CONTROL STRATEGY OF ELECTRIC MACHINERY STEPLESS TRANSMISSION SYSTEM

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Abstract: In order to solve the problem of the dynamic matching of the step less transmission system, the power machine step less transmission on the electric vehicle was studied. The double motor was used as the power source. The main motor M1 mainly provided the driving force. The speed regulating motor M2 was used to adjust the output speed. The speed range was wide, and the quality was light. The system flexibility was high. The basic performance of the permanent magnet synchronous motor for vehicle was introduced. According to the actual design requirements, the transmission scheme was selected, and the transmission principle was designed. The corresponding characteristic parameters of the transmission system were calculated. According to the driving demand under different working conditions, the control structure of the step less transmission system was designed. The test bench was built to test the power machine step less transmission. According to the working point and resistance load at different speed, the test bench was driven and loaded. The characteristic data of the transmission system in the stable running state were collected and analyzed. The results showed that the step less transmission system had stable step less speed regulation. Therefore, the method provides high transmission efficiency.

Keywords: Step less transmission; Electric machinery; Optimization design; Characteristic research.

1. Introduction

At present, oil and other energy are increasingly scarce. The global climate warming and other environmental problems are becoming more and more prominent. "Energy conservation and environmental protection" has become the main issue of the current social development. The traditional fuel vehicles have significant shortcomings in energy sources, energy utilization efficiency and the impact on the environment. It is imperative to change from traditional energy vehicles to new energy vehicles. The power source of the electric vehicle is the vehicle power supply, and the motor is used as the direct input device to replace the fuel engine. It has great advantages in the high efficiency of energy utilization and low pollution to the environment. The new energy will be the key development direction of the automobile industry for a long time in the future [1].

The transmission is an important part of the automobile power assembly. At present, most of the mechanical properties of automobile power sources, including engines and motors, cannot be directly used for vehicle driving. They usually need to decelerate and increase torsion by transmission to meet actual driving needs. The transmission plays the role of the power source and the driving wheel. Its function generally includes adjusting speed, transmission power and power change. The function of the transmission is closely related to the power of the vehicle and the quality of the economy. It can even affect the life of the vehicle [2].

According to the transmission ratio energy, the transmission can generally be classified into two major categories: the variable speed and the step less speed change. The transmission ratio, which can be changed in a certain interval, is usually called a step less transmission. The abbreviation is CVT. CVT can achieve continuous adjustment of speed, which makes the power source match the best performance of the whole vehicle. It can not only guarantee the economy and power of the vehicle, but also improve the driver's driving feeling and operation comfort [3]. According to the difference of control and transmission mode, the step less transmission can be classified as three kinds of mechanical, fluid and power transmission. Usually, the traditional step less drive only uses one of the above dynamic transmission forms. With the improvement of the requirements of the transmission system and the progress of technology, a variety of composite step less transmission technology is adopted in various power transmission forms.

In order to solve the problem of pure power drive, the mainstream power vehicles on the market usually use the power supplied by power source through the confluence device. Planetary rows are widely used. The motor and the engine are connected to the power elements of the planetary row, respectively. With the aid of planetary arrangement, the continuous change of transmission ratio and the increase of output torque are easy to be realized. The matching of the dynamic performance of the two power sources has been improved. The efficiency of energy utilization is improved [4].

2. Theory of Power Machine Step Less Transmission

Although the single CVT mode can achieve the step less regulation of speed, each of them has some limitations and shortcomings. Therefore, it is seldom applied in practical engineering. In order to integrate the advantages of all kinds of step less transmission and make up for its shortcomings, the composite step less transmission is gradually developing. At present, the main application forms include: hydraulic mechanical transmission and power mechanical transmission [5].

At present, the hydraulic mechanical transmission is usually used to combine the hydraulic system with the planetary gear train. The hydraulic system can realize the continuous adjustment of the parameters of the flow. The distributaries converge of the hydraulic power is realized through the planetary gear train. Through the combined output of two parts, the uninterrupted regulation of the transmission ratio in a certain interval is completed. Usually, it can be classified as three kinds of hydraulic mechanical diverter transmission, hydraulic mechanical continuous variable speed transmission and hydraulic mechanical transmission [6].

The electric machinery step less transmission is a compound transmission. Through this transmission system, the efficiency of the mechanical transmission can be combined with the precise control of the electric drive. Compared to purely mechanical transmission, its continuous adjustment of the speed ratio is stronger. Compared to the purely electric drive, its power and adaptability to harsh conditions have been significantly improved. The motor is used instead of the hydraulic system. Compared with the hydraulic mechanical step less transmission, its portable and controllability is better. Therefore, in the vehicle transmission system, the power machine step less transmission is applied. Especially in some complex conditions, it can significantly improve the matching degree of power source and load. The power and economy of the vehicle have been improved [7].

The power machine step less transmission is also called the electromechanical composite step less transmission. It not only includes planetary transmission mechanism, deceleration mechanism and other mechanical transmission devices, but also includes power battery pack, motor control system, motor and other power transmission devices. In this system, the main body of the planetary gear shift mechanism is a planetary gear system with multiple degrees of freedom. Its main function is to realize the shunt and confluence of the mechanical power. The motor control system is made up of electronic devices. Its main function is to manage the flow of electric power [8].

The basic working flow of the transmission system is as follows. The power battery group provides the power source for the whole system. The output power of the power system is allocated to the main motor M1 and the speed control motor M2 according to the actual driving demand. Electrical power is converted into mechanical power through the motor. The planetary gear transmission mechanism is inputted for confluence. Then, the confluence is exported to the deceleration mechanism. Finally, it is transmitted to the wheel drive vehicle. A planetary row is a differential planetary gear system with a degree of freedom. The two inputs can be independent of each other. By adjusting the input speed of the two motors, the output speed of continuous and step less change can be obtained. Considering the actual driving conditions and the inner cycle effect of the planetary row, the two motor is not always used as an input element. There are the following conditions.

The power is diverted through the main motor M1 into the planetary row. One passes through the transmission to the wheel. The other is back to the speed control motor M2. At this point, as a generator, the power generated by the M2 is transmitted to the power cell group. Then, the power is stored [9].

3. Optimal Design of Power Machine Step Less Transmission

The vehicle will encounter the effect of continuous changing load such as air resistance, rolling resistance, and ramp resistance during driving. At the same time, it needs to output different speed to adapt to driving demand. The transmission system can provide the transmission ratio corresponding to the demand, so as to ensure the power and economy of the vehicle.

The traditional level transmission can solve the above problems to a certain extent. However, because of the limited speed gear, it cannot provide the optimal transmission ratio for the actual working conditions.

At the same time, the complexity of the mechanical structure is limited, and there is not a special increase in the position of the gear. The CVT can solve this problem well. With the change of the external load and the speed of the target, the continuous speed and torque are provided to achieve the best power and economy [10].

A small electric car is used as a research object. In view of its specific working conditions, a power machine step less transmission is designed. The power matching of the power machine step less transmission and the motor is completed. It has a large speed range. The transmission efficiency in the main working section is guaranteed.

3.1 Basic parameters of the target vehicle

For vehicle, its dynamic performance is the corresponding driving performance determined by longitudinal external force in the process of smooth pavement (concrete or asphalt) running along a straight line, which is the requirement of reaching the average speed.

It is the most basic requirement for the car. Electric cars usually include three indicators. They are the maximum speed of the vehicle, the maximum climbing degree and the acceleration time. From the point of view of the energy supply of electric vehicles, the above indexes are used to test the power and torque of the motor. Based on the basic parameters of the target vehicle, the corresponding dynamic index evaluation needs are given according to the force of the body. It lays a solid foundation for the subsequent motor matching and the parameter design of the step less transmission. According to the requirements of the project, a small electric vehicle is an object. The parameters and dynamic performance indexes of the vehicle are shown in Table 1.

Table 1 The parameters of the target vehicle

Vehicle parameters	No-load quality m_0/kg	Full load quality m_a/kg	Frontal area A/m^2
	800	1000	1.8
	Air resistance coefficient C_D	Rolling resistance coefficient f	Wheel radius r_D/m
	0.3	0.015	0.31
Dynamic parameters	The maximum speed v_{max} (km/h)	Climbing degree (20km/h)	
	100	30%	

3.2 Design of transmission scheme for power machinery step less transmission

A number of one - stage planetary rows are connected in series into a multistage planetary array. It can expand the speed range of the transmission system. Multiple single - row combinations are bound to increase the complexity of the planet's platoon. Its mechanical cost and weight will be greatly increased. The characteristics of the step less transmission of power machinery have been studied. The follow-up is only ready to set up the corresponding small test bench. The problem of reversing is not considered. The cost of the experiment is limited, and the two-stage planetary arrangement is adopted [11].

There are several indicators for the design of the transmission scheme. The speed ratio of the transmission system has a larger range. The power split ratio of ρ is continuous in stage to prevent power fluctuation. The maximum value of ｜ρ｜is smaller. The relative reverse speed ratio I' curve has a slow change. Considering the speed range of the speed control motor, the speed of the motor should be as small as e, which is initially limited to (-3, 3). In order to improve the efficiency of energy utilization, the efficiency of the system is high.

In this scheme, the power battery power supply is powered by the motor control system (e is the speed ratio of the motor) for two motors.

The main motor M1 provides the main power. The clutch C1 or C2 is connected to the tooth ring b_2 of the planetary row 2 or the tie rod x_1 of the planetary row 1.

The power of the M2 road of the speed regulating motor is connected by the first stage gear mechanism (the transmission ratio is i_1) and the sun wheel a_1, a_2. The planetary row is composed of two single rows of two stage planetary rows with characteristic parameters of p_1 and p_2, respectively.

The two power lines are passed through the planetary confluence flow to the x_2 of the 2 of the planets or the ring b_1 of the planetary row 1.

Through the gear d, it is transferred to the gear f.

Then, through the subsequent progressive deceleration mechanism, the current is finally exported to the wheel. Among them, C3 and C4 are two friction plate sync rings, which are normally engaged. When the load torque is too large, it automatically disconnects from the joint. This can prevent the damage of the motor. As a speed regulating motor, the output power and torque of M2 are smaller than that of the main motor M2.

Considering some sudden conditions in the working process, the above measures can play a protective role on two motors. The speed regulation interval is divided into three sections according to the transmission scheme. The III section is a low speed start section, which is only powered by M1.

The planetary row is operated as a whole, and the motor M1 speed directly acts on the following transmission mechanism. The I and II segments are high speed segments. Planetary transmission is used. M1 and M2 work at the same time. The internal circulation of planetary transmission is considered. When optimizing the parameters, speed range corresponding to the segment ρ<0 interval should be decreased as much as possible.

As two sets of changeover clutches, the change of combination of C1 and C2 can achieve the purpose of replacing the output stage. i_3 represents the reduction gear transmission ratio.

The three working positions and the corresponding working status are shown in Table 2.

Table 2 The three working positions and the corresponding working status

Stage	C1	C2	C3	C4	p	i_1	i_3
I	+	-	+	+	p_2	i_{11}	i_{31}
II	-	+	+	+	p_1	i_{12}	i_{32}
III	+	+	+	-	\	\	i_{32}

”+” and “-“ represent clutch engagement and disengagement, respectively. I, II, and III represent the three shift stages in the forward state.

3.3 Principle and calculation of the main parameters

In this scheme, the speed range of the transmission is increased by the superposition of the output speed of the three working sections. In order to efficiently use its speed range, it is naturally required that there should be no overlapping of output speeds between several work sections. The speed range is divided according to the driving condition of the target model. The high, middle and low segments correspond to the I, II and III segments, respectively. The speed regulation interval of III section is 0-20km/h, I and II are between 20-100km/h.

In the design of the transmission scheme, the stable condition should be considered. The load of the vehicle at a constant speed is stable, and the transmission parameters can be guaranteed to the highest transmission efficiency in a stable condition. In addition, the design requirements should be met as much as possible. When the vehicle runs at a constant speed, the corresponding speed v has the corresponding demand driving power P (v) and the driving torque r (v). According to the theory of planetary transmission and the optimal efficiency curve of the main motor, the working point of the motor can be deduced at a constant speed. The specific derivation process is as follows:

When the speed is v, the driving power is:

$$P(v)=\frac{v}{3600\eta_\tau}\left(mgf+\frac{C_D A v^2}{21.15}\right) \tag{1}$$

The corresponding driving torque is:

$$T(v)=\frac{r_D}{\eta_\tau}\left(mgf+\frac{C_D A v^2}{21.15}\right) \tag{2}$$

The M1 working point of III section can be obtained directly:

$$n_{M1,3}(v_3)=\frac{i_2\cdot i_{32}\cdot v_3}{0.377\cdot r_D} \tag{3}$$

$$T_{M1,3}(v_3)=9549\frac{P(v_3)}{n_{M1,3}} \tag{4}$$

For the two sections of I and II, the driving torque r (v) and planetary transmission rules can be obtained separately according to the demand. When the speed is v, the torque of the motor is as follows:

$$\mathrm{T}_{M1,1}(\mathrm{v}_1)=\frac{\mathrm{p}_2}{(1+p_2)i_2 i_{31}}T(v_1) \tag{5}$$

$$\mathrm{T}_{M2,1}(\mathrm{v}_1)=\frac{i_{11}}{(1+p_2)i_2 i_{31}}T(v_1) \tag{6}$$

$$\mathrm{T}_{M1,2}(\mathrm{v}_2)=\frac{1+p_1}{p_1 i_2 i_{32}}T(v_2) \tag{7}$$

$$\mathrm{T}_{M2,2}(\mathrm{v}_2)=\frac{i_{12}}{p_1 i_2 i_{32}}T(v_2) \tag{8}$$

4. Performance Test of Power Machine Step Less Transmission

4.1 Construction of test bench

The experiment table has two motors and a transmission bench. The actual power of the motor M1 is relatively small (5kW). Its speed range can meet the requirements of the previous theoretical design. In order to achieve a good match, the motor M2 also adjusts the power and speed of the motor accordingly. Therefore, the connection between the transmission and the M2 is changed into a set of small transmission ratio worm and worm gear. The drive power reduction only needs to adjust the corresponding load, and the other parameters of the transmission stand are unchanged. Through the bench test, the step less speed regulation characteristics and the corresponding system efficiency characteristics of the power machine step less speed transmission are verified.

This does not affect the qualitative analysis of the performance.

The test platform also has a FC250 magnetic powder dynamometer, which is loaded on the step less transmission system in the test.

The layout scheme of electric machinery step less transmission test stand is mainly composed of motor M1 and speed motor M2, which are connected with two torque speed sensors through the coupling respectively. The torque, speed and power input from the two motors to the system are collected by sensors. The two sensor is then connected to the two input terminals of the planetary transmission to provide power for the transmission. Finally, as an output end, the three element is connected to the magnetic powder dynamometer via third torque speed sensors.

The magnetic powder dynamometer simulates the load in the test, and the corresponding sensor is used to measure the torque, speed and power of the output end of the transmission. Sensors, motors and dynamometer are connected by data acquisition card, signal line and dynamometer. Signal acquisition and signal control are realized by IPC.

4.2 Results and analysis

There is a positive correlation between the speed of driving and the resistance of road surface at a constant speed on a certain load. According to the principle of transmission designed in this paper, the speed of the vehicle can be reached and stabilized by adjusting the working point of two motors. Based on the above principle, the output end of the transmission system is loaded by the magnetic powder dynamometer to simulate the road condition load. The resistance torque corresponding to the different speed points in the theoretical calculation is taken as its set value. Then, the working point of the two motor is controlled to verify the corresponding characteristics of the transmission at a uniform speed.

Due to the size limit of the test bed, the transmission element of the transmission terminal is the gear. That is, there is no follow-up i_3 part of the transmission. In actual loading, it is necessary to divide the resistance torque of each section by the corresponding i_{3j}, j = 1,2,3. It can be seen from the calculation that the output resistance torque range of each working section under standard road conditions is respectively I section (21.88Nm, 44.01Nm), II section (6.19Nm, 7.88Nm), III section (5.78Nm, 6.41 Nm). Taking into account the feasibility of the experiment and the accuracy of the corresponding control test equipment, the load T_i applied to the three work sections is set as follows:

I section: T_{lmin}=21.5Nm, T_{lmax}=44Nm.

One test point was taken per 0.5Nm, with 46 groups.

II section: T_{lmin}=6Nm, T_{lmax}=8Nm.

One test point was taken per 0.25Nm, with 9 groups.

III section: T_{lmin}=5.75Nm, T_{lmax}=6.5Nm.

One test point was taken per 0.25Nm, with 4 groups.

Taking the minimum resistance torque 21.5Nm of the I section as an example, it is shown that in the experiment, the working point of the motor is adjusted to the theoretical value first through the industrial control machine, as shown in Figure 1 to Figure 6. Then, through the industrial control machine, the magnetic powder dynamometer is slowly loaded to the 21.5Nm. After stable operation of the system, the sampling is carried out. The speed, torque, and power data of the two motors and the output end of the transmission are recorded. The next test point is measured in the above order, and all the points in the section are completed by analogy.

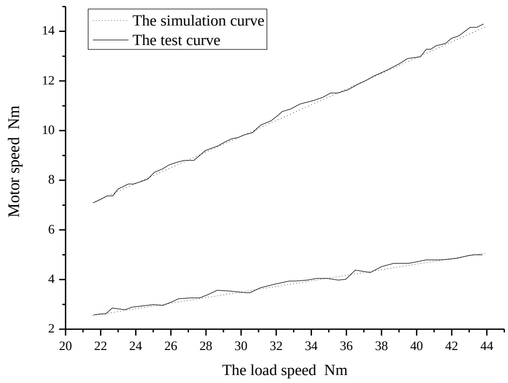

Figure 1. I segment motor torque

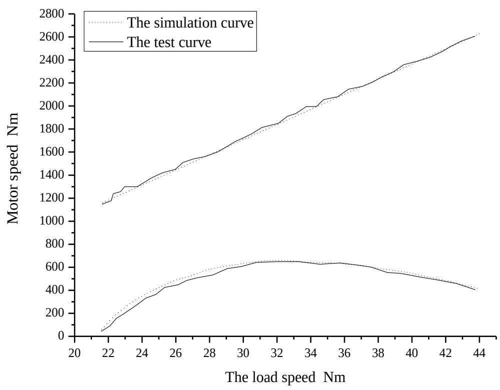

Figure 2. I segment motor speed

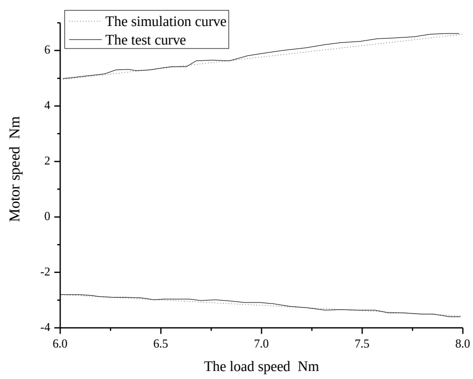

Figure 3. II segment motor torque

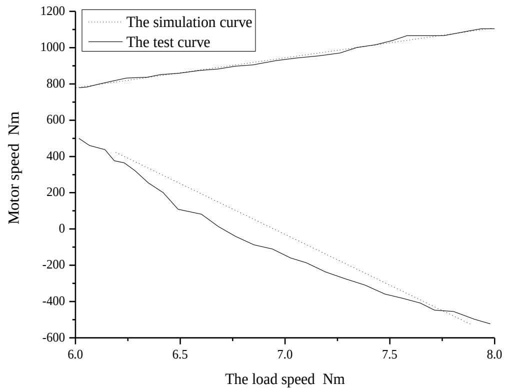

Figure 4. II segment motor speed

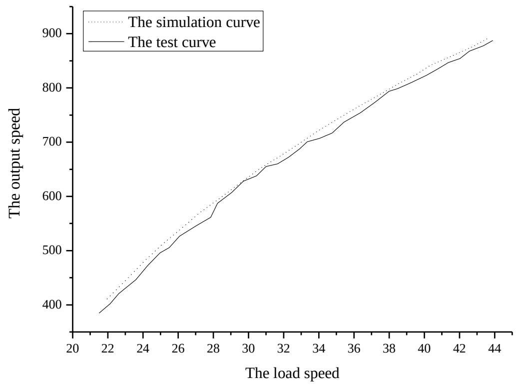

Figure 7. Speed regulation characteristics of I segment

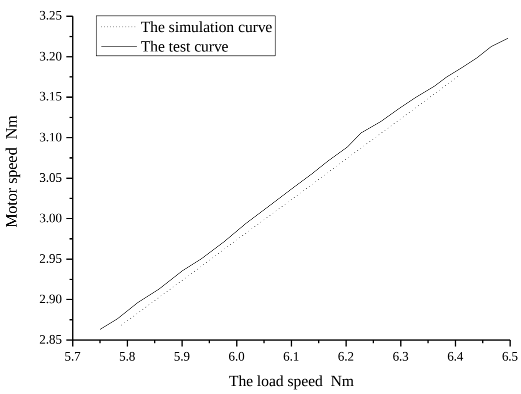

Figure 5. III segment motor torque

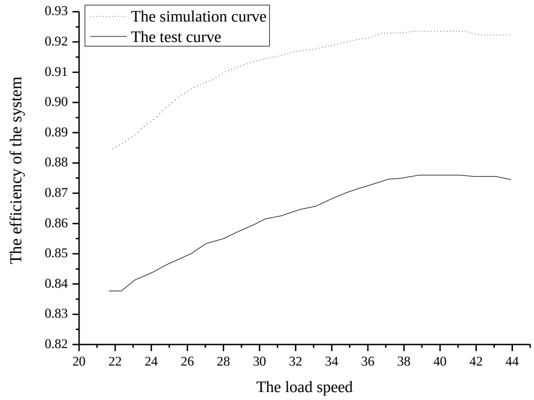

Figure 8. Efficiency characteristics of I segment

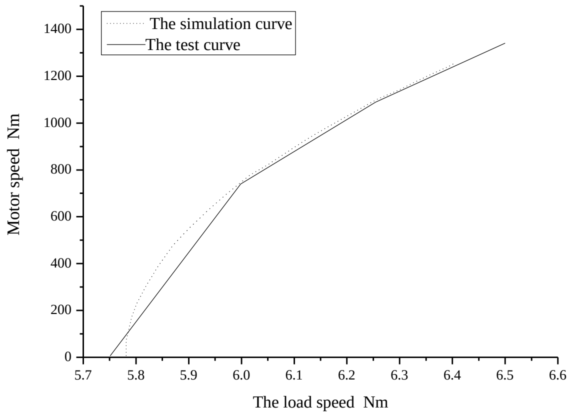

Figure 6. III segment motor speed

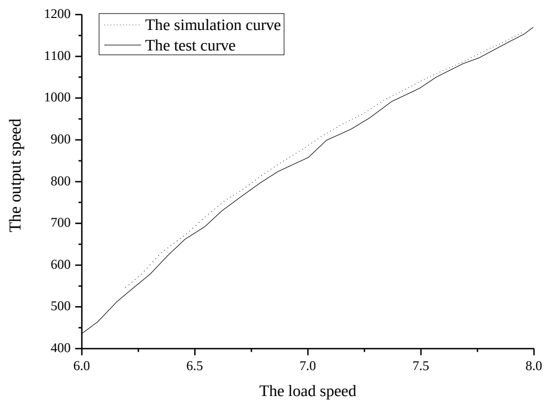

Figure 9. Speed regulation characteristics of II segment

The speed regulation characteristic of the transmission can be collected directly through the output end sensor. According to the experimental data, the relationship between the output speed and the resistance torque is drawn, as shown in Figure 1, Figure 3, and Figure 5.

The efficiency characteristics can be obtained by the acquisition of the motor and the output power. The motor map diagram is invoked for calculation.

The relationship between the efficiency of the transmission system and the resistance torque is drawn, as shown in Figure 2, Figure 4, and Figure 6.

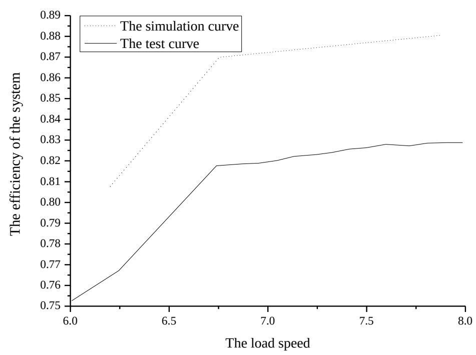

Figure 10. Efficiency characteristics of II segment

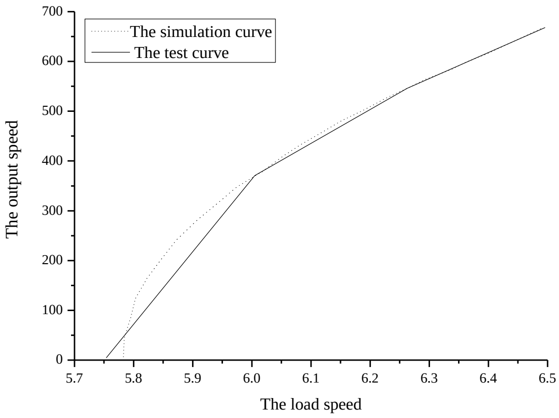

Figure 11. Speed regulation characteristics of III segment

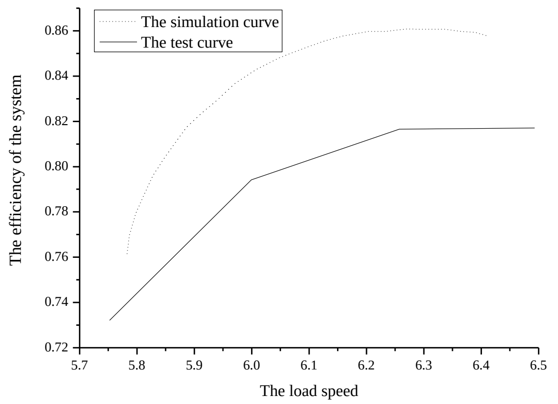

Figure 12. Efficiency characteristics of III segment

As can be seen from Figure 7, Figure 9, and Figure 11, the change of the motor torque, speed and the speed n_0 of the transmission output end is consistent with the simulation results when the actual loading is run. There is little difference in the numerical value. The factors include the following aspects. The optimal design results are adopted in the gear transmission ratio of all levels in the simulation curve. The gear pair has a slight deviation from the theory because of the limit of the number of teeth. The actual platform has the error of processing and assembly. There is the existence of friction, which overcomes the same load T_i. The actual motor drive torque T_{M1}, T_{M2} should be greater than the theoretical value. When the corresponding steady state is reached, the output speed n_0 will be smaller than the theoretical value. The test results show that under certain road conditions, the electric mechanical continuously variable transmission can reach the pre-set speed by adjusting the working points of the two motors. In the range of speed regulation, each speed point can be operated steadily. Its step less speed regulation performance is good and controllable.

As can be seen from Figure 8, Figure 10, and Figure 12, In the actual loading operation, the system efficiency can be kept above 73%.

The maximum can be 87.8%. The efficiency characteristic is relatively good.

The trend of transmission system efficiency η is in accordance with the simulation curve. However, there is a certain deviation in the numerical value. The efficiency of the system is about 5% lower than that of the theoretical value. Compared with the low speed section, the efficiency difference of the high-speed section is greater. The test rig is self-made and assembled.

The purpose of this paper is to analyze the characteristics of the transmission system. In the overall accuracy, it has not reached the product level, so the efficiency will be affected. At the same time, the ideal model is used in both simulation and calculation. In the aspect of transmission loss, only the gear pair and the meshing loss of the bearing are considered.

However, in the actual operation, there will be the actual loss of parts heating and so on. Therefore, the efficiency loss of the high-speed section is more serious. It is necessary to strengthen the construction and improvement of the theoretical model.

Due to the limitation of time and experimental conditions, no tests were carried out on the acceleration conditions and the steady speed conditions. The corresponding test can be left to the follow-up study.

5. Conclusion

The step less transmission technology can complete the optimal match between the vehicle and the driving equipment. It plays a significant role in enhancing the power and economy of the automobile. At present, energy shortage and environmental requirements are increasing. Electric vehicles will become the main research direction of the automobile industry. In view of the step less transmission technology of electric vehicle, the corresponding power machine step less transmission is designed. The working characteristics of the permanent magnet synchronous motor for vehicle are understood. The main motor M1 is matched with the vehicle parameters and the dynamic demand of the target vehicle. The planetary arrangement is compared.

According to the actual design requirements, the transmission scheme is selected. The principle of transmission is designed and the characteristic parameters are calculated. The speed regulation characteristics and power diverting situation are analyzed, and the speed control motor M2 is matched. A power machine step less transmission test bed was built. The step less transmission was tested in steady state. Its operating data is collected for analysis. Within its range of speed regulation, the electro-mechanical continuously variable transmission has stable step less speed regulation and high system efficiency.

References

[1] Gramblička, S., Kohár, R., & Stopka, M. (2017). Dynamic analysis of mechanical conveyor drive system. Procedia Engineering, 192, 259-264.

[2] Wenqi, L. U., Kehui, J. I., Dong, H., Zhang, J., Wang, Q., & Guo, L. (2017). Double position servo synchronous drive system based on cross-coupling integrated feedforward control for broacher. Chinese Journal of Mechanical Engineering, 30(2), 272-285.

[3] Sattar, M., Wei, C., Jalali, A., & Sattar, R. (2017). Analytical kinematics and coupled vibrations analysis of mechanical system operated by solar array drive assembly., 224(1), 012001.

[4] Li, J., Sumner, M., Padilla, J. A., & Zhang, H. (2017). Fault signal propagation through the pmsm motor drive systems. IEEE Transactions on Industry Applications, 53(3), 2915-2924.

[5] Sparham, M., Sarhan, A. A. D., Mardi, N. A., Hamdi, M., & Dahari, M. (2017). Anfis modeling to predict the friction forces in cnc guideways and servomotor currents in the feed drive system to be employed in lubrication control system. Journal of Manufacturing Processes, 28, 168-185.

[6] Michajłow, M., Jankowski, Ł., Szolc, T., & Konowrocki, R. (2017). Semi-active reduction of vibrations in the mechanical system driven by an electric motor. Optimal Control Applications & Methods, 38.

[7] Xu, M., Wu, X. M., Yu, X., Chen, G. J., Xu, M., & Wu, X. M., et al. (2017). Dynamic performance of auxiliary hydraulic power unit based electro-hydraulic variable speed drive system. ARCHIVE Proceedings of the Institution of Mechanical Engineers Part C Journal of Mechanical Engineering Science 1989-1996 (vols 203-210), 095440621772777.

[8] Wang, H., & Sun, D. (2017). Optimal matching between a diesel engine and a prhts transmission. Journal of the Brazilian Society of Mechanical Sciences & Engineering, 1-13.

[9] Walker, P., Zhu, B., & Zhang, N. (2017). Powertrain dynamics and control of a two speed dual clutch transmission for electric vehicles. Mechanical Systems & Signal Processing, 85, 1-15.

[10] Zhang, X., Zhang, J., Zhang, W., Liang, T., Liu, H., & Zhao, W. (2018). Integrated modeling and analysis of ball screw feed system and milling process with consideration of multi-excitation effect. Mechanical Systems & Signal Processing, 98, 484-505.

[11] Wang, J., He, G., Zhang, J., Zhao, Y., & Yao, Y. (2017). Nonlinear dynamics analysis of the spur gear system for railway locomotive. Mechanical Systems & Signal Processing, 85, 41-55.