and the barrel into Heydenreich's formula, such as the caliber, the weight of the bullet, the mass of the propellant, the muzzle velocity of the bullet, the maximum chamber pressure, the length of the barrel (bore part), the cross-sectional area of the bore, and the volume of the chamber. The input parameters of the ammunition and the barrel are listed in Table 1.

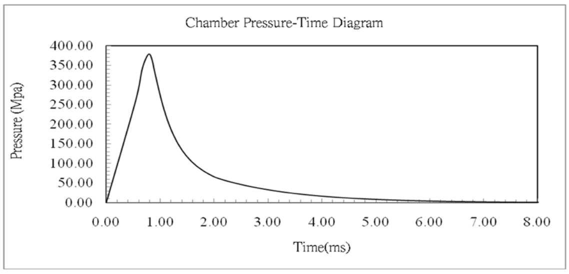

Fig. 4. Relationship of barrel mean chamber pressure versus time

Table 1. Input parameters for theoretical calculation of chamber pressure

Input Parameter	Value (Unit)
Caliber D	12.7 (mm)
Weight of the Bullet m_D	42.87 (g)
Weight of the Propellant m_Y	15.23 (g)
Muzzle Velocity of the Bullet v_0	887 (m/s)
Max. Chamber Pressure P_{max}	379.23(MPa)
Length of the Barrel (Bore Part) x_m	1,030 (mm)
Cross-sectional Area of the Bore S	131.53 (mm^2)
Volume of the Chamber V_0	24683.4 (mm^3)

Simulation Model Establishment of the New Transmission Mechanism

Barrel short recoil-operated automatic weapons are usually designed by adding an accelerator device to increase the recoil energy (United States Army Materiel Command, 1970), but this kind of design of an accelerator usually complicates the mechanism and increases the number of parts in the gun, therefore adding extra weight. In this study, a kind of action principle of automatic weapons with the barrel short recoil without an accelerator was designed. Furthermore, this study applied the principle of the Italian inertia-driven system along with the barrel short recoil operation and drew the concept design for a geometric model, as shown in Fig. 5. This drawing shows that the model was designed with symmetrical geometry as far as possible to make the center of mass and the force axis of the main transmission parts and springs such as barrel, bolt, bolt carrier, barrel spring, inertia spring, and recoil spring overlap with each other, so as to reduce the influence of the moment and vibration forces of the transmission mechanism motion and improve the transmission efficiency and shooting accuracy. Among these springs, the inertia spring was special because of its high stiffness characteristic to absorb and transmit energy.

In this study, the concept design graphics were first drawn by using the SolidWorks software, and then, converted them into Parasolid graphics files to import into the ADAMS mechanism simulation software and established the dynamic motion simulation model of the new mechanism, as shown in Fig. 5. We simplified the conceptual design model of the simulation and focused on the mechanism recoil energy transmission instead of the extraction and ejection performance of the cartridge shell; therefore, the cartridge case was not drawn and the bullet was placed on the bolt as the beginning point of the simulation motion. The material of each transmission mechanism part was set to steel. The connection joints (including fixed joint, revolute joint, translational joint, and cylindrical joint) between parts were set according to the constraint condition of the mechanism motion, and the forces (including chamber pressure force, spring force, and contact force) were set subsequently. The chamber pressure force acted on the bottom of the bullet pushing toward to muzzle and pushed the bolt backward to recoil. The joints locations, types and contact forces setting values of the new transmission mechanism are listed in Table 2.

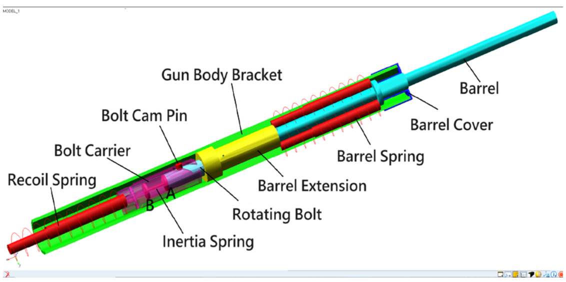

Fig. 5. Concept design graphic of the new firearm mechanism developed in this research

Table 2. The joints locations, types and contact forces setting values of the new firearm mechanism

Joints Locations	Types	Contact Forces
Gun Body Bracket & Barrel Cover	Fixed Joint	Barrel & Barrel Cover
Barrel & Barrel Extension		Barrel & Gun Body Bracket
Gun Body Bracket & Base		Barrel Extension& Gun Body Bracket
Blot Cam Pin & Rotating Bolt		Bullet & Barrel
Barrel Extension & Gun Body Bracket	Translational Joint	Rotating Bolt & Barrel Extension
Bolt Carrier & Inertia Spring		Blot Cam Pin & Bolt Carrier
Bolt Carrier & Base		Inertia Spring side A & Rotating Bolt
Rotating Bolt & Bolt Carrier	Cylindrical Joint	Rotating Bolt & Inertia Spring side B
Bullet & Barrel		

Simulation Results and Analysis

Fig. 6-11 present the visualization diagrams of the continuous simulation motion of the concept design simulation mechanism model run in the ADAMS software. Fig. 6 shows the initial position diagram of each part when T = 0 ms. Fig. 7 shows that when T = 4.3 ms, the barrel and the bolt were locked with each other to compress the inertia spring to soon make the bolt cam pin move freely and straight after the chamber pressure force was exerted. At the same time, the bolt carrier almost stayed put because of the inertia of the bolt carrier self-weight. Fig. 8 shows that when T=16.6 ms, the bolt started to unlock from the barrel. Fig. 9 shows that when T = 31.4 ms, the barrel reached the maximum recoil distance and the bolt was unlocked completely, and the bolt carrier received energy from the inertia spring to continue to recoil. Fig. 10 shows that when T = 90.6 ms, the bolt carrier reached the maximum recoil distance and the barrel returned to the initial position. Fig. 11 shows that when T = 185.4 ms, the bolt carrier returned to the initial position and completed a shooting cycle.

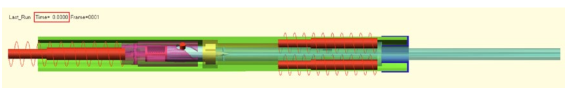
Fig. 6. Initial position diagram of each part when T = 0 ms

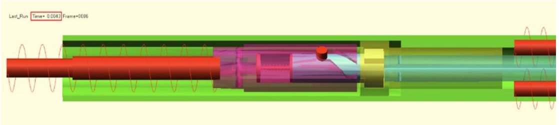

Fig. 7. Barrel and bolt locked with each other to compress the inertia spring when T = 4.3 ms

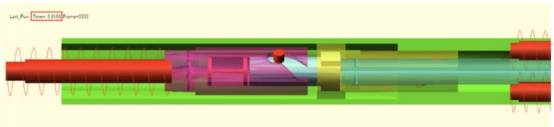

Fig. 8. Bolt starts to unlock from the barrel when T = 16.6 ms

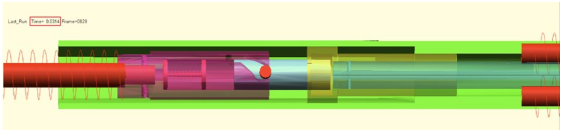

Fig. 9. Barrel reaches the maximum recoil distance and the bolt is unlocked completely when T = 31.4 ms

Fig.10. Bolt carrier has reached the maximum recoil distance, and the barrel has been returned to the initial position when T = 90.6 ms

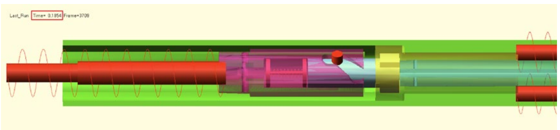

Fig.11. Bolt carrier returns to the initial position and completes a shooting cycle when T = 185.4 ms

The performance of the automatic weapon transmission mechanism was usually judged on the basis of the following characteristics and analysis: muzzle velocity of the bullet, rate of fire, time and chamber pressure of unlatching, maximum recoil distance of bolt and the corresponding time, the time to return to the initial position of the bolt carrier, and maximum recoil distance of the barrel. In the ADAMS simulation, the time step was set to 5,000 steps in 0.25 s, and the results were analyzed as follows:

1.Bullet muzzle velocity analysis: Fig. 12 shows the relationship between the distance and the time between the center point of the muzzle and the center point of the bullet bottom. When the distance was zero, the bullet reached the muzzle and the corresponding time was 2 ms. According to the velocity versus time relationship (as shown in Fig.13), the muzzle velocity was 927.2 m/s.

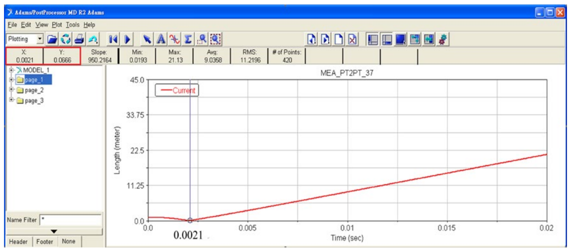

Fig. 12. Distance to the center point of the muzzle is 0 when T = 2 ms

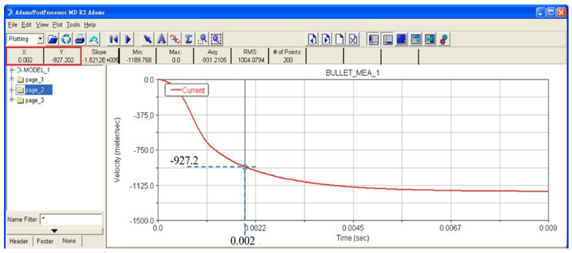

Fig. 13. Muzzle velocity is 927.2 m/s when T = 2ms

2.Fig. 14 shows the relationship between the distance from the center of mass of the bolt to that of the bolt carrier versus time. The moment when the firing chamber pressure increased, the inertia spring was compressed in a very short time period to store energy and the distance was closed soon. Then, the inertia spring compression stopped and the stored energy was released; furthermore, the distance was increased immediately. When the bolt returned to the relative initial position, the corresponding time was 16.6 ms. It was the time when the bolt began to rotate and unlock from the barrel. According to Fig. 4, at the same time, the chamber pressure decreased significantly to the safe pressure value.

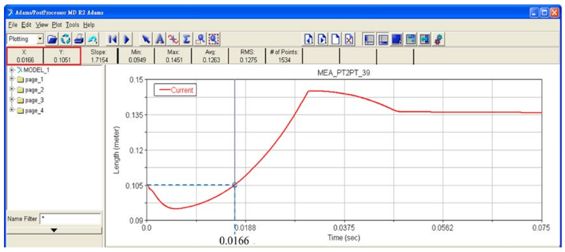

Fig. 14. Bolt starts to unlock from the barrel when T = 16.6 ms

3.Fig.15 shows the relationship between the recoil distance of the bolt carrier versus time. We found that the maximum recoil distance of the bolt carrier was 27.68 cm at 89.2 ms and the bolt carrier returned to the initial position at 185.4 ms and completed one fire cycle. The time of 185.4 ms could be converted into the rate of fire of 323.6 rounds/min (60 min/0.1854 s = 323.6 rounds/min).

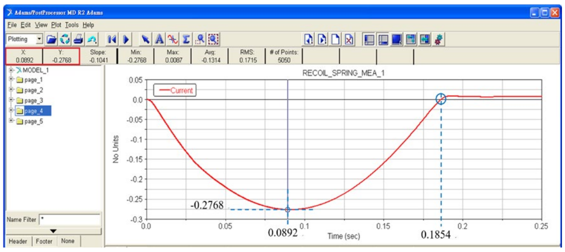

Fig. 15. Bolt carrier recoils backward until the stop position at 89.2 ms and returns forward to the initial position at 185.4 ms

4.Fig.16 shows the relationship between the recoil distance of the mass center of the barrel extension versus time. We found that the maximum recoil distance was 11.8 cm when the time was 31.4 ms.

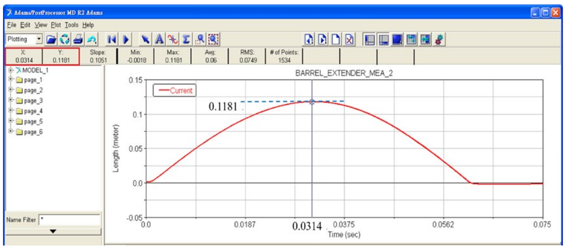

Fig. 16. Maximum recoil distance of the barrel is 11.8 cm when T = 31.4 ms

Fully Automatic Live Ammunition Shooting Verification

According to the result of the ADAMS software simulation analysis, the concept design of the automatic weapon transmission mechanism developed in this study was feasible. In order to verify the application performance of the concept design model, we used a 0.5-in caliber semi-automatic weapon as the experimental gun instead of producing the same mechanism with a simulation model. The original bolt carrier assembly of the experimental gun was transformed to have the new transmission function. The original trigger assembly of the experimental gun was modified to fill our full-automatic firing need and made to have the fully automatic shooting function. We shot the experimental gun for nine rounds fully automatically and used the FASTCAM SA1.1 high-speed camera (shown in Fig. 17) at the rate of 3,000 images per second to record the same (shown in Fig. 18–27). The following pictures were captured by the high-speed camera.

Fig. 17. FASTCAM SA1.1 high-speed camera (Photron, 2014)

1.Fig. 18 shows the shooter pulled the trigger to start the nine rounds of automatic shooting (video frame number: 1475).

2.Fig. 19 shows the first round cartridge case ejection and the second cartridge feeding into the barrel from the magazine (video frame number: 1475–2145, total number of frames: 670).

3.Fig. 20 shows the second round cartridge case ejection and the third cartridge feeding into the barrel from the magazine (video frame number: 2145–2499, total number of frames: 345).

4.Fig. 21 shows the third round cartridge case ejection and the fourth cartridge feeding into the barrel from the magazine (video frame number: 2499–2959, total number of frames: 460).

5.Fig. 22 shows the fourth round cartridge case ejection and the fifth cartridge feeding into the barrel from the magazine (video frame number: 2959–3351, total number of frames: 392).

6.Fig. 23 shows the fifth round cartridge case ejection and the sixth cartridge feeding into the barrel from the magazine (video frame number: 3351–3718, total number of frames: 367).

7.Fig. 24 shows the sixth round cartridge case ejection and the seventh cartridge feeding into the barrel from the magazine (video frame number: 3718–4172, total number of frames: 454).

8.Fig. 25 shows the seventh round cartridge case ejection and the eighth cartridge feeding into the barrel from the magazine (video frame number: 4172–4581, total number of frames: 409).

9.Fig. 26 shows the eighth round cartridge case ejection and the ninth cartridge feeding into the barrel from the magazine (video frame number: 4581–4970, total number of frames: 389).

10.Fig. 27 shows the ninth round cartridge case ejection and the tenth cartridge feeding into the barrel from the magazine (video frame number: 4970–5344, total number frames: 374)

The average time of the nine rounds was calculated as 0.133s. The rate of fire was 451 rounds/min, calculated using the time frequency (rounds per minute).

Fig. 18. Shooter pulled the trigger to start nine rounds of fully automatic shooting

Fig. 19. First round cartridge case ejection and second round cartridge feeding into the barrel chamber from the magazine

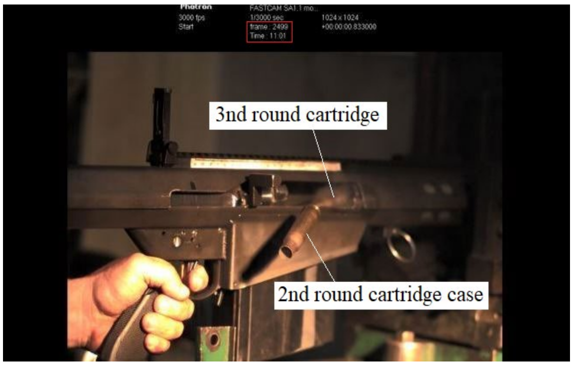

Fig. 20. Second round cartridge case ejection and third round cartridge feeding into the barrel chamber from the magazine

Fig. 21. Third round cartridge case ejection and fourth round cartridge feeding into the barrel chamber from the magazine

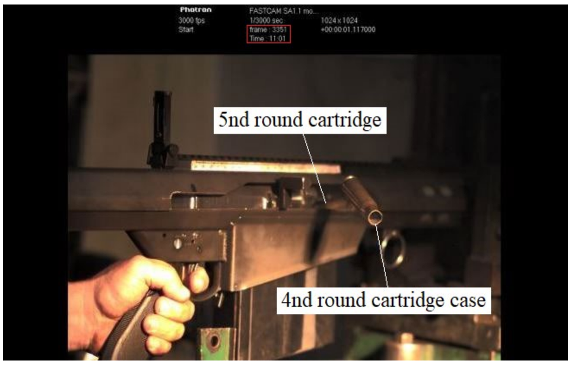

Fig. 22. Fourth round cartridge case ejection and fifth round cartridge feeding into the barrel chamber from the magazine

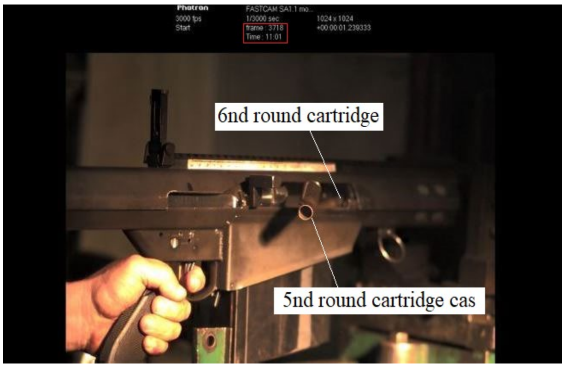

Fig. 23. Fifth round cartridge case ejection and sixth round cartridge feeding into the barrel chamber from the magazine

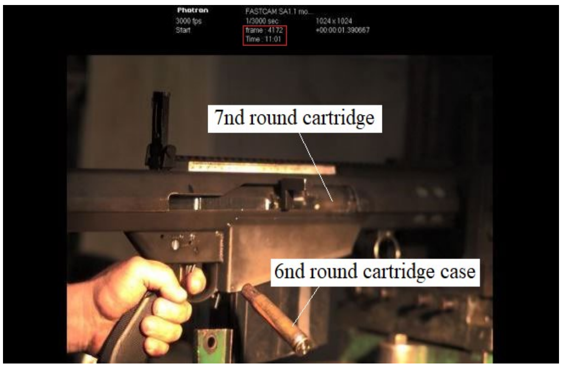

Fig. 24. Sixth round cartridge case ejection and seventh round cartridge feeding into the barrel chamber from the magazine

Fig. 25. Seventh round cartridge case ejection and eighth round cartridge feeding into the barrel chamber from the magazine

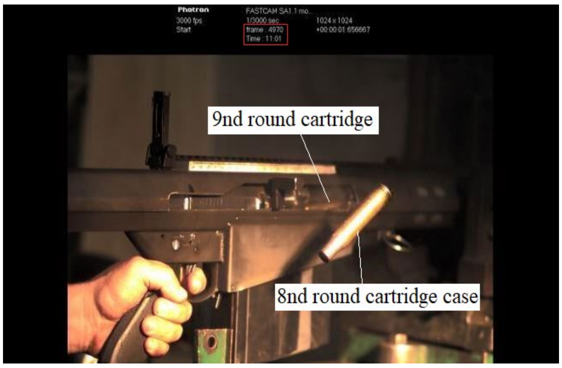

Fig. 26. Eighth round cartridge case ejection and ninth round cartridge feeding into the barrel chamber from the magazine

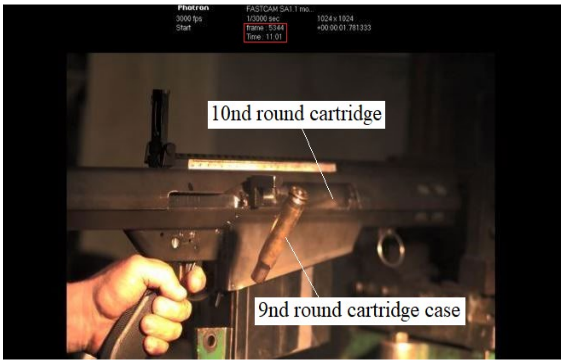

Fig. 27. Ninth round cartridge case ejection and tenth round cartridge feeding into the barrel chamber from the magazine

Because the high-speed camera's memory was not sufficient, the tenth round cartridge's video recording was incomplete. However, from the high-speed video of the first nine rounds, we verified that the new transmission mechanism could replace the original bolt carrier assembly and drive the bolt carrier to the designed last position without the original accelerator. The observed phenomena could verify that the transmission mechanism could be another good choice for automatic weapon transmission system research and development.

CONCLUSION

In this study, the ADAMS mechanism motion simulation software was used to evaluate the theoretical feasibility of a new mechanism concept design and analyze the important performance parameters. After the analysis results showed that the transmission concept design and theory were feasible, we used a semi-automatic sniper gun as the experimental platform to implement the fully automatic shooting function to verify the concept design's feasibility. The results of high-speed photography and video showed that the hybrid transmission mechanism with the barrel short recoil-operated system and the inertia-driven system could support shooting normally in the fully automatic mode. Therefore, the new mechanism concept design action principle could be applied to automatic weapons, particularly high-chamber-pressure weapons such as rifles and machine guns.

The development potential of the new transmission mechanism developed in this study could be explained as follows:

1.The recoil energy could be efficiently transmitted by using only the high-stiffness spring without the complex mechanism design. This would help to reduce the number of parts and the overall weight of the gun.

2.The reciprocating movement action lines of the bolt, bolt carrier, and the spring group were close to the recoil force action line and the axis of the barrel caused by the ammunition chamber pressure. This made the shooting vibration of the gun small, the stability high, and the shooting accuracy better.

3.Because of the characteristics of the transmission energy storage and absorbance of the inertia-driven system, the strong chamber recoil force could be absorbed first by the high-stiffness inertia spring and then transferred as the transmission energy to the bolt carrier. This could reduce the recoil force of the gun, make the shooting stable and comfortable, and relieve the shooter's psychological pressure.

4.Because of the delay blowback effect of the interaction between the short recoiling barrel, the rotating bolt, and the high-stiffness spring, the chamber pressure in the barrel could be reduced to under a safe value when the bolt unlocked from the barrel extension. The continuous firing rate of the new-transmission-type automatic weapon was moderate and could avoid violent vibrations, control difficulties, and ammunition wastage.

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NOMENCLATURE

D	Caliber of weapon
m_D	Weight of bullet
m_Y	Weight of propellant
v_0	Muzzle velocity of bullet
$p_{\max}$	Maximum chamber pressure
X_m	Length of barrel (rifling zone)
S	Cross-sectional area formula of barrel(rifling zone), $0.82D^2$
P_{mean}	Mean chamber pressure
g	Acceleration of gravity
η	Chamber pressure efficiency
x_p	Projectile distance at the highest chamber pressure
t_p	Time at the highest chamber pressure
v_p	Projectile velocity at the highest chamber pressure
p_m	Muzzle pressure
t_m	Muzzle time
x	Projectile distance
λ	x / x_p
p	Chamber pressure at any position in the barrel
v	Bullet velocity at any position in the barrel
t	Time at any position in the barrel
$\sum(\eta)$, $\theta(\eta)$, $\Phi(\eta)$, $H(\eta)$, $T(\eta)$	Function of the chamber pressure efficiency η
$\psi(\lambda)$, $\phi(\lambda)$, $\delta(\lambda)$	Function of the value of λ
$P(t)$	Residual chamber pressure in the barrel versus time during "after-

	effect period"
P_k	The average chamber pressure in the barrel when the bullet exits the muzzle
α	$SP_k / \left(\beta - 0.5\right) m_Y V_0$
T	Time during "after-effect period"
t_k	The duration time after the bullet exits the muzzle
β	$1.35 \frac{D}{V_0} \sqrt{\frac{P_k L'}{m_Y}}$
V_0	Chamber volume
L'	$X_m + \frac{V_0}{A}$
A	Cross-sectional area formula of chamber
ms	Millisecond

自動武器傳動機構概念設計模擬及應用

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摘 要

本研究針對以義大利貝利尼(BELLINI)霰彈槍傳動機構為基礎之新型自動武器傳動機構進行概念設計分析模擬及實彈射擊驗證。義大利貝利尼霰彈槍採用慣性驅動系統(Inertia Driven System)機構，進行發射藥燃燒產生的高壓氣體後座力之能量傳動，使霰彈槍可行半自動射擊(扣住扳機 1 次射擊 1 發)。本研究將此慣性驅動系統與槍管短後座傳動原理相結合，研創一種新型的自動武器傳動機構進行能量傳動，可行全自動射擊(扣住扳機 1 次多發連續射擊)，此種機構為全世界首創。本研究採用電腦輔助設計軟體 SolidWorks 及機構動態模擬分析軟體 ADAMS，對新創自動武器傳動機構進行動態模擬分析，觀察其運動情況(槍機之退殼、拋殼、後座到位、復進、進彈及閉鎖狀態)並分析運動性能參數是否符合槍枝設計規格要求。最後，藉由將新型機構導入 M82A1 狙擊槍進行實彈射擊驗證，順利完成全自動射擊(原 M82A1 狙擊槍僅能半自動射擊)，證實了新型自動武器傳動機構理論之可行性。