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Prediction on Torque Required for Electromechanical Compound Transmission System

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This paper intends to predict and analyze the torque of the modern Electromechanical Compound Transmission System (ECTS) as required with current technologies. The analytical method is defined in such a way that the Matlab / Simulink platform constructs a forward simulation model for ECTS. The analysis of the model turns out that the overload of the system battery power has been improved, while the real-time performance and the control effect of the algorithm are demonstrated. It is concluded that the model built on Matlab / Simulink platform can effectively interpret the torques as required for ECTS.

1. Introduction

In modern times, the ECTSs have changed dramatically since they are susceptible to many factors in the course of social development. The most typical model is no doubt the vehicles. Vehicle, as a representative of ECTSs, can operates smoothly only when its torque and power are fully provided as specified in accordance with relevant standards. Currently, with rapid development of vehicles, the powers, materials, technologies, etc., have been improved up to a new level, which forces us to reposition power support system and torque as required. In order to ensure smooth operation of new vehicles, it is required to know well and predict the parameters and the torque as required for ECTSs based on the modern technologies.
As for torque prediction method, this paper takes military, civilian vehicles as examples, the traditional requirements for any of which will be predicted based on the torque system flow rate.The following gives its analysis process in detail: First, a prediction model is established, and then based on the model application system flow rate, the future road topography, steering and road conditions are reasonably predicted, followed by the speed of the hybrid vehicle, so as to determine the limit point of the fuel tank. Usage state of battery is evaluated eventually to closely combine dynamic fuel and energy support.

2. Literature review

For the theoretical research of mechatronic transmission system, it started earlier abroad. In 1969, William GLivezey applied for the patent of vehicle dual mode mechatronic transmission. In 1971, the SAE technical report published the research on the design and testing of the electromechanical composite transmission system by Gelb and so on. Suntharalingam and so on proposed the definition of the dual mode electromechanical transmission system and analysed the characteristics of the specific electromechanical composite transmission system (Suntharalingam et al., 2014). Ahmadizadeh and other scholars carried out the system parameter comparison and characteristic analysis of the Toyota Corporation hybrid power vehicle LexusGS450h and Highlander. The single mode electromechanical transmission system of Toyota Corporation and the General Company dual mode scheme were compared and analysed, and the system power shunting characteristic under the two cases was clarified (Ahmadizadeh et al., 2017).
From the above, it can be known that, thanks to the good automotive technical basis, the research on the mechanical and electrical compound transmission system has been in depth, and has already had more mature products. However, the finished products are mainly concentrated on passenger cars. The research on electromechanical transmission system for heavy vehicles is rarely seen in the literature.

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Compared with foreign countries, the research on electromechanical composite transmission system in China is relatively late, and the vehicle type is relatively small. Su and others also proposed a coupling form of mechanical and electrical transmission system, which connected engines and motors through two planetary mechanisms (Su et al., 2018). By controlling the separation and combination of different clutches and brakes, the different driving modes of the vehicle are realized, but this structure is only in the phase of the program analysis, and there is no real product model.

In the study, Zhao and others pointed out that, in the hybrid bus SWB6116HEV introduced by the sham coach bus, the drive motor coupling with the drive shaft after the gearbox was coupled by a gear torque coupling device with a constant speed ratio, and then connected by the drive shaft, the rear axle, the half shaft and the wheel. The engine crankshaft was connected to the ISG rotor and connected through a clutch and gearbox. The original engine's flywheel was cancelled and replaced by the motor rotor. The battery supplied power to ISG and TM through the DC/AC inverter, and stored the power from two motors (Zhao et al., 2017).

In the military vehicle, Wang and so on, in the research, pointed out that the hybrid drive system should be really into the practical stage, and needed the breakthrough of relevant key technologies. In recent years, the development of high and new technology has made it a reality. It mainly includes the breakthrough of high power density electronic drive technology marked by high speed induction motor, permanent magnet synchronous motor, switched reluctance motor manufacturing technology and control technology, as well as the breakthrough of energy storage technology characterized by lithium-ion battery, nickel cadmium battery, electromagnetic power accumulator and super-capacitor technology. It also contains the breakthrough of the integrated control technology of the hybrid drive vehicle, represented by the motor control technology and the integrated control technology of the engine generator and motor group, as well as the power distribution and energy management technology and the breakthrough of the heat dissipation technology of the electronic components. These technological breakthroughs have contributed to the application of hybrid drives on armored equipment, such as the human ground combat vehicles in the US FGS, the Swedish SEP armored combat vehicle, and so on (Wang et al., 2016).

In the study, Huang and others pointed out that western developed country were actively carrying out the exploration, development and application of a variety of electric drive technologies, such as pure electric drive and electromechanical transmission, and so on. The United States, Britain, Germany, France and Sweden launched a variety of electric driving demonstration models. In 2001, the United States completed the research on 20t class electric drive demonstration vehicle based on M113. In the same year, the General Dynamic Corp ground system branch and the national motor vehicle center of the United States launched 8 * 8 advanced hybrid electric drive demonstration car AHED. The United States general power ground system company also launched a new hybrid electric car with the AM General Company, called the "AGMV (Advanced Ground Motor Vehicle)". Similar to the advanced hybrid electric train, the heavy and high maneuverable tactical truck of the United States military used a multi motor drive electrical drive structure (Huang et al., 2017).

In the study, Zhang and Shen pointed out that the German Longke Company has long been devoted to the development of new technology for electric transmission of military vehicles (Zhang and Shen, 2016). The German Longke Company has developed the EMT1100 mechatronic transmission device cooperated with the magnetic motor company. In order to meet the development requirements of the heavy tank electric drive system, the REX, which was introduced by German company in July 2006, was modified on the basis of HSWL106 transmission and integrated the advantages of both mechanical and electrical transmission. The device is installed between the internal combustion engine and the mechanical transmission, consisting of a planetary mechanism coupler and two disk type power generation / motors, and the system is planned to be used for 30t grade tracked vehicles.

In China, the research on hybrid driving of military vehicles started late. Zhuang and so on pointed out that in 1994, Beijing Institute of Technology began military vehicle electric transmission technology research and project demonstration work (Zhuang et al., 2016). In 1996, the Academy of Armored Forces Engineering and the Shanghai Institute of Electrical Science began to study the military electric transmission, and carried out the experiment of the principle of the 60kW digital military vehicle electric drive system. In 2001, the Hongqi seven 8011C transmission prototype developed by Xiangtan electric group of Hunan used the traditional DC motor drive system. During the period of "11th Five-Year", the Beijing Institute of Technology adopted a dual motor independent drive scheme to develop a prototype vehicle for the light tracked vehicle. During the "11th Five-Year" period, a prototype of light-duty electric drive tracked vehicle was developed and passed the 3000km reliability road test. Technical breakthroughs have been made in the integration of the system, the coordinated control of the independent drive of the bilateral motor, the integrated control of the engine generator set, the integrated networked control of the electric drive system and the energy management technology, and the integrated cooling of the electric drive system.

To sum up, the research work is mainly aimed at the research on the electromechanical composite transmission system and the main direction is the civil vehicle and the military vehicle, but the torque prediction method is not studied. Therefore, based on the above research, this paper focuses on the demand torque prediction method of electromechanical composite transmission system. The torque demand information of the electromechanical composite transmission system is regarded as a random time series, and a mathematical model is established by using the analysis and prediction method of time series to realize the on-line prediction of the future torque demand of the electromechanical composite transmission system. Based on the predicted demand torque information, the output power of the engine is controlled in the electromechanical composite transmission system, which can effectively improve the power overload of the battery.

3. Method

3.1 Analysis of ECTSs

The dual-mode ECTS proposed in this paper is mainly designed to satisfy the requirements of the high-power and the high-torque drive system for heavy vehicles, see Fig.1 for the system structure. This system consists of several parts such as motors A and B, three planetary units, clutches CL0 and CL1, brake B1, transmission input and output. Engine is connected with C1 at the input side via clutch CL0. Motor A is coupled to R2, and Motor B to S1, S2 and S3. C2 is connected to R1 and to C3 via CL1; R3 is connected to B1. C3 is used as the transmission output of the system. The rear axle is coupled via drive output terminal to transmit power to the wheels. C, R, S represent the planet carrier, ring gear and sun gear of appropriate planetary mechanisms, respectively.

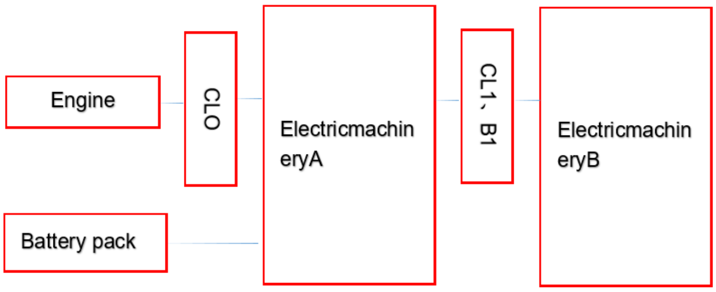

Figure 1: System structure

When the clutch CL0 is engaged, the two hybrid drive modes are enabled via the respective engagements of the clutch CL1 and the brake B1, as shown in Table 1.

Table 1: Dual mode system manipulation relationships

Pattern	CL0	CL1	B1
EVT1Pattern	joint	separate	joint
EVT2Pattern	joint	joint	separate

EVT1 mode: the brake B1 is engaged, and the clutch CL1 is released, the planet carrier of the planetary unit k2 is not connected with the output terminal. The gear ring of k1 joints the planet carrier of k2. Gear ring of k3 is braked. Three sun gears of k1, k2, k3 joint. EVT1 mode mainly is activated when the vehicle speed is low, the driving torque is highly required. EVT2 mode: The brake B1 is released, and the clutch CL1 is applied, the planet carrier of the planetary unit k2 is coupled with the output terminal. Gear ring of k3 rotates with the corresponding planet wheel. The EVT2 mode is activated only when the vehicle speed is higher and the driving torque is lower.

3.2 System modelling method

Currently, in the simulation method for actually applied vehicle, the simulation architecture can be divided into two types according to the different transmission paths of the control signals and the energy flows in the process, i.e. facing-backward and facing-forward architectures, as shown in Fig. 2.3. Commonly used modeling tools for facing-forward type include PSAT, HYZEM, Path, and those for facing-backward type come

ADVISOR and SIMPLEV, etc.

Figure 2: Backward simulation

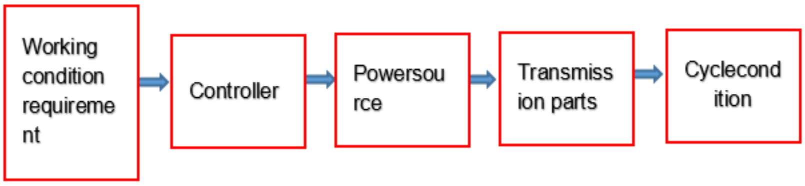

Figure 3: Forward simulation

The facing-backward simulation starts from the system for requirements. Assume the vehicle drives under the cycle conditions as specified, the speed and driving torque required for the vehicle are calculated. Then the reverse transmission computation along the direction opposite to the actual vehicle torque transmission route can be carried out. According to the pre-defined energy management strategy, the required power or torque is distributed between power sources. The facing-backward simulation operation is less, but simulation speed is faster. A significant disadvantage is that it can not be directly used for development and testing of vehicle control strategy. A driver model is introduced into the facing-forward simulation architecture. Acceleration or brake pedal opening is adjusted according to the deviation between the speeds required under the working conditions and calculated from simulation, which is then converted into the driving power or torque specified for the vehicle. The controller determines the power distribution according to the energy management strategy and dominates the working status of the relevant parts, and then transmits them directly to the appropriate parts in the form of control instruction so as to activate the control of the complete vehicle. Facing-forward simulation architecture uses the procedure similar to the actual drive process for processing various parameters of the parts, such as control signal generation and transmissions and delivery of its actually provided torque, speed and so on. Therefore, system control strategies can be efficiently developed and tested in this simulation architecture until the design requirements are met. This paper adopts facing-forward simulation to build the vehicle model for the dual-mode ECTS via Matlab.

3.3 Motor model

The motor performance test is conducted in order to characterize external propertyies and efficiency of the motor and its controller that the modeling procedure requires. Technical parameters for motor and its controller in the performance test are shown in Table 2. The curve of external properties and efficiency characteristics of motor measured by part performance test is obtained.

Table 2: Technical parameters of motor and controller

Electric machinery	Electric machinery A, B
form	Permanent magnet synchronous motor
Rated power	180kW
peak power	320kW
Maximum working speed	6000r/min
Rated working voltage	550V

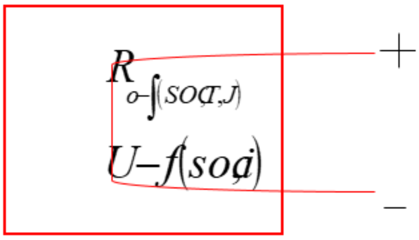

Figure 4: Internal resistance model

After that, the power battery model is established. The principle model gets more complicated since the battery charge-discharge process is vulnerable to many factors (such as temperature, current, etc.), manifesting strong nonlinearity and time-varying features. In the simulation of ECTSs, the common power battery model includes the internal resistance and resistance-capacitance types. The internal resistance model is relatively simple. It uses the series circuit composed of an ideal voltage source and an internal resistance as an equivalent circuit, as shown in Fig. 4.
Battery model also uses the experiment modeling. The power battery test is conducted aiming at battery capacity under different conditions, battery terminal voltage and battery internal resistance in order to characterize the working behaviors of the power battery, determine the reasonable working range, make clear the performance of the battery management system and provide available test data for future construction of the battery simulation model.

4. Results and analysis

The structure of dual-mode ECTSs is introduced concretely. The system performance is also analyzed on several fronts such as speed, torque and power. On this basis, the experimental model is taken, complemented by the theoretical model, to establish the facing-forward and -backward simulation models for ECTSs, including the motor, the power battery and the system model.
Based on the analysis of the change law in the efficiency of ECTSs, the integrated control strategy for the dual-mode ECTS is developed, which integrates the division of the system working mode, the regulation of the switchover rules, the distribution rules of the system power as required, and decision methods for quantitative control, etc. In the system EVT mode switchover control strategy, the switch point is determined by improving the overall efficiency of system. The system power distribution strategy concerns about what is the impact of system efficiency on vehicle performance, and how to optimize the engine control volume, and if necessary, adjust it. The simulation test is carried out under driving conditions of heavy vehicles, while the effectiveness of the integrated control strategy is validated, thus providing the basis for exploring system power distribution optimization and control strategies and real vehicle test in the latter words.

5. Conclusion

ECTSs can meet some special requirements of wide range of governor, large driving power and high power consumptions of auxiliary system and specific function system for heavy and non-road vehicles that differ from the general light vehicles. When the hybrid technology is applied on heavy and off-road vehicles, dual-mode ECT is a feasible solution since it enables a better overall performance. Under the support of the "National Project 973: Basic Study on a Type of Electromechanical Composite Transmission System for Vehicles", this topic includes a study made on the optimal control strategy of the dual-mode ECTS with specific works as follows:
Based on the structure optimization analysis of the dual-mode ECTS studied in this paper, the facing-forward simulation model was built on the Matlab / Simulink platform. The integrated control strategy was also developed for ECTS, integrating the division of the system working mode, the regulation of the switchover rules, the distribution rule of the power required for the system and the decision methods for the quantitative control of various power components. In the process of system EVT mode switch and power distribution, given that the system efficiency has an impact on the performance of the vehicle, the quantitative control of the engine gets an optimal adjustment. A simulation has been carried out under the driving conditions of heavy vehicles to test the engine control effect.
On this basis, in order to improve the performance of ECTS with the optimal control strategy, we can further explore the following subjects: first, the integrated controller is developed based on FPGA and embedded system to make sure the real-time optimization control strategy can be better applied in practical system.

Secondly, the modern intelligence transportation technology is integrated with time series analysis to achieve online long-term scale prediction on the required torque for ECTS. Thirdly, the nonlinear control theory is applied to solve the optimal control of the power distribution in the ECTS, further improving the control effect. Fourthly, based on the rapid development of vehicles, this paper only focuses on current vehicles and does not attempt to make a prospective study in a long run. Theoretically, the forward-looking study can improve the practical value of this paper and more deeply strengthen the quality of vehicle operation and production. Worse, therefore, is that this point has not yet been involved.

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