International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 4 Issue 8 ǁ August. 2016 ǁ PP. 31-36

Research on the Electric Shifting Control System of AMT based on Brushless DC Motor

DongxuLiu[1],XunchengWu[1],Weiwei Zhang[1]
[1](*Shanghai University Of Engineering Scienceautomotive Engineering College, China)*

Abstract: According to automatic shift requirements on the control system,we have developed anelectric shifting control system of AMT, When the vehicle in the running process andit can be shifted in good position control precision, short shifting time and automatically shifting action. First, the research on Brushless DC motor control system and the use of different PID control algorithm, and ultimately the offline simulation model was built with the double closed-loop method, the implementation of motor in no-load and load conditions, the simulation test was carried out. The results show that the control methods are feasible; the electric shift system offline simulation model was developed, and the real time simulation test of electric shift system under the condition of different shift was done. The test results show that the control method can meet the control requirements of the position and time of the shift process, and it has good operation and coordination ability.

Keywords: automatic mechanical transmission,Brushless DC motor control system, PID Control,double closed-loop

I. INTRODUCTION

Automated Mechanical Transmission is a kind of system where electronic control system is equipped on the dry clutch and shafted gear transmission. It takes the advantages of the traditional manual transmission and auto-shift, making it playsan very important role in automatic transmission products.Shift control system replace the driver to complete the shift action under different driving conditions, its stability and reliability directly determine the performance and safety of the vehicle. As the power source of the electric shift actuator, the shift process control under the motor is mainly to achieve the implementation of motor speed and displacement control, its performance directly determines the performance of electric transmission system.

II. DETERMINATION OF CONTROL METHOD OF SELECT AND SHIFT MOTOR

2.1. PIDcontrol algorithm

PI control is the most common form of Brushless DC motor control system，although the differential link can effectively reduce the overshoot and reduce the maximum dynamic error,it also easy to make system under high frequency interference. In order to improve the reliability of the control system, the digital PID controller is generally used, and the difference equations can be expressed as:

$$u(k) = K_{\mathrm{P}}e(k) + K_{\mathrm{I}}\sum_{j=0}^{k} e(j) + K_{\mathrm{D}}\left(e(k) - e(k-1)\right) \quad (1)$$

Where K_p is the proportional coefficient，K_I is the integral coefficient，K_D is the differential coefficient，$e(k)$ and $e(k-1)$ are the deviation value of the sampling timecorresponding to the time of k and $k-1$. The use of the PID control algorithm in motor control systemeasy to produce large error and dynamic effect is poor.And now we can use the incremental PID control. The algorithm has some advantages such as the calculation amount is small, do not need accumulation,the impactof misoperationis small, easy to obtain the better control effect and so on.By formula (1) we can get the incremental PID controller algorithm:

$$\Delta u(k) = K_{\mathrm{P}}\left(e(k) - e(k-1)\right) + K_{\mathrm{I}}e(k) + K_{\mathrm{D}}\left(e(k) - 2e(k-1) + e(k-2)\right) \quad (2)$$

In PID control system, in order to avoid output amount of the controller over the implementation of institutions may allow for maximum motion range corresponding to the limit control, causing system large overshoot, and produce even larger oscillation, the Integral Separated PID control algorithmis used in some systems, when system error is large, cancelling the integral effect of the controller, when the system error is small, introduce the integral control to eliminate the static error, and improve the control accuracy, specific steps are as follows: ①according to the actual situation, artificially set the threshold $\varepsilon > 0$;②when $|e(k)| > \varepsilon$ using PD control, so that the system can avoid excessive overshoot, at the same time having a faster response

speed;③when$|e(k)| \le \varepsilon$ using PID control to ensure the control accuracy of the system, the integral separation PID control algorithm can be expressed as:

$$u(k) = K_{\mathrm{P}}e(k) + \beta K_{\mathrm{I}}\sum_{j=0}^{k} e(j) + K_{\mathrm{D}}\left(e(k) - e(k-1)\right) \quad (3)$$

Where β is the Correlation coefficient of integral term, when $|e(k)| \le \varepsilon$, $\beta = 1$;when $|e(k)| > \varepsilon$, $\beta = 0$.

2.2. Control Mode Selection

In this paper, the control method of the gear shift motor adopts the double closed loop speed regulation control mode, the system control principle is shown in figure 1. The current regulator is used with discrete digital PI control algorithm, speed regulator uses discrete digital integral separation PID control algorithm, position control is input the difference of the target position and the current position into discrete digital PD controller and output the motor brake control instructions.

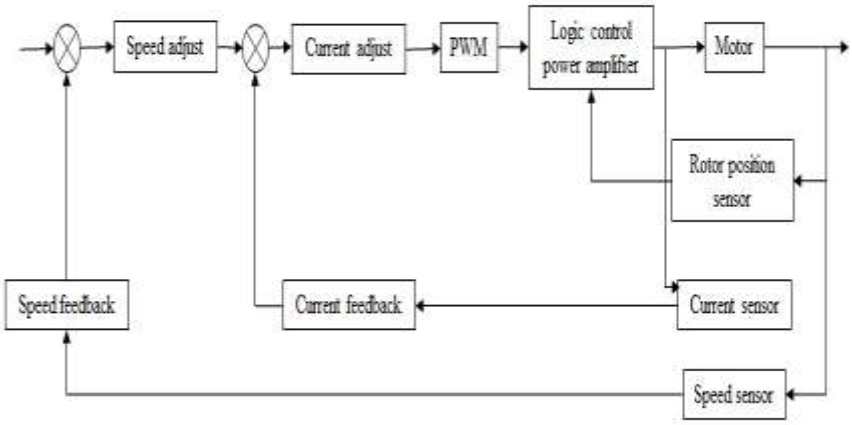

Fig.1 The principle diagram of the double closed loop speed control system

According to the selected motor control method, the corresponding system MATLAB/Simulink off-line simulation model is set up and the related parameters are adjusted.

2.3. Simulation Test Underthe Double Closed-Loop Method

Based on the double closed-loop control method to establish off-line simulation model, setting the reference speed 2000 rpm and debug controller parameter for simulation test, gear motor in no-load and with the same load conditions, the rotating speed of the motor and shifting fork shaft displacement curve is obtained. 1) the speed of the shift motor and the shifting fork shaft displacement curve as shown in Figure 2 and 3 under the double closed loop no-load condition. The speed of the shift motor and the shifting fork shaft displacement curve are shown in Figure 4 and5 under the condition of double closed loop load.

From figure 1, 2, 3, 4 can be seen in the double loop control method: 1) under no-load condition gear motor can reach the target speed within 0.015s, and there is no change and overshoot in a period of time; the shifting fork shaft displacement can reach 9.90 mm at 0.160 s, 0.179 s reach the target position and remain unchanged, and there is no overshoot; 2) under load condition the shift motor speed can reach 1998 rpm at 0.014 s, when the load resistancetorque increased gradually, motor controller adjusts duty ratio of the armature to increasecurrent, and increase the output driving torque greater to balance the load resistance torque. The load speed has overshootafter the load decreasedsuddenly, and reached the peak speed of 2091 rpm at about 0.148 s; the shifting fork shaft displacement can reach 9.90 mm at 0.159 s, 0.176 s at 10.03 mm and remained unchanged, the overshoot is less.

According to the above, we can draw a conclusion that in the double loop of control, system has good anti load disturbance, compared to the no-load,under the condition of with load, system running almost no time delay, due to the low speed reference, the system relatively open loop system running time increased but still meet the control requirements of the shift time,the location precision and has a better position maintain ability and dynamic performance, so the control method is feasible.

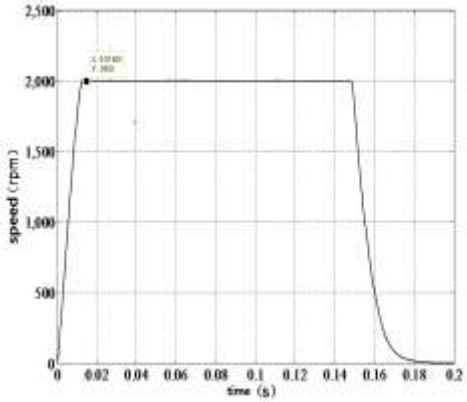

Fig. 2 Gearshift motor speed under double closed-loop and no-load conditions

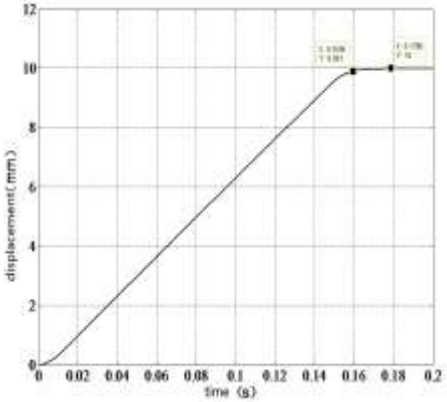

Fig.3 Fork shaft displacement under double closed-loop and no-load conditions

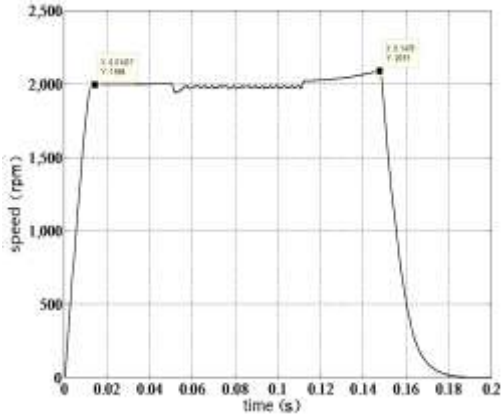

Fig.4 Gearshift motor speed under double closed-loop and load conditions

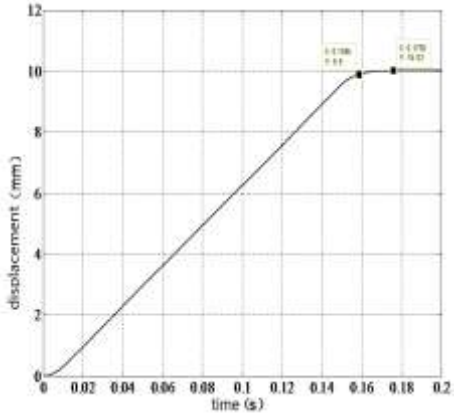

Fig.5 Fork shaft displacement under double closed-loop and load condition

III. THE ELECTRIC SELECT AND SHIFT GEARCONTROL SYSTEM OFF-LINE SIMULATIONTEST

3.1. the establishment of the off-line simulation model of the electric shift system

General AMT shift process has strict timing requirements, including three stages of withdrawal, selection and suspension. Shift control of the entire process must accomplish the implementation of each phase of position control ofactuator firstly, then coordinate each stage to ensure that each stage only a motor in operation, otherwise it will produce movement interference and damage mechanism. For the further study of the selected motor control method and control performance in the gearshift control system, Based on the double closed loop control method, an off-line simulation model of the gear shifting control system is established in this paper. Simulation test was carried out on different shift working conditions to observe the control effect of the controller. Combined with the control target of the electric control system, an off-line simulation model of the system is established in MATLAB/Simulink. Select and shift system controller mainly composed by the select and shift gear motor controller and operation timing control module, which motor controller mainly realize the motor running basic functions including start, stop and reversing action, , The double closed loop control method is adopted on this basis, and the reference speed and the target position are set to realize the position control of the actuator in each stage of the shift process and meet the time requirements of the selected shift.

In order to make the control system safe and reliable, besides meeting the above functions, it still need the protection circuit, motor drive load in start braking moment armature current will reach several times the rated current, therefore need to do the current limiting protectionon this stage. Starting current amplitude limit by add a current limit amplitude module after speed loop to achieve, usually the amplitude is set about two times of the rated current, this limited amplitude works only when the current flowing through the DC bus so that limit the amplitude protection role, the brake armature current no longer flows through the bus, the limiting effect disappeared. Brake current limit amplitude can be realized by a logic circuit, the sensor collect the motor armature current and compare with the amplitude, within the limits of normal braking or control full bridge inverter bridge arm disconnect to reduce the current,thus control the armature current in a certain range.

The control of the time sequence of the shifting operation is realized by using the sensor to collect the axial displacement and the rotation angle displacement of the shifting fork shaft to be judged by the logic circuit, then output corresponding stage execution mechanism. According to the different shift working conditions,the process of the shift motor is divided into 1-3 stages, the preset motor clockwise rotation is the positive direction, the motor start and stop is reverse logic relationship truth as shown in table 1.

Table.1 Motor start & stop and positive & negative logic relation truth table

Shift condition	Selector motor		Shift motor	
	Start/stop （1/0）	forward / reverse （1/0）	Start/stop （1/0）	forward / reverse （1/0）
0-1	1	1	0	1
	0	1	1	1
1-2	0	0	1	0
	1	0	0	0
	0	0	1	0
2-3	0	0	1	1
3-4	0	0	1	0
	1	0	0	0
	0	0	1	0
4-5	0	0	1	1
5-4	0	0	1	0
4-3	0	1	1	1
	1	1	0	1
	0	1	1	1
3-2	0	1	1	0
2-1	0	1	1	1
	1	1	0	1
	0	1	1	1
1-0	0	0	1	0
	1	0	0	0
0-R	1	1	0	0
	0	1	1	0
R-0	0	0	1	1
	1	0	0	1

3.2. The simulation experiment and result analysis

Under no-load condition, the current limit of the gear shift motor is simulated and tested when the motor is starting and braking, the amplitude is 2, and the response curve of the three-phase current of the motor is shown in Figure 6 and 7 respectively.

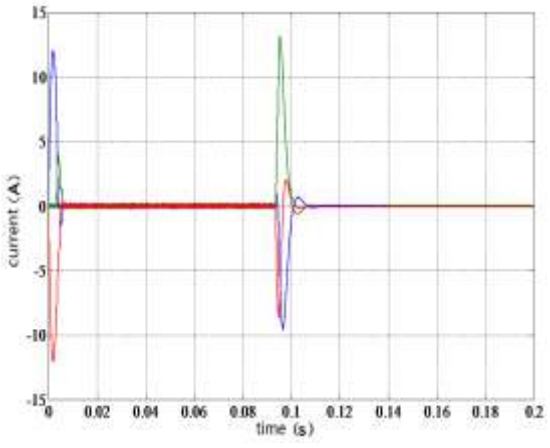

Fig. 6 Motor phase current curve without amplitude limiting

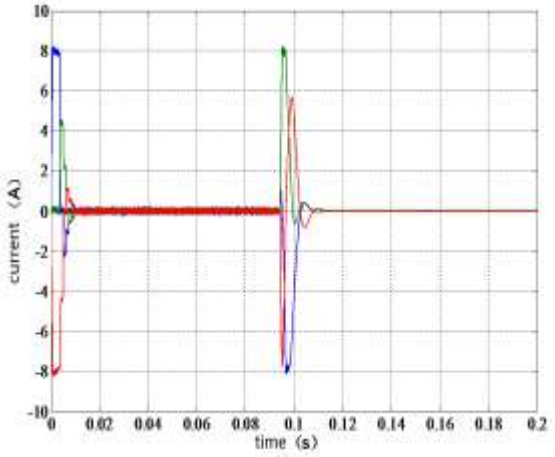

Fig. 7 Motor phase current curve with amplitude limiting

From Figure 6 and Figure 7, we can see that compared to the limited current amplitude before, the motor three-phase current during start and brake vary in the limited amplitude range after it is limited, overcurrent protection function, so the current limit protection method is feasible.

By modifying gear value of the system model, only under the shift fork shaft self-locking resistance of different shift condition to do simulation test, testing the response speed,location accuracy and operation coordinationof select and shift execution control mechanism. In this paper, we take first block and second block as an example to illustrate, the rotation speed of the shift motor, the axial displacement of the shifting fork shaft and the rotation angle displacement curve are shown in Figure 8, 9 and 10 respectively.

From figure 8, 9, 10,we can see that, initially, the shift motor starts to run according to the control command output by the running time sequence control module, and drives the shifting fork shaft to move back and back through the driving mechanism. At about 0.116 s, the shift motor stops, reaches the first target position and remains unchanged, and there is no overshoot,complete withdrawal. At this point, the operation sequence control module outputs a running command corresponding to the selector motor, so that the selector motor begins to move to drive the shifting fork shaft to rotate to make the shift point shift from 1 to 2, the R shift fork gap position to the 2 and the 3 shift fork gap position. At about 0.222 s, the selection of the gear motor stops, reaching the target location and remain unchanged and there is no overshoot, complete the selection of the action. Then shift motor received start command and began to run, and reach the second target position at about 0.371 s, and keep unchanged and there is no overshoot and the hanging block the action, finally complete the entire shift processfor the first block to the second block.

To sum up, without considering the reduction of block and synchronous resistance,the system controller based on the double closed loop control method can make the selection of the shift actuator safely and reliably complete the shift action in a short time andmeet the control requirements of the shift time, position accuracy and operation coordination.

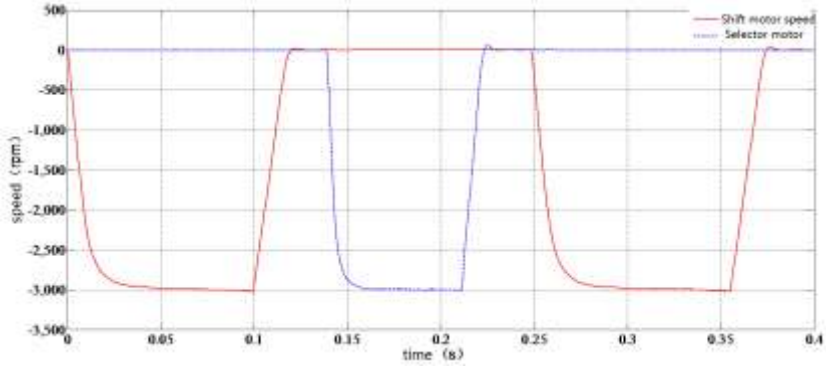

Fig. 8 Motors speed curve in the first gear shift to the second

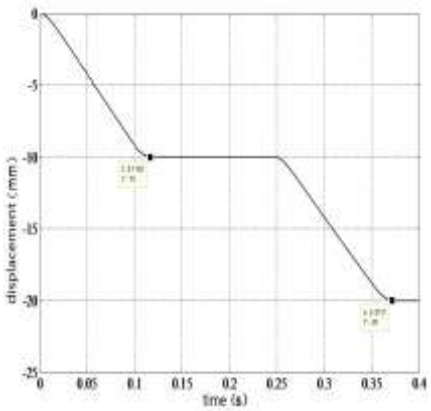

Fig. 9 Fork shaft displacementcurve

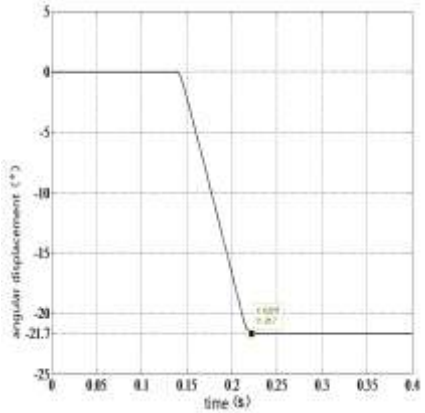

Fig. 10 Fork shaft angular displacement curve

IV. CONCLUSION

The main work is the study of the control method of the electric shift system in this paper, according to the requirement of automatic shift control system, the control target of the electric shift control system is proposed, and the control system of Brushless DC motor and the different PID control algorithms are studied, finally, the double closed loop speed control mode is selected, and the corresponding system off-line simulation model is established in MATLAB/Simulink. The simulation test was carried out on the motor under the condition of no load and load. An off-line simulation model of the electric shift system is developed by using the double closed loop control method,and the off-line simulation test was carried out for different shift working

conditions. The test results show that the control method can meet the control requirements of the position and time of the shift process, and it has good operation and coordination ability.

REFERENCES

[1]. Tseng C, Hsieh M. Analysis and optimization of clutch actuator on automated manual transmission system[C]. SAE Paper 2005-01-1782, Detroit, USA, 2005.

[2]. R.P.G. Heath, A.J.Child. ZeroshiftAutomated Manual Transmission (AMT)[J]. SAE Paper. 2007-26-061.

[3]. Turner A. J, Ramsay K, Clark R. E, et al. Development of high force electromechanical linear actuator for shift-by-wire automated manual transmissions[C]. SAE Paper 2006-01-0360, Detroit, USA, 2006.

[4]. ZhongZaimin, Kong Guoling, Yu Zhuoping, et al. Concept Evaluation of Novel Gear Selector for Automated Manual Transmission[J]. Mechanical Systems and Signal Processing, 2012, 31: 316-331.

[5]. KanakoShimojo, Yuji Yasui, Eijiro Shimabukuro, et al. New Concept Sliding Mode Control for AMT[J]. SAE Paper. 2005-01-1594.

[6]. Peng Jiankun,Shi Shaoyou, He Hongwen, et al. Shift control strategy simulation on dual motor driven electric vehicle[J].Transportation Electrification Asia-Pacific, IEEE Conference and Expo, 2014, Page(s): 1-4.

[7]. Wei Li.Research of AMT control system based on brushless DC motor [D]. Changchun: Jilin University, 2007

[8]. Gao Zhi, ZhongZaimin, Sun Zechang. Electric AMT selected gear motor actuator optimal position control [J]. Automotive engineering, 2011,33 (6): 20-24. (2): 133-137.

[9]. Cao Pengbiao, Chen Xinbo, ZhongZaimin. AMT gearshift process [J]. Mechanical and electrical integration, 2011 (10): 23-26.

[10]. GuoLishu, Ge Anlin, Zhang Tai. Control of shift process of automatic mechanical transmission [J]. Journal of agricultural machinery, 2003,34 (2): 1-3.

[11]. Xia Changliang. Brushless DC motor control system [M]. Beijing: Science Press, 2009.

[12]. Liu Jinkun. Advanced PID control MATLAB simulation [M]. third edition, Beijing: Publishing House of electronics industry, 2011

[13]. Yang Di, Li Litao, Yang Xu. Development environment and application of system real time simulation [M]. Beijing: Tsinghua University press, 2002.