

Analysis of a Shift Quality Metric for a Dual Clutch Transmission

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ABSTRACT

This paper defines the shifting quality evaluation index in detail for DCT (Dual Clutch Transmission) from the perspective of control. The vehicle model for DCT is built using MATLAB / Simulink tools, including the models of driver, load, controller, engine, clutch, transmission (synchronizer), actuators, and vehicle dynamics model. And then a control quality evaluation system is designed. The AHP (Analytic Hierarchy Process) is used to determine weights of the control quality evaluation index and the shifting quality control objectives through the co-simulation of vehicle system model and evaluation system, namely expected control range of each evaluation index, which provides reference and guidance for shifting control strategy and control algorithm of DCT. During the process of shifting control, we apply the strategy of fuzzy control and select the highest shifting quality rating scale as the objective function to optimize clutch engagement speed and engine throttle which influences the shifting quality. Then the optimal solution of fuzzy control rules is obtained. Based on the model of vehicle and the simulation platform of evaluation system about DCT, the simulation result about shifting quality before and after the optimization is observed. Simulation results show that the shifting quality of the vehicle is significantly improved after the optimization of shifting fuzzy control rules.

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INTRODUCTION

At present, there are no clear criteria to judge the quality of shift quality and shift control effect about DCT (automatic mechanical transmission). Nationally and internationally, it is usually uses the subjective evaluation method, that is, based on the shock of degree, work of slipping which is produced by transmission system to assessment the shift quality roughly. Research personnel make the vehicle shift quality achieve their think of good level through a lot of online calibration, but sometimes it has to modify control strategy when the calibration cannot be solved, its workload can be imagined. Investigate its reason is that the shift control target is not yet concrete for the automatic transmission at present. How to let the evaluation index specific and to make the control goal clearly is the primary key problems that the researchers need to solve.

After having the control objectives, the second key problems that placed in front of researchers is how to optimization the control strategy and algorithm for shift quality. The DCT shifted quality need to meet multi-

evaluation index, but multi-index can't achieve at the same time. The optimization about one index, may at the price of worsening another index. The multi-evaluation index needed to make overall plans and take all factors into consideration, balance weight, compromise consideration in the control. Therefore, it's a key and difficult problem to aim at the study of optimization scheme and optimization method for the DCT shift control.

This paper took the research on shift quality evaluation and optimization of a DCT prototype, on the one hand, the control target and control method were determined for DCT system shift control through the evaluation, and provided guidance and reference for objective evaluation and calibration; On the other hand, it is optimized the control strategy and control algorithm of DCT system which based on determinate control target, and then used it to improve the quality of shift.

THE SUBDIVISION DEFINITION OF SHIFT QUALITY EVALUATION INDEX

Shift quality means that under the premise of guaranteeing the vehicle dynamic performance and the lifetime of power transmission system, shifted quickly and smoothly and meet comfort requirements. In the process of shifting vehicles, the engine speed will generate large fluctuations, flutter, flame out and destroy the smooth of shifting if the clutch engaging too fast; To the contrary, if the clutch engaging too slow, the slipping work will increase quickly and reducing the clutch service life, and then the shift time will be longer, it cannot satisfy the promptness of shift. Thus, this paper defines the following evaluation indexes from the perspective of control as shown in [table 1](#) and [figure 1](#).

Table 1. Shift quality evaluation indexes

Evaluation indexes	Units
Peak acceleration(a_p)	m/s ²
Positive maximum jerk(j_{p-p})	m/s ³
Negative maximum jerk(j_{p-n})	m/s ³
Engine speed fluctuation($\Delta\omega_e$)	rpm
Minimum speed engine (ω_{e-min})	rpm
Shift time(t_L)	s

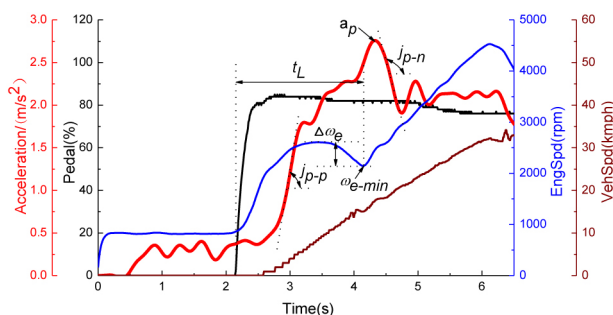


Fig.1. Shift quality evaluation index illustrations

THE MODEL AND EVALUATION SYSTEM DESIGN

The Overall Design of Simulation Model

The vehicle system simulation model is built using MATLAB / Simulink tools, including the models of driver, load, controller, engine, clutch, transmission (synchronizer), actuators, and vehicle dynamics model. The overall design of simulation model as shown in [figure 2](#), the main functions and data flow of the vehicle system model state below:

- 1). The engine model is according to the input of throttle valve adjust variable $\Delta\alpha$ and engine speed ω_e to calculate the engine output torque T_e ;
- 2). The clutch and its actuators device model are according to the input of engine output torque T_e , resistance torque T_l , the speed difference between clutch disc and engine speed $d\omega_c$ and the clutch speed v_c that given by controller to calculate the clutch delivered torque;
- 3). The transmission(synchronizer) model is according to the target gear of controller to calculate the synchronous torque T_s , synchronization time t_s and transmission ratio i_g ;
- 4). The load model is according to the input signals of T_{out} , u_a to calculate the T_l ;
- 5). The vehicle dynamics model is according to the input T_e , T_c , T_l to calculate these parameters that including T_{out} , u_a longitudinal acceleration a and clutch disc speed ω_c etc.;
- 6). The controller model is according to the given vehicle operation parameters v_c and $\Delta\alpha$ to control the clutch and engine;
- 7). The driver model can give the handle position signal L_{pos} , accelerator position signal Acc_p , braking switch signals B_{on} and driving mode (sports/economy) that reflect the driver intentions,;

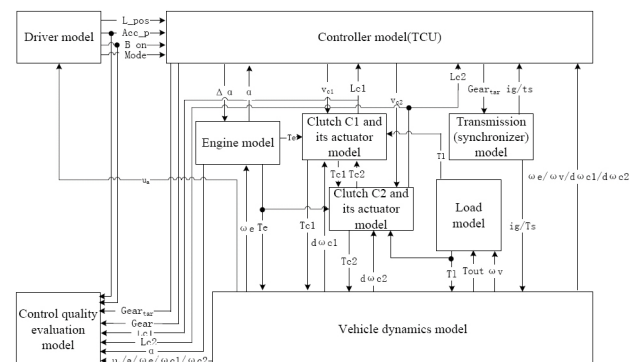


Fig.2. The overall design of simulation model

The Control Quality Evaluation System Design

The overall design of simulation model integrated control quality evaluation model and used the input Acc_p , B_{on} , L_{c1} , L_{c2} , $Gear$, u_a , a , ω_e , ω_c to control the extraction of quality evaluation index and calculate the evaluation rating.

The control quality evaluation system can not only extract evaluation index under all kinds of driving condition by the input data and signals, but also gives corresponding objective evaluation results according to the extraction of evaluation index. A 1-10 level was given as the standard of objective evaluation. The calculation steps for objective evaluation results of the evaluation system as shown in Figure 3. Because of the difference between each evaluation index dimension, it is need to dispose normalized before calculating the result of evaluation rating, the evaluation indexes will be 0-1 value after normalized. And then, the objective evaluation rating result can be calculated which based on the different weights allocation and the results are still in 0-1 range. Finally, the control quality objective evaluation results (1-10) that under the corresponding condition can be obtained through the normalized processing.

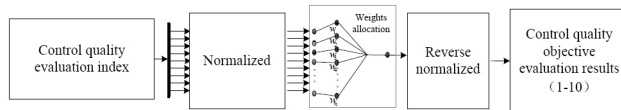


Fig.3. The calculation steps for objective evaluation results

The Evaluation Index Weights Allocation that Based on the Method of AHP (Analytic Hierarchy Process)

In the problems of evaluation indexes weights allocation, the weight is different because of the emphasis that valuator attention is different. Therefore, this paper applies AHP to confirm each single index weight of the evaluation system and sets up the AHP structure model and judgment matrix.

With big throttle shift as an example, the judgment matrix was constructed, the weight was obtained from the calculation and the consistency ratio CR was calculated, and then the consistency was checkout, as shown in table 2.

It can be seen from the shift quality evaluation index weights that calculated in the table 2, the weights about t_L , a_p , $\Delta\omega_e$ are greater with big throttle shift and weights about j_{p-p} , j_{p-n} are smaller which indicated that at this time drivers are more attention of the power and ignore shift comfort. Therefore, it is consistent with the reality by the AHP to determinate each index weight, which validated the correctness of evaluation index weights allocation algorithm and provides theory basis for the next step to determine the weight coefficient of optimal objective function.

Table 2. The each index judgment matrix and weight of shift quality (big throttle shift)

Index	a_p	j_{p-p}	j_{p-n}	$\Delta\omega_e$	$\omega_{e-\min}$	t_L
a_p	1	4	4	4	3	1/2
j_{p-p}	1/4	1	1	1/3	1/3	1/5
j_{p-n}	1/4	1	1	1/3	1/3	1/5
$\Delta\omega_e$	1/4	3	3	1	1/2	1/3
$\omega_{e-\min}$	1/3	3	3	2	1	1/2
t_L	2	5	5	3	2	1
weight	0.29	0.05	0.05	0.11	0.16	0.37
Consistency check	$CR = 0.0422 < 0.1$					

The Control Objectives Given by Evaluation

Table 3. The control expectations interval of the shift quality evaluation indexes

Shifting mode	a_p	j_{p-p}	j_{p-n}	$\Delta\omega_e$	$\omega_{e-\min}$	t_L
	m/s ²	m/s ³	m/s ³	rpm	rpm	s
Light throttle	1~3	3~5	-5~-3	0~300	>700	1.5~2.5
Medium throttle	2~5	4~8	-8~-4	200~500	>900	0.8~2
Big throttle	3~6	6~10	-10~-6	300~600	>1000	0.5~1

The simulation platform which based on the vehicle system model and evaluation system integration reaches the evaluation index of control expected interval when shift quality evaluation achieved optimal through the evaluation, such as shown in table 3. The results are given in the table is the optimal control targets of DCT system shift quality and ensuring each index fell on within the control expectations