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Smoothness Simulation of Mild Hybrid Vehicle with Automatic Mechanical Transmission

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Abstract

Aiming at the market shares of automatic mechanical transmission, the driving smoothness was studied. Based on the dynamical model of automatic mechanical transmission, the numerical model of automatic mechanical transmission had been established and a shifting strategy was analyzed. The result shows that the impact of automatic mechanical transmission on the condition of shifting fast can meet the national legislation.

***Keywords**: automatic mechanical transmission; dynamical model; shifting strategy; smoothness*

1. Introduction

The automatic mechanical transmission (AMT) is a new automatic transmission improved from traditional manual stepped transmission. As AMT retains the dry clutch and most of power assemblies of gearing system, it is characterized by simple structure and high transmission efficiency [1-2]. For the moment, the efficiency of hydraulic automatic transmission is relatively low; the continuously variable transmission (CVT) is subject to limited driving torque; and double-clutch transmission is not yet fully mature and only mastered by leading automobile enterprises. Therefore, the study on AMT system combined with engineering can make Chinese vehicle command market shares of transmission, which has broad prospects for development.

There are a lot of studies on the traditional AMT system at home and abroad: Germany BENZ company used the automatic shifting program, and selected the transmission shifts according to the degree of ridering the accelerator pedal, and achieved shifting through the control of engine speed and engagment speed of clutch [3]; Korean Han-Sang Jo [4] raised the control strategy of combing the engine and induction motor for the AMT shift process of hybrid electric vehicle (HEV); Qin Datong [5] from Chongqing University carried out detailed studies on the hybrid power transmission system with AMT, and put forward different coordinated shift control logics in the context of the disengagement and engagement of clutch

To further strengthen the coordination of engine, clutch and transmission in the drive system of hybrid electric vehicle (HEV), this paper, starting fom formulating shifting strategy, analyzes influencing factors during the shifting of AMT, so as to ultimately achieve the purpose of optimizing the shifting smoothness. The work contains two major parts, namely, the clutch engagement and the formulation of shifting strategy in the process of shifting.

2. AMT Shifting Dynamics Analysis

In this paper, a car model of Chang'an Automobile Company is taken as an object for analysis. As shown in Figure 1, the drive system of this car consists of the internal

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combustion engine, integrated starter generator (ISG), automatic mechanical transmission, synchronizer, transmission shaft and other major components; the engine is integrated with ISG motor, which is in favor of the arragnement of the whole system. The object of the study in this paper, namely, the connection of AMT with the motor output shaft, is in favor of directly outputing the power of motor to achieve the purpose of driving wheels. Thereinto, the dynamics analysis on the shifting procedure of AMT will be made in this section.

The AMT shift will inevitably generate power interruption, and the entire cycle consists of three main phases: ① start time of shift; ② gear-selection and gear-shifting phase ; ③ completion time of shift. In order to facilitate the study, a simplified vehicle shift schematic diagram is established, as shown in Figure 1:

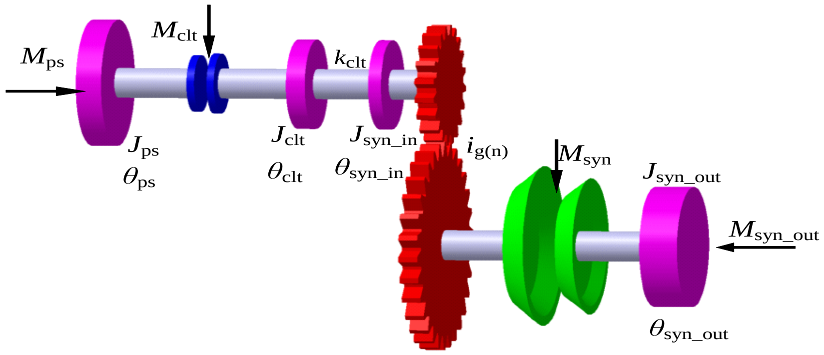

Figure 1. Schematic Diagram of Traditional System Mechanism

Where, M_{ps} is the power source output torque (N·m); J_{ps} is the equivalent rotational inertia of motor (kg·m^{2}); θ_{ps} and θ_{clt} are the angular displacements of driving disc and driven disc of clutch respectively (rad); M_{clt} is the torque transmitted by clutch (N·m); J_{clt} is the equivalent rotational inertia of driven disc of clutch (kg·m^2); k_{clt} is the equivalent torsional rigidity of input terminal (N·m/rad); J_{syn_in} and J_{syn_out} are the equivalent rotational inertia of driving terminal and driven terminal of synchronizer (kg•m2); $i_{g(n)}$ is the transmission ratio; M_{syn} is the synchronizing torque of synchronizer (N•m); θ_{syn_in} and θ_{syn_out} are the angular displacements of the input terminal and output terminal of synchronizer (rad); and M_{syn_out} is the force torque of synchronizer (N•m).

According to Figure 1, the shift process of AMT can be divided into three phases:

① Start time of shift

At this time, the vehicle is in a stable running state, where the engine is rigidly connected with the drive system, and the clutch normally transmits the operation torque. The equation of system dynamics meets:

$$\begin{cases} (J_{ps}+J_{clt})\ddot{\theta}_{ps}=M_{ps}-k_{clt}(\theta_{ps}-\theta_{clt}) \\ (\dfrac{J_{syn\_out}}{i_{g(n)}^{2}}+J_{syn\_in})\ddot{\theta}_{clt}=k_{clt}(\theta_{ps}-\theta_{clt})-\dfrac{M_{syn\_out}}{i_{g(n)}} \end{cases} \quad (1)$$

②Gear-selection and gear-shifting phase

Car drivers will shift gears according to the car speed, acceleration, gear signal and road conditions at certain times. The control phase of clutch engagement can be broken don into the following three processes: the complete engagement, slipping friction and complete disengagement of clutch. Similarly, during the process of shifting to new gears, the clutch corresponds to these three phases, and is just in reverse order with the process of disengaging the clutch. The dynamic equations of these processes will be described in detail in the AMT shift strategy section.

③ Completion time of shift

After the rotate speed of driving and driven part of the clutch are in accord, the completion of AMT shift process is the time that the transmission system is in the new gear when the torque transmitted by the clutch reaches a maximum.

In this case, the dynamic equation of transmission system meets:

$$\begin{cases} (J_{\mathrm{ps}} + J_{\mathrm{clt}})\ddot{\theta}_{\mathrm{ps}} = M_{\mathrm{ps}} - k_{\mathrm{clt}}(\theta_{\mathrm{ps}} - \theta_{\mathrm{clt}}) \\ (\dfrac{J_{\mathrm{syn\_out}}}{i_{\mathrm{g(n+1)}}^{2}} + J_{\mathrm{syn\_in}})\ddot{\theta}_{\mathrm{clt}} = k_{\mathrm{clt}}(\theta_{\mathrm{ps}} - \theta_{\mathrm{clt}}) - \dfrac{M_{\mathrm{syn\_out}}}{i_{\mathrm{g(n+1)}}} \end{cases} \tag{2}$$

3. Modeling Of Engine

Studies have shon that the output characteristics of engine in unstable conditions are different from that in stable conditions [6]. Consindering that the engine mostly works in unstable conditions, the correction factors need to be used to simulate the dynamic torque of engine:

$$T_{\mathrm{ed}} = T_{\mathrm{e}}(1 - \gamma \frac{d\omega_{\mathrm{e}}}{dt}) = T_{\mathrm{e}}(1 - \gamma\varepsilon_{\mathrm{e}}) \tag{3}$$

Where γ is the coefficient of variation of torque, and this paper takes 0.08; ε_e is the acceleration of crankshaft angular. The simulation model of engine is estalbished in MATLAB software, as shon in Figure 2:

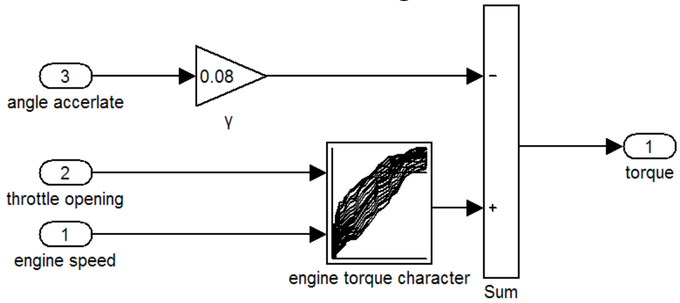

Figure 2 Engine Model

4 AMT Shift Control Strategy

The AMT shift process must give consideration to dynamic property and comfort. The dynamic property mainly refers to the reduction of power consumption as much as possible in the shift process; the comfirt is the main indicator of ride performance, requiring no discomfortable feeling produced from passengers[8].

4.1 Amt Shift Schedule

The shift schedule refers to the man-made rules that the shifting time follows the changes in control parameters between two gears. Currently, the single parameter, two and three-parameter shift schedule is more common.

Taking account into the university and practicality of combined two-parameter shift schedule, this paper develops control strategies with the vehicle speed and the opening of accelerator pedal as the control parameters, as shown in Figure 3. As can be seen from Figure 3, the combined two-parameter shift schedule includes several change rules adapting to vehicle performance: the smoothness and steadiness is the target in the case of small opening; both the economics and power are required in the case of moderate opening; and the dynamic output is the primary in the case of large opening.

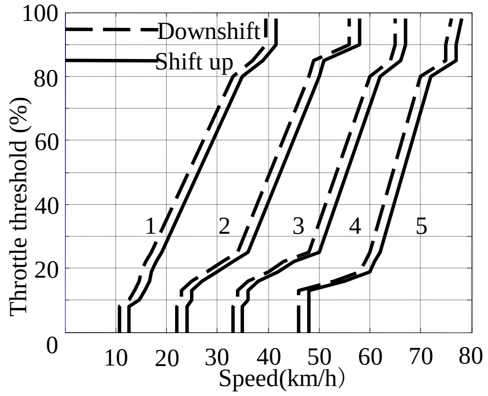

Figure 3 Two-Parameter Shift Schedule

4.2 AMT Shift Process Control

The core of AMT shift control lies in the control of clutch. In this section, with the stage of the clutch shifting to the gear from the neutral position as the research object, its dynamics analysis and control strategies are developed.

After the synchronizing process of the synchronizer, the clutch is ready for engagement after complete disengagement. To ensure the shorter shift period of AMT, the clutch at this phase should engage rapidly. At this point, there is:

$$\begin{cases} J_{\mathrm{ps}}\ddot{\theta}_{\mathrm{ps}} = M_{\mathrm{ps}} \\ \left(\dfrac{J_{\mathrm{syn\_out}}}{i_{\mathrm{g(n+1)}}^{2}} + J_{\mathrm{syn\_in}}\right)\ddot{\theta}_{\mathrm{clt}} = -\dfrac{M_{\mathrm{syn\_out}}}{i_{\mathrm{g(n+1)}}} \end{cases} \quad (6)$$

At the clutch sliding phase, the torque transmitted by the clutch becomes larger with the increase in the stroke, and the system reduces the speed difference between the driving and driven part through their sliding and friction. To take into account both the temperature of the system and the ride comfort, this phase should take the smoothness of shift as the main target, and control the slow engagement of clutch. The dynamics equation is:

$$\begin{cases} J_{\mathrm{ps}}\ddot{\theta}_{\mathrm{ps}} = M_{\mathrm{ps}} - M_{\mathrm{clt}} \\ J_{\mathrm{clt}}\ddot{\theta}_{\mathrm{clt}} = M_{\mathrm{clt}} \\ \left(\dfrac{J_{\mathrm{syn\_out}}}{i_{\mathrm{g(n+1)}}^{2}} + J_{\mathrm{syn\_in}}\right)\ddot{\theta}_{\mathrm{clt}} = -\dfrac{M_{\mathrm{syn\_out}}}{i_{\mathrm{g(n+1)}}} \end{cases} \quad (7)$$

When the clutch fully engages, the transmission torque reaches the ceiling and will not increase. At this point, there is:

$$\begin{cases} (J_{\mathrm{ps}} + J_{\mathrm{clt}})\ddot{\theta}_{\mathrm{ps}} = M_{\mathrm{ps}} - k_{\mathrm{clt}}(\theta_{\mathrm{ps}} - \theta_{\mathrm{clt}}) \\ \left(\dfrac{J_{\mathrm{syn\_out}}}{i_{\mathrm{g(n+1)}}^{2}} + J_{\mathrm{syn\_in}}\right)\ddot{\theta}_{\mathrm{clt}} = k_{\mathrm{clt}}(\theta_{\mathrm{ps}} - \theta_{\mathrm{clt}}) - \dfrac{M_{\mathrm{syn\_out}}}{i_{\mathrm{g(n+1)}}} \end{cases} \quad (8)$$

Therein, the whole engagement process completely follows the “fast-low-fast” law, and reasonably gives consideration to both the smoothness and work of slipping on the basis of ensuring the shifting time to meet the subjective feelings of drivers.

5. Simulation Results

In order to make an quantitative and qualitative analysis on the shift process, this paper establishes a transmission system shift model for AMT vehicles with the MATLAB software, and simulates the gear-up shift process of transmission system (the second gear to the third gear, for example) by embedding the control strategy and combining the complete vehicle parameters (see Table 1).

Table 1. The Complete Vehicle Simulation Model Parameter Table

Name		Parameter Values
Complete vehicle shipping mass (kg)		1800
Coefficient of air resistance C_D		0.32
Windward area of vehicle A （m^2）		2.87
Engine	Output volume (ml)	1590
	Rated power (kW/rpm)	75 / 6000
	Maximum torque (N·m/rpm)	132 / 3500
Total rotational inertia of engine and ISG motor ($kg \cdot m^2$)		0.125
Transmission ratio i_g	The first gear	3.577
	The second gear	2.022
	The third gear	1.348
	The fourth gear	0.977
	The fifth gear	0.787
Transmission ratio of main reducing gear		3.947
Radius of the tire (m)		0.31

If we set the initial speed as 40km/h and the accelerator pedal as 25%, Figure 4 is the system simulation result. The central processor issues a shift command in reponse to the intention of the driver. Figure 4 shows that from 0s to 0.88s, the system is in the state of disengagement of clutch, and the rotating speed of the central driving and driven part becomes the same (280rad/s), different and the same again (193rad/s) in sequence; at the time of different rotting speed, the driving and driven part synchronize through sliding and friction, and generate a total work of friction of 134J combined with the next engagement of clutch; during the interval between 0.3s and 0.7s, the clutch engages rapidly, and its stroke moves quickly to 100% state from its initial position; after shifting to the netural position, the synchronizer makes the driving and driven part become synchronous, and at this moment, the clutch returns quickly after 1.1s until back to its original position. In the entire shift process, it's totally 1.39s from the issuing of the shift command to the power restoration, which is in line with the state's setting for the shift time of semi-automatic transmission, and the maximum impact of the entire process is $10.7m/s^3$, showing that the control strategy put forward in this paper can meet the operational requirements of drivers.

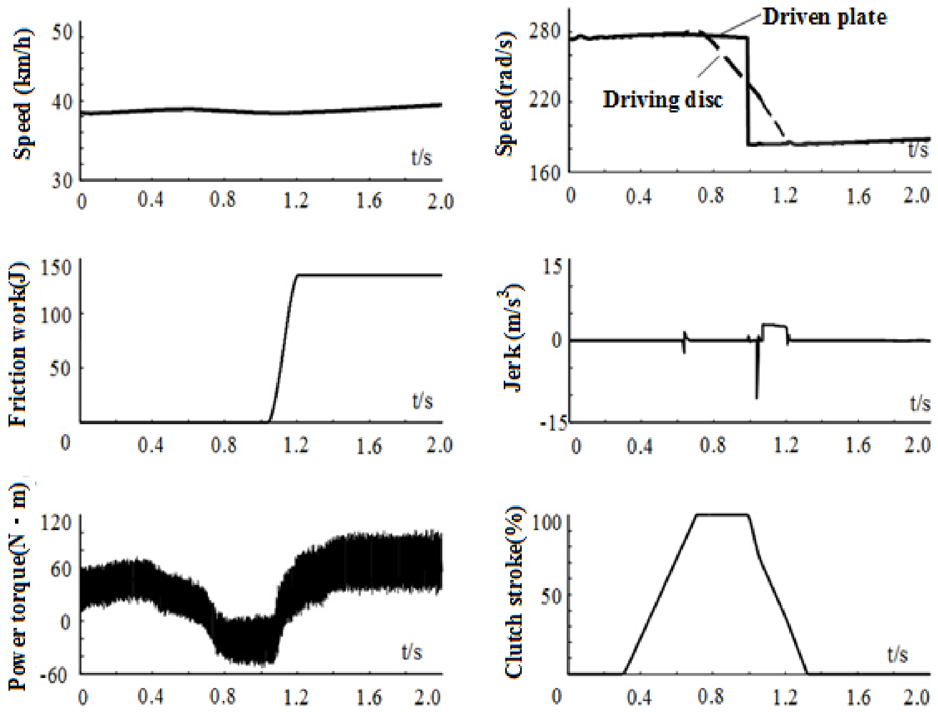

Figure 4. Shift Performance Parameter Simulation Result Diagram

6. Conclusions

1) The key of clutch part lies in the control of the clutch engagement speed and moment, which directly affects the subjective feeling of drivers. The "fast-slow-fast" control strategy developed in this paper can fully meet the drivers' rapid shift intention, and the impact of the entire shift process is not more than $11m/s^3$;

2) The control of engine speed aims at assisting and adjusting the speed difference between the driving and driven disc of the clutch, so that the clutch can rapidly reach the synchronization after the completion of its slidng and friction; the control strategy in this paper takes into account both the work of friction and shift time, and the final simulated work of friction does not exceed 140J, which confirms once again the reasonability and effectivity of the control strategy.

References

[1] L. Zhenjun, L. Fei and H. Hongwei, "Three-dimensional Modeling and Simulation of Dual-clutch Automatic Transmission [J]", Mechanical Transmission, vol. 34, **(2010)**, pp. 26-30.
[2] Z. Zhisen, "Gear-selection and Gear-shifting Process Control of Automatic Mechanical Transmission (AMT) System [J]", Mechanical Transmission, vol. 38, **(2014)**, pp. 52-54.
[3] H. Ohinishi, J. Ishii and M. Kayano, "A study on road slope estimation for automatic transmission control [J]", JSAE Review, no. 21, **(2000)**, pp. 235-240.
[4] R.C. Baraszu and S.R. Cikanek, "Torque fill-in for an automatic shift manual transmission in a parallel hybrid electric vehicle [C]", Proceedings of the American Control Conference, **(2002)**, pp. 1431-1436.
[5] C. Shujiang, Q. Datong and H. Minghui, "AMT Comprehensive Shift Strategy of Blade Electric Vehicles (BEV) with both Dynamic Property and economics [J]", China Mechanical Engineering, vol. 19, **(2014)**, pp. 2087-2092.
[6] X. He and J. Hodgson, "Hybrid electric vehicle simulation and evaluation for UT-HEV [N]", SAE. Paper, 2000-01-3105, pp. 459-473.
[7] G. Ziqiang, "Overview of the Development of Lithium Ion Batteries for Foreign Electric Vehicles [J]", Battery Industry, vol. 6, no. 5, **(2001)**, pp. 227-232.

[8] G. Shuli, G. Anlin and Z. Tai, "Shift Process Control of Electronically Controlled Automatic Mechanical Transmission [J]", Journal of Agricultural Machinery, vol. 34, no. 2, **(2003)**, pp. 1-3.

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