Overview and Research on Mechanical Drive Empty Return and Its Influence Mechanism

Kaiping Yu, Dongya Si Tianfang Luo and Yuancheng Pan
School of Mechanical Engineering, PLA Army Academy of Artillery and Air Defense, Hefei, China

*Corresponding author: sdy873@163.com

Abstract. The length of transmission chain and the empty return of mechanical drive from motor to turret cause different height and orientation of transmission route for the receiver unit and the turret, thus affecting the aiming and firing accuracy of artillery automatic aiming system. In an effort to solve the problem, taking a certain type of artillery aiming system as the research object, the article systematically analyses the feature of empty return of mechanical drive and its influence mechanism, providing technical support for the improvement of the feedback accuracy and the aiming accuracy for the artillery aiming system.

Keywords: Aiming system, mechanical drive, empty return, accuracy.

1. Introduction
Automatic aiming and firing are the design goals for the modern artillery, which require advanced automatic aiming system. In particular, the high firing accuracy, aiming speed and acceleration make the high accuracy of mechanical drive essential for the aiming mechanism. However, restricted by various error factors existed in the production and assembly, for instance, the production error and gear clearance among all gears or worm wheels of transmission chain, the fabrication and installation deviation of various connecting parts and the abrasion caused by long-term operating, all of them could make the empty return occur while transmission. Meanwhile, in order to guarantee the flexible transmission, a small amount of clearance must be permissible to store up lubricating oil and compensate the size change caused by temperature and elastic deformation. Clearance is inevitable. There will be angle deviation while changing the direction of rotation for the drive system. When the empty return of mechanical drive from the motor to the turret is relatively large, it will be difficult in making sure the independent accuracy of line of aim.

The empty return amount existed in the mechanical drive of the artillery aiming system determines the accuracy of the mechanical drive. For example, the empty return amount of the mechanical drive for the elevating machine will not only compromise the service life of its drive mechanism, but also give rise to the dynamic angle of jump for the barrel in the longitudinal plane, thus causing the initial disturbance of ballistic trajectory of projectile and affecting the firing accuracy of the artillery. The empty return amount existed in the steering device will not only affect the stability of drive due to the rotational impact, vibration and noise generated while swerving, but also cause the deviation of aiming
angle due to the idle angle of the driving shaft. Therefore, it is essential to study the empty return of mechanical drive for the artillery aiming system.

The deep study on the influence mechanism of empty return for mechanical drive can provide references to shorten the transmission chain, eliminate the transmission clearance, and reduce the mechanical empty return. The development of high-accuracy empty return detection device and the improvement of the mechanical feedback accuracy of aiming system can effectively solve the impact on the accuracy of aiming line caused by the inconsistency of height and orientation of transmission route for the receiver unit and the turret. Hence, it will be of significant importance to improve the aiming and firing accuracy of artillery to conduct deep research on the empty return of mechanical drive for the aiming mechanism and its influence mechanism and improve its feedback drive accuracy.

2. The general technology schemes

The structural parameters of a certain type of artillery aiming system can be obtained through research or searching information. Then, calculate the empty return amount of each gear pair based on empirical formula and obtain the empty return amount of elevating machine and steering device by the conversion of the drive ratio. Next, study the influence of the empty return to the artillery aiming system, which includes two aspects: one is to establish the empty return motion model of the take-off and landing part of the elevating machine when the projectile moves in the chamber. By doing so, the dynamic equation and the vibration equation of forced damping of empty return angle are derived to study the influence mechanism of empty return on vibration characteristics of elevating machine. The other is to build the the nonlinear mathematical model of directional servo system to quantitatively study the influence of mechanical transmission of directional servo system on the dynamic characteristics, control accuracy and stability of the directional servo system through theoretical analysis and simulation calculation. At last, precise measurement of the empty return amount for the steering device and elevating machine can be achieved through the development of the empty return feedback detection device of drive. The general technical road map is shown as figure 1.

![Figure 1. The general technical roadmap](image-url)
3. The analysis on the empty return of mechanical drive for aiming system

The empty return means that when the driving wheel rotates reversely, the driven wheel lags behind the driving wheel at a certain angle, which will generally be represented by lose motion error. The analysis on lose motion error refers to the analysis on empty return. The empty return characteristic analysis of artillery aiming system mainly solves the problem of accurate and fast calculation of the empty return of transmission between the structural components of steering device and elevating machine, which is as shown in figure 2. According to the structural parameters of the steering device and elevating machine and the calculation formula of the transmission clearance, the empty return between different transmission pairs is solved, and then according to the transmission ratio of each part, the empty return value is obtained. The study includes (1) the calculation of empty return amount of the transmission pair; (2) the comprehensive calculation of empty return amount of steering device; (3) the comprehensive calculation of empty return amount of elevating machine.

![Diagram showing the empty return characteristic analysis of the mechanical drive of the artillery aiming system](image)

**Figure 2.** The calculation of empty return amount for the transmission of aiming system.

The empty return of self-propelled artillery mainly generates from the aiming mechanism. It is an inevitable phenomenon for both elevating machine and steering device, which is determined by the structural feature of the transmission device. The empty return of the elevating machine includes the empty return generated from the meshing gap between the high and low gears and the tooth arc, the mating gap between the high and low gears shaft and the friction cone spline, the movement of worm gear and worm center line caused by the wear of copper bushing, and the mating gap between the runner key and the worm key and so on. There are two parts for the empty return of the steering device, one part is the empty return generated by the clearance between its internal driving parts, accounting for about 50%, and the other part is generated by the tooth clearance of the driving gear of the steering device meshing with the turret seat ring.

The anticlockwise rotation of driven wheel drives the turret seat ring to rotate clockwise. When the driven wheel converts the anticlockwise rotation to clockwise rotation, the master gear will inevitably have a certain angle of empty return to mesh with the turret sea ring to drive it to rotate anticlockwise, then, then angle of empty return for the master gear is the amount of empty return. According to the requirements of precision grade, dimensional error and assembly of each part, consult relevant design manuals and literature to solve the problem according to the calculation formula of transmission clearance of each part. The empty return amount of each part shall be calculated firstly and then obtain the angle of empty return of driving shaft by comprehensive calculation, which is shown as figure 3.
4. The study on the influence mechanism of the empty return of mechanical drive

The empty return of mechanical drive will generate significant influence on the vibration and servo performance of the aiming system. When fire the artillery, the dynamic jump caused by the empty return of elevating machine will reduce the firing accuracy of the artillery and meanwhile, the clearance non-linear characteristics generated can impact the stability and positioning accuracy of the servo system for the steering device. In order to reveal the influence mechanism for the empty return of mechanical drive to the artillery aiming system vibration and its servo performance, the study has been conducted in two aspects: (1) the study on the empty return vibration characteristic of the drive of elevating machine; (2) the study on the non-linear characteristic and its impact on servo performance for the empty return of the drive of steering device.

4.1. The impact on the vibration characteristic of elevating machine for the empty return of mechanical drive

When fire the artillery, the forces on the elevating machine of the artillery are complex. The dynamic jump of artillery is caused by a lot of vibration factors, among them, the empty return angle generated by the take-off and landing part of the elevating machine is an important aspect, which seriously impacts the firing accuracy of the artillery. The previous calculation of the empty return angle was mostly based on the typical artillery construction and design theory, which was carried out by segmental moment decomposition and iteration. However, the calculation accuracy of such method relied heavily on the precision of drawing curves and the dividing time periods, and each modification of the calculation has to be redrawn, which was very complicated and made the solving efficiency compromised.

while studying the vibration characteristics of the empty return of mechanical drive for elevating machine, based on the analysis of the force and motion state of the takeoff and landing part and some basic assumptions and physical models to establish the empty return motion model of the takeoff and landing part when the projectile moves in the chamber, thus deducing the dynamics equation and the forced damping vibration equation of empty return angle, which is as shown in Figure 4.
The analysis on the force and motion state of the takeoff and landing part

Basic assumptions and physical model

The empty return kinetic equation of the takeoff and landing part when the projectile moves in the chamber

The forced damping vibration equation of empty return angle

The value of empty return angle while finishing the internal ballistic trajectory

Laplace transform

Figure 4. The analysis on the vibration characteristic of empty return of mechanical drive for elevating machine.

In the case of modern artillery without special measures to increase the damping, the system is underdamping. At this point, empty return motion can be regarded as the superposition of reciprocating motion and resultant moment actuated motion, therefore, it is necessary to further use the Laplace transform method to obtain the analytic solution when the resultant movement is in the general form according to the characteristics of the vibration generated by the empty return angle under the underdamping characteristic. The value of empty return angle at the end of internal trajectory can be solved through the analytic solution of the angle of empty return. The solution obtained from the Laplace transform method for the empty return angle has higher calculation efficiency and requires no need to consider the drawing and segmenting process. The value of empty return angle at the end of the internal ballistic trajectory obtained can provide the basis for the fire control system to correct the firing elements.

4.2. The impact on the servo performance for the empty return of drive for steering device

4.2.1. The analysis on the non-linear characteristic of empty return. There are gaps among internal transmission parts of steering device and the toothed side of the driving gear meshing with the turret seat ring. When the transmission mechanism moves reversely, the driving transmission parts cannot move along with the driven parts synchronously, as the driving part needs to rotate the empty stroke of the clearance size to drive the reverse motion of the driven parts, thus forming the annular clearance characteristic. Such clearance causes the empty stroke error in the reversible transmission, and the relation between the output shaft and the input shaft of the transmission device is not a single-valued linear relationship, but a non-single-valued nonlinear relation with a hysteresis ring.

4.2.2. The impact for the empty return of the mechanical drive on the servo performance. The typical servo system consists of drive motor, transmission mechanism, actuator, sensor a control system. It is an automatic control system taking mechanical position or angle as control object. Transmission mechanism, as the crucial part of the servo system, its performance will directly impact the quality of the servo system. The modern self-propelled artillery has high-accuracy and high-dynamic technical features, therefore, the intrinsic empty return existing in its transmission chain will inevitably have impact on the performance of servo system in the aiming mechanism, which includes: (1) the uncertainty of clearance lowers down the positioning accuracy of the system, thus increasing the static difference; (2) the existence of clearance causes the hysteresis effect of the system, which equivalently introduces the additional lag phase angle, decreasing the stability. With the deteriorative stability, the dynamic oscillation response of the system exacerbates, causing the instability of the system.
5. Conclusion
The paper solves the problem of accurate and fast calculation of the empty return of transmission parts between the structural components of steering device and elevating machine by analyzing the empty return characteristics of artillery aiming system. The influence mechanism of the empty return of mechanical drive on the aiming mechanism is elaborated aiming at the impact of empty return on the vibration characteristics of elevating machine, the dynamic characteristics of the servo system of steering device, and the control accuracy and stability. It provides the basis for reducing or even eliminating the influence of empty return and improving the stability and accuracy of artillery aiming mechanism. It also has practical application value for allowing full play to the performance of artillery equipment and promoting the combat effectiveness of troops.

References
[1] CHEN Yang. Self-Propelled Gun Barrel Aiming Direction Measuring Technology [J]. Journal of Sichuan Ordnance, 2015 (10): 32 - 35.
[2] Li Jianzhong, Sun Liping, Sun Zelin. Measurement System Driver Control of Muzzle Angle and Gun Bore Camber [J]. Ordnance Industry Automation, 2011, (6): 71 - 74.
[3] WANG Zi Mo. A Study on the Test System of Artillery Stabilization Precision [D]. Changchun University of Science and Technology., 2013: 14 - 17.
[4] SU Zhong-ting, HAN Xiao-ping, WANG Lei, SONG Chao. Dynamics Simulation Analysis of Artillery Traversing Mechanism Contact with Clearance [J]. Machinery Design & Manufacture 2017 (10): 37 - 41.
[5] XU Zhi-yuan, GE Jian-li, YANG Guo-lai. Overall Structural Parameter Sensitivity Analysis and Optimization of Gun Muzzle Disturbance [J]. Journal of Ordnance Equipment Engineering. 2016 (6): 46 – 48.
[6] Qiang, GU Keqiu, WANG Li. Sensitivity Analysis and Optimization Research of Gun Structure Parameters Affecting Initial Projectile Disturbance [J]. 2014 (4): 39 - 43.
[7] XIAO Hui, YANG Guo-lai, SUN Quan-zhao. Research on Flexible Multi-body Dynamics Structure Optimization of Artilleries [J]. Acta Armamentarii. 2017 (1): 27 – 34.
[8] YUE Pengfei, WANG Deshi. Research on Dynamics and Backlash Angle of Gun Rotating Parts [J]. Journal of Gun Launch & Control. 2017 (1): 52 - 56.
[9] CAO Guangqun, LIU Shuhua, FAN Linsheng, LI Taiyang, FANG Dongxu. Dynamic Characteristic Analysis of a Certain Artillery with 0° Firing Angle Considering Soil and Direction Angle [J]. Journal of Gun Launch & Control. 2017 (3): 12 - 15.
[10] Bai Yali, Li Chengren, Wang Huanhuan. The Analysis of Gear Transmission Error of Traversing Mechanism of Gun Based on Integrated Method [J]. Fire Control Radar Technology. 2016 (1): 104 – 108.