Simulation Analysis of Transmission System of Module Propellant Storehouse Based on ADAMS

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Abstract. A virtual prototype of the transmission system of a module propellant storehouse is established in ADAMS simulation environment. First, dynamic analysis of the key parts of the transmission system, mainly clutch, is carried out. Then, the 3D model needs to be simulated is established in SolidWorks. Finally, combined with the macro commands in ADAMS, the virtual prototype model of the transmission system is established in ADAMS, which can complete the dynamic simulation of the whole loading process. In the simulation process, the parameters are adjusted and optimized to meet the actual situation. The simulation results are analyzed and verified, which can provide some reference basis for the design and selection of driving motor, electromagnetic clutch and other key parts of the transmission system.

Keywords: module propellant storehouse; electromagnetic clutch; virtual prototype.

1. Introduction

Automatic ammunition loading technology is one of the key technologies to improve the firing rate of artillery [1]. And the module propellant loading is a promising method for the large caliber artillery [2].

The automatic storehouse of modern artillery plays the function of storing and conveying module propellants. Every cartridge can store up to 6 module propellants, and the number required for each artillery shot is usually less than 6. According to the demand, there is a pushing chain to push a certain number of module propellants from the storehouse into the loading device. Then, the artillery can complete the following loading task and shooting mission.

During the process of module propellants selection, the forced acceleration process and the inertia deceleration process should be fully considered to ensure that correct number of module propellants can be pushed into the loading device. Electromagnetic clutch which can be quickly engaged and released is used to get a certain driving force for the pushing chain [3-4]. Among them, clutch engagement time, torque rising time and clutch released time will directly affect the efficiency and accuracy of the pushing chain [5-10].

The traditional design method usually adopts this process: structure design -- building test bench -- test -- modifying parameters -- changing design. Such a design method needs to go through a long cycle [11]. In this study, the virtual prototype software ADAMS is used to simulate and analyze the transmission system of a module propellant storehouse, especially the electromagnetic clutch and the pushing chain. Aims to solve the above difficulties in the design process.
2. Description of Module Propellant Storehouse

2.1. Structure of Transmission System

The whole system is driven by a motor, and the driving torque is transmitted to the pushing chain through the clutch. The pushing chain drives the module propellants to slide in the cartridge. A damping block is installed at the outlet of the cartridge to slow down the module propellants. Finally, the selected number of module propellants can be pushed into the loading device, while the remaining module propellants in the same cartridge can be stayed by deceleration of the damping block, waiting for the next loading.

A type of module propellant storehouse bench is shown in figure 1. The flow chart of torque transfer is shown in figure 2.

![Figure 1. A type of module propellant storehouse principle bench.](image)

![Figure 2. Schematic diagram of dynamics between driving motor and pushing chain.](image)

Take the clutch as the boundary to create the dynamic relationship between the driving end and the load end:

\[ J_e \frac{d(i\omega_e)}{dt} = M_e - \frac{M_c}{i} \]  \tag{1}

\[ J_m \frac{d\omega_e}{dt} = M_m - M_c \]  \tag{2}

In the above formula, \( i \) is the transmission ratio between the driving motor and the driving wheel of clutch; \( M_e \) is the output torque of the driving motor; \( M_c \) is the torque transmitted by the clutch, \( M_m \) is the load torque on the chain, \( \omega_e \) is the speed of the driving plate of the clutch, and \( \omega_d \) is the speed of the driven plate of the clutch.
2.2. Structure and Dynamics Analysis of the Clutch

Electromagnetic clutch is the main torque transmission component of the system, and its performance directly determines the efficiency and accuracy of the module propellants selection.

The side profile of the clutch is shown in figure 3.

![Figure 3. Side profile of an electromagnetic clutch.](image)

The clutch consists of the driving plate, the driven plate, the electromagnet and the control mechanism and other components. The release and engagement of the plates are controlled by the electromagnet with 24V DC power. Engagement process can be roughly divided into four stages:

1. The driving plate and the driven plate are completely separated, then they are engaged close by the electromagnet.
2. The driving and driven plates have been engaged together and relative slip occurs, and there is a distance between the chain head and the modules. Velocity of the driven plate is increased quickly.
3. The chain head begins to contact the module propellants, the clutch's plates still have relative slip and the velocity of the driven plate is increased gradually.
4. The speed of the driven plate is increased to the same as that of the driven plate. The driven plate and the driven plate start to rotate synchronously and the interaction force is changed to the static friction force.

In the first stages, the clutch state can be expressed as formula (3):

\[ M_e = 0; \]
\[ \omega_n = \frac{\omega_d}{i}; \]
\[ \omega_d = 0; \]  \hspace{1cm} (3)

In the second and third stages, the clutch state can be expressed as formula (4):

\[ M_e = \int_{r_1}^{r_2} p f \pi r^2 \cdot dr = \frac{2 \cdot F_s \cdot (r_2^3 - r_1^3)}{3 \cdot (r_2^2 - r_1^2)} \cdot f; \]
\[ \omega_n = \frac{\omega_d}{i}; \]
\[ \omega_d < \omega_n; \]  \hspace{1cm} (4)

In formula (4), \( r_1 \) is the inner diameter of clutch friction plate, \( r_2 \) is the outer diameter of clutch friction plate. \( F_s \) is the suction force produced by electromagnets. \( f \) is the friction coefficient of the
clutch friction plate, it can be described as formula (5):

\[ f = (a + bV)e^{-cV} + d; \]
\[ V = (\omega_a - \omega_d) \times \bar{r}; \]

(5)

Formula (5) comes from the empirical formula of friction coefficient of variable-speed friction plate.

In the fourth stages, the clutch state can be expressed as formula (6):

\[ M_c = M_m; \]
\[ \omega_a = \omega_d; \]

(6)

3. Establish the Simulation Model

3.1. Modeling in SolidWorks and ADAMS

The driving torque on the pushing chain can be realized by the driving force function in ADAMS, the main task of modeling is the transmission mechanism except the clutch. The whole pushing chain is composed of chain unit and idler wheel, while each chain unit is fixed by a pin shaft. The idler wheels are installed at the connection between two adjacent chains and contacted with the locking plates and sprockets.

After assembling the pushing chain in SolidWorks, save it as Parasolid (.X_t) and then import it into ADAMS. In the simulation, cancel the pin shaft and add constraints as a simplified alternative. Edit the material, mass, and moment of inertia of each part in ADAMS. Add the corresponding constraint relationship and contact relationship between each part.

Finally, after the addition of cartridge, damping block and module propellants, the whole simulation model is shown as figure 4.

![Simulation Model in ADAMS](image)

**Figure 4.** Module propellants storehouse simulation model in ADAMS.

3.2. Verify the Model in ADAMS

In order to verify the reliability of the simulation model, set a drive on the driving sprocket as type velocity, set the drive speed is 2rps, and set the module propellants to the invalid state. The driving sprocket in this model has five teeth and a chain pitch is 40mm. The average speed of the chain head can be estimated to be 400mm/s. The actual velocity curve after simulation is shown in the figure 5. According to figure 5, it can be found that the average speed of chain head is close to 400mm/s as
expected. During the startup phase, there are some speed mutations due to impact. In the stable stage, periodic oscillation occurs due to the polygon effect of chain drive. The chain model can be used in the next simulation.

![Figure 5. Velocity of chain head.](image)

4. Kinetic Calculation and Verification
The rated speed of the drive motor is $\omega_r = 1500 \text{ rpm}$, and the transmission ratio $i$ is 3, there is clearly $\omega_s = 500 \text{ rpm}$. It is assumed that the motor speed is constant during the whole process, the mass of each module is 2kg, the length of each module is about 180mm, and the friction coefficient between the module and the cartridge is 0.09.

According to formulas (4) and (5), write an function for $M_x$, which is assigned to the driving sprocket, values in this simulation are as follows:

$$F_s = 800N; \; r_1 = 15mm; \; r_2 = 80mm; \; a = 0.006; \; b = 1.14; \; c = 0.94; \; d = 0.226;$$

The simulation translational velocity of the pushing chain head can be recorded by ADAMS. The experimental results are collected by the digital encoder which installed at the driving sprocket on the experimental bench, after converted calculation, translational velocity of actual chain head can be obtained. Simulation velocity curve and experimental velocity curve are shown in the figure 6.

![Figure 6. Translational velocity of the pushing chain head in experiment (left) and simulation (right).](image)
5. Analysis and Conclusion

(1) According to the simulation velocity curve and the experimental velocity curve, the trend is broadly consistent, and the curve can reflect the four stages which is described in section 2.2. It can prove that the formulas in section 2.2 can express the change of driving force of clutch.

(2) The sharp drop of velocity at the beginning and the end can also fit with experiment results, it represents the collision and separation between the chain head and the module propellant are simulated correctly. On the other hand, the simulation curve has certain periodicity during the period of constant speed, but the experimental curve is erratic at the same stage. Some solid explanations are the deformation of module propellant caused by the shock vibration and the noise in the experimental environment. These factors are not considered in this simulation study.

(3) In general, this simulation study can simulate the selection process of module propellants. The following work about section and design of transmission system, especially the driving motor and electromagnetic clutch, can rely on this simulation model.

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References

[1] Liu Z M, Sun D P and Fan Z G 2013 Automatic ammunition handling technique of medium and large caliber gun Journal of Gun Launch & Control (03): 93-96.
[2] Qian H Y, Yu Y G and Liu J 2020 The influence of ambient temperature after gun firing on thermal safety of modular charge in the chamber Acta Armamentarii 41(02): 254-261.
[3] Yu XZ and Guo W 2008 Test and selection of the friction disk type magnetic clutch Mechanical Research & Application (02): 122-124.
[4] Miao C S, Liu H O and Zhao Y N 2015 Study of launch control for heavy-duty off-road vehicles based on clutch engaging speed Acta Armamentarii 36(05): 769-776.
[5] Chen Q P, Shu H Y and Chen L M 2016 Analysis on temperature field of electromagnetic clutch of in-wheel motor for micro-electric vehicle Int. J. Electr. Hybrid. Veh. 8(2): 109–21.
[6] Liu X, Chen Y, Jiang Y, et al. 2017 Simulation Research of engaging process of clutch based on ADAMS Journal of Mechanical Transmission.
[7] Yan H, Liu J, Mao Q, et al. Analysis on Wear Life of Sprag Clutch of the Logarithmic Surface's Wedge[J]. Machine Design & Research, 2018.
[8] Martin S, Jakob R, Martin K, et al. 2015 Observer design for an electromagnetically actuated dry clutch IFAC-Papers OnLine 48(11): 53–8. http://dx.doi.org/10.1016/j.ifacol.2015.09.159
[9] Yu W G and Gu C L 2017 Dynamic analysis of a novel clutch system for in-wheel motor drive electric vehicles IET Electr. Power Appl. 11(1): 90–8.
[10] Piao C H, Huang Z Y, Wang J and Cho C D 2010 Torque analysis and shape optimization of electromagnetic clutch Key Eng. Mater. 426–427: 122–6.
[11] Yuan Y L 2018 Dynamic analysis of planetary gear train based on ADAMS MATEC Web Conf. 175.