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Online performance evaluation of a heavy-duty automatic transmission launching process

Gang Tao[a], Meng Wu[a], Fei Meng[b,*]

[a] School of Mechanical Engineering, Beijing Institute of Technology, Beijing, China
[b] Merchant Marine College, Shanghai Maritime University, Shanghai, China

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ABSTRACT

To improve the repeatability of control effectiveness of automatic transmission launching process, the method of online evaluation of a heavy-duty automatic transmission launching process is studied, which deals with not only the evaluation of launching quality, but also the refining direction of control parameters when launching quality is not well enough. First, automatic transmission launching process and its key control parameters are anatomized. Second, overall evaluation and phase evaluation indices are proposed in light of launching quality and ideal control process respectively. Third, evaluation model based on BPNN (Error Back Propagation Neural Network) is built and trained using Matlab neural network toolbox. The trained evaluation model is then ported to MCU (Micro Controller Unit) to implement online evaluation. Finally, vehicle tests are carried out. The results indicate that the developed online evaluation method of automatic transmission launching process has a high accuracy and successfully substitutes mechanical evaluation for manual evaluation.

1. Introduction

As is widely used in heavy-duty and military vehicles, automatic transmission (AT) has its advantages of steady launching process, continuous power shifting and self-adjustments to driving resistance [1]. Researches have been done to refine the controlling of AT shifting process, which has great impacts on the performances of AT. The shifting process of AT is usually one clutch engaging and another one disengaging [2]. During this process, various parameters such as engine speed, oil temperature, abrasion, manufacturing errors could have significant influence on the controlling of actuators [3,4]. Thus, accurate and robust controlling strategies are needed to improve the repeatability and stability of AT shifting control effectiveness [5,6].

The controlling of AT shifting process is divided into four major phases: oil filling, torque alternating, rotation rate synchronizing and clutch engaging. Several controlling strategies have been developed based on different parameters in the shifting process. Based on rotation speed, Zeng, Srinivasan and Rizzoni from Ohio State University have set the referential target track for turbine rotation speed in the advantage of linearizing the transmission model. During the launching process, tracking control is implemented with PID towards the referential target track and the tracking performance is verified through simulation tests [7]. Gao, Chen and Sanada have set the referential target track for the variation of clutch slip and traced the referential target track by two-degree-of-freedom control method [8]. They have proposed a timing control strategy for clutches to be engaged and disengaged. The premise of this strategy is the acquisition of accurate value of clutch pressure and torque from the drive shaft [9].

The estimated turbine torque value is used for controlling the shifting process. In [10], a turbine torque estimation method based on neural network is proposed. In [11], the authors combined two estimation methods together to estimate the turbine torque value. Depending on the torque value of the output shaft, turbine torque is estimated through characteristic curve of hydraulic torque converter and engine respectively. Based on the coordination control strategy of engine and transmission, Sarawoot Watechagit [12] proposed to control the engine during the torque phase to eliminate the torque hole generated in the transition from torque phase to inertia phase. Song have proposed to control the engine torque and clutch torque simultaneously. The referential target track of turbine rotational speed and transmission output torque is well traced through sliding wear control and the overall control of engine together with transmission is actualized [13]. Despite different control parameters, tracking control strategy is widely used in the controlling of vehicle shifting process [5,14]. In order to deal deal with non-linear parameters and uncertainties in the powertrain, sliding

* Corresponding author. Tel.: +86 21 38283367.
E-mail address: feimeng@shmtu.edu.cn (F. Meng).

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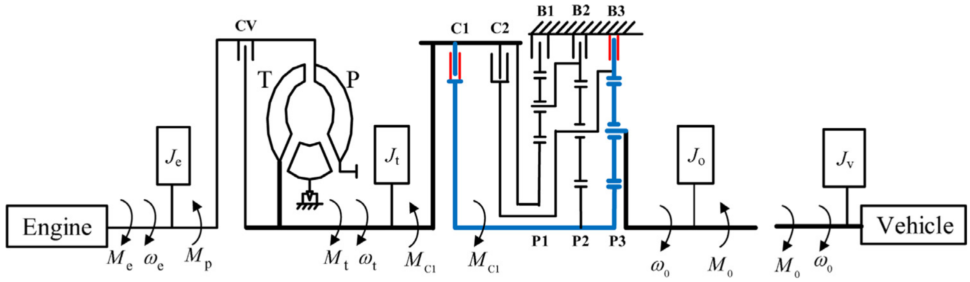

Fig. 1. Dynamic model of the first gear launching process.

mode control and two-degree-of-freedom control are also well attended [15].

With the development of controlling strategies, various evaluation and methods of shifting process have also been studied. The evaluation that are widely used typically are jerk, work of slipping and time for shifting. The evaluation methods of AT shifting quality have been basically divided into subjective evaluation method [16,17], objective evaluation method and pseudo subjective evaluation method [18,19]. Because of the coupling between evaluation of shifting quality and the strong non-linear characteristics of subjective evaluation which are hardly described by mathematical functions, researchers have focused on evaluation strategies based on BP neural network recently. In [20], the authors have proposed to establish the relationship between the subjective and the objective evaluations. Based on optimized back-propagation neural network, Lei et al. [21] have established an objective evaluation model for mode switching and shift quality. The authors in [22–24] indicate that the proposed objective evaluation methods are in good agreement with the traditional subjective evaluation method and can evaluate the vehicle gear shift quality properly.

The evaluation strategies proposed in literatures above are all off-line evaluations which only verify the feasibility of substituting subjective evaluation with objective evaluation using BPNN. The evaluation strategy proposed in this paper aims to revise the control parameters online with BPNN model, which is further described in the following text. Also, compared to the literatures, the output of the proposed BPNN are the revising directions of control parameters instead of only evaluation results of shifting quality.

As a special case of AT shifting process, AT launching process has usually only one clutch needs to be controlled. However, inappropriate control can still easily trigger negative impact during this process because of the transmission gap and the absence of engine coordination control. The control parameters of shifting process, such as oil feeding duration, are usually obtained through calibration under certain experimental conditions. While in actual control process, various factors such as engine speed, oil temperature, abrasion and manufacturing errors could have significant influence on the control effectiveness. The unchangeable control parameters are incapable of guaranteeing the repeatability of control effectiveness [25,26]. Thus, an online evaluation and revision method for AT launching process is carried out in this paper. Compared to traditional off-line shift quality evaluation, including subjective evaluation method and objective evaluation method, the new online evaluation method not only evaluates the launching process quality, but also determines the revising direction of control parameters through evaluation model based on BPNN in order to get better quality in the next launching process when poor quality occurs. The revising direction of control parameters indicates which control parameter is to revise and whether it shall be increased or decreased in the next launching process. The BPNN established in this paper is taken as classifier for determining the revising direction of control parameters. The input of BPNN are the evaluation indices and the output of the BPNN are the revising directions of control parameters instead of only evaluation results of shifting quality, which is specifically described in literatures [21–24]. The proposed online evaluation method can also be applied to shifting processes with only evaluation to refine.

In this paper, the dynamic model of launching process is established in the first step as theoretical basis for the designing of ideal control target of launching process and the determination of key control parameters and evaluation. Second, the key control parameters of launching process are determined and analyzed. Third, based on launching quality and the ideal control of launching process, the overall and phase evaluation are proposed respectively. The evaluation model based on BPNN is established and trained in the next step to implement real online evaluation. Finally, on vehicle experiment is carried out and the experiment result is analyzed.

2. Launching process analysis

Dynamic model of launching process is shown in Fig. 1. Take the first gear launching process for example. Before this process, clutch B3 has been fully engaged. The launching process is the engaging of clutch C1.

In Fig. 1, ω_e, ω_t, ω_0 refer to angular velocities of engine, turbine and output shaft respectively; M_e, M_p, M_t, M_0, M_{C1} are the torques of engine, pump, turbine, output shaft and clutch C1; J_e, J_t, J_0, J_V are rotary inertia of engine pump, turbine active parts of the clutch, output shaft and vehicle. The dynamic equations of this launching process is established as follow. First, the torque formulation of the turbine, the input shaft and the active parts of clutch C1 can be obtained by

$$J_t\dot{\omega}_t = M_t - M_{c1} \tag{1}$$

Second, the torque formulation of the driven parts of clutch C1, the planetary P3 and the output shaft can be obtained by

$$M_0 = M_{c1} \cdot i_1 \tag{2}$$

where i_1 refers to transmission ratio of the first gear.

The shift jerk is defined as the change rate of the vehicle longitudinal acceleration. It is an important objective evaluation index of launching quality. Assuming that load is constant.

$$j = \frac{da}{dt} = \frac{d^2u_a}{dt^2} = \frac{r_d}{i_0 \cdot J_V} \cdot \frac{dM_0}{dt} \tag{3}$$

where j is the shift jerk, m/s^3; a represents the vehicle longitudinal acceleration, m/s^2; u_a is the vehicle longitudinal velocity, m/s; r_d represents the driving wheel radius, m; i_0 is the ratio from output shaft to driving wheel.

According to the formulas above, the shift shock of the launching process is

$$j = \frac{r_d \cdot i_1}{i_0 \cdot J_V} \cdot \left(\frac{dM_t}{dt} - \frac{d\dot{\omega}_t \cdot J_t}{dt} \right) \tag{4}$$