A Shifting Strategy That Reduces the Number of Shifts for Urban Conditions

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Abstract. Nowadays, urban conditions have become the main operating conditions for vehicles. Urban traffic congestion leads to a higher rate of vehicle idle speed and frequent shifts. This paper proposes a new shifting strategy in order to effectively improve the problem of frequent shifting, which is called flexible shift. In view of the fact that the electric vehicle cancels the clutch, shifting is completed directly by the control of the motor during the shifting process. Reducing the number of shifts can effectively reduce wear and increase the life of the transmission, which can be realized by the flexible shift. This paper uses MATLAB to simulate the shifting times of this shift strategy under FTP conditions. The simulation results show that electric vehicles with flexible shifting control strategy can significantly reduce the number of shifts, improve comfort, reduce hardware loss, and do not reduce economic efficiency.

1. Introduction

The shift schedule of the automatic transmission is essentially a control process that replaces the driver’s judgment and operation with a previously established control strategy [1]. According to the number of inputs in the control process, it can be divided into single parameters, dual parameters and multi-parameter shift rules [2,3,4]. According to the goal of control, it can be divided into dynamic shift law and economical shift law[5].The general engine is expected to have better economy when it is in medium or low load, and it is desirable to have better dynamic performance in medium and high loads. Therefore, in order to balance power and economy, a combination shift control strategy is usually adopted, that is, a threshold is set [6]. When the accelerator opening is smaller than the threshold, an economical shift control strategy is adopted. When it is greater than the threshold, the dynamic shift control strategy is adopted.

However, it is often necessary to follow the vehicle due to congestion in urban roads. At this time, the vehicle speed is unstable and the accelerator pedal opening degree changes greatly. The transmission will often shift between adjacent gears, which has a great influence on noise, thermal model and vibration, resulting in poor driving performance. In addition, because electric vehicle motors can quickly adjust the torque and speed [7], it is possible to choose to cancel the clutch and complete the shift process directly through the control of the motor during the shift under the premise of improving the transmission efficiency and simplifying the transmission mechanism. However, this will result in the input shaft of the transmission being splined to the output of the motor when synchronizing and engaging the gear, causing wear to the synchronizer. Therefore, reducing the number of shifts can effectively reduce wear and increase the life of the transmission. So, this paper
hopes to optimize the vehicle's shifting frequency under complex conditions by trying new control methods.

2. Traditional shift law

The central controller looks up the corresponding gear position on the shifting curve map according to the accelerator pedal opening value and the speed to determine whether a shift is needed during the running of the vehicle. Each of the upshift and downshift curves in this control strategy is fixed. The gear position is determined according to the correspondence between the vehicle speed and the accelerator opening degree. Generally, between the adjacent gears, the speed corresponding to the upshift curve of the accelerator opening is set to be higher than the speed corresponding to the downshift curve. This is to prevent frequent shifts. However, this control strategy will still cause the vehicle to enter a cyclic shift in a complex condition, especially in urban condition.

When a vehicle is driving in the urban area, it often encounters traffic jams. When the road is slightly congested, the driver needs to follow the vehicle. The driver reacts to factors such as the distance between the two vehicles and the speed of the vehicle. The vehicle operating conditions are shown in figure 1.

![Diagram of transmission's running condition in traffic jam](image)

**Figure 1** The diagram of transmission’s running condition in traffic jam

The speed at this time may be between the downshift curve and the upshift curve. Due to the large weight of the vehicle, there will be a certain degree of lag from the change of accelerator opening to the change of speed. However, the traditional control strategy will determine the target gear based on the vehicle speed and the accelerator pedal signal value, which can easily cause frequent shifting problems. Assuming that the vehicle passes through a crowded road, the driver sees that the speed of the vehicle in front slows down and releases the accelerator pedal. At this moment, due to the inertia of the vehicle, the speed changes little in a short time. The control system judges the state of the vehicle from the A area to the B area based on the vehicle speed and accelerator pedal opening signal. Afterwards, the speed drops and enters the C area, and the transmission shifted down. Then the preceding vehicle accelerates and the inter-vehicle distance increases. In order to follow the vehicle, the driver depresses the accelerator pedal. At this time, the accelerator pedal opening increases. Because the inertia of the vehicle is greater, the vehicle speed rises more slowly. The control system judges that the vehicle enters the D area according to the corresponding relationship between the accelerator opening and the vehicle speed. Then the vehicle speed increases to enter the E area, and the transmission is upshifted. In the course of a deceleration and acceleration of the preceding vehicle, the transmission needs to complete the downshift and upshift process. When passing through a congested road section, such conditions are always encountered, which will greatly increase the wear of the internal friction parts of the transmission and result in a poor driving experience.

It can be seen that simply using the open-loop look-up table to select the target gear will cause the vehicle to shift frequently under complex conditions. When the vehicle passes through a crowded road, the accelerator pedal opening value is from large to small and then from small to large. The vehicle
decelerates and then accelerates, that is, the acceleration goes from negative to positive. The changes of accelerator pedal opening, speed and acceleration are shown in figure 2.

![Figure 2](image-url) The curve of speed, acceleration, accelerator pedal opening of vehicle in traffic jam

Through analysis, we can see that there are three main reasons for frequent shifts under complex conditions. The first point is that the driver’s control of the accelerator pedal has some lag with respect to the road conditions [8]. The second point is that due to the inertia of the vehicle, there is a certain lag in the change of the opening of the accelerator pedal to the change of the vehicle speed. The third point is that the simple open-loop look-up table shifts have drawbacks [9].

3. Flexible shifting

In view of the phenomenon of frequent traffic shifts in urban congestion, two optimization methods are proposed. The first is to start from the selection time and increase the limit of the target gear time limit for the transmission shift. Before the control system issues a shift instruction, determine whether the length of the selected target range exceeds the threshold value. If the threshold is exceeded, an instruction to perform a shift is issued. If the target gear is selected for a short time and does not exceed the threshold, the original gear is maintained. The second method is based on the change of accelerator opening value and the change of acceleration to determine the driving condition of the vehicle, and setting the threshold based on the average speed within a certain period of time. When the speed is faster, the downshift is delayed. When the speed is slow, the upshift is delayed. So it can achieve the purpose of reducing the number of shifts. The advantage of the first method is that it can be optimized with a threshold value, which has the advantage of saving time and labor. However, because only the time threshold is considered, it has a certain defect. First, the time threshold needs to be established. When the time threshold is set too large, it will affect the power and economy, and it will give the driver a bad feeling of shift delay. When the setting is too small, the effect of optimizing the number of shifts for the vehicle under complex conditions is limited. Secondly, the most direct feeling to the driver is the speed [10]. This method does not take into account the speed factor in the optimization process, so it is difficult to link the driving experience with the calibration of the threshold. If it is simply to optimize with a threshold, the freedom considered is less and the effect of optimization is limited [11].

Through the above analysis, this paper chooses to study the accelerator pedal opening value and acceleration in the case of complex conditions and correct the input speed to change the shift timing so as to achieve dynamic shifting and reduce the number of shifts. This is the proposed flexible shift.

In the design of control strategies for flexible shifts, the impact of vehicle speed needs to be considered. On the one hand, different drivers have different perceptions of speed. On the other hand, at different speeds, it is necessary to consider the effects of flexible shifts on dynamics and economy. In the shift map, there are many conditions for entering the cycle shift, and the corresponding speed range is also large. In order to ensure that the control strategy can better achieve the economical and dynamic requirements, it is necessary to set the threshold of the vehicle speed. So a satisfactory speed as input is needed. However, frequent shifts are caused by a certain lag from the driver’s intention to the vehicle speed, so the current instantaneous speed is not suitable for the driver’s ideal speed. The vehicle has undergone one or more changes in the speed before entering the cycle shift. When the
speed is lower than the driver’s ideal speed, the driver depresses the accelerator pedal and the vehicle accelerates. When the speed is higher than the driver’s ideal speed, the driver releases the accelerator pedal and the vehicle slows down. It can be seen that these changing speeds oscillate above and below the ideal speed of the driver, so the average of multiple cycle speeds before entering the cycle shift is taken as the input of the driver’s ideal speed.

When the vehicle speed is lower than the threshold, the system enters the delay upshift. At this time, the vehicle is driving on the crowded road section. The driver’s demand for power has reduced and TCU choose the delayed upshift control strategy. Once the vehicle accelerates and the transmission reaches the second gear, TCU will choose a delayed downshift control strategy. When the vehicle speed is faster and TCU enters the delayed shift strategy, the driver wants higher dynamics. At this time, there is a higher requirement for the output speed of the transmission. The low gear may not meet the requirements even when the motor rotates at the maximum speed. Even when the requirements are met, the motor efficiency will be lower because of the higher motor speed. Therefore, the delay downshift control strategy is entered at this time. Once the vehicle decelerates and the transmission enters the first gear, the TCU will choose to enter a delayed upshift control strategy.

When the vehicle is driving on a congested road, TCU will choose the flexible shift. When the vehicle has passed through the congested road, the control system can make a judgment and choose the normal shift control strategy. This requires a judgment mechanism. When the vehicle is working on a good road condition, the accelerator opening value should be constant or change linearly, so it is judged based on the change of the opening degree of the accelerator pedal whether it is necessary to exit the flexible shift. The optimization flow chart is shown in figure 3.

The input parameters in the optimization method are accelerator opening value, vehicle speed and acceleration. The optimization steps are:

1. Accelerator pedal opening, acceleration, speed sampling

   Accelerator pedal sampling: Assuming that the potentiometer sampling time of the accelerator pedal is $\Delta t_1$, sampling is performed $n_1$ times, and the accelerator opening degree value of each sampling is $\alpha_{ij}$. The pedal opening degree of the $n_1$ acquisition is taken as the average value of the pedal opening degree value $\alpha_i$ at the current moment. The calculation is as shown in Eq.1.

   \[
   \alpha_i = \frac{\sum \alpha_{ij}}{n_1} \tag{1}
   \]

   Where, $\alpha_i$: the average value of accelerator pedal opening. $\alpha_{ij}$: accelerator opening value for each sample.

   Speed sampling: Assuming that the output shaft speed sensor sampling time is $\Delta t_2$, sampling $n_2$ times. The sampling rotation speed is $\omega_t$ each time. Convert the $n_2$ sampling rotation speed into speed and take the average as the input of the current speed $V_i$. The calculation is as shown in Eq.2.
\[ V_i = 0.3377 \cdot \frac{\sum_{n=1}^{n_2} \omega \cdot \tau}{n_2 \cdot \omega \cdot \tau} \]  

(2)

Where, \( V_i \) : current driver’s ideal speed, km/h; \( \omega \) : the rotation speed of transmission input shaft, rpm.

Acceleration sampling: Convert the rotation speed of \( n_2 \) samples into acceleration and take the average as input \( a_i \) of current acceleration. The calculation is as shown in Eq.3.

\[ a_i = \frac{\sum_{a}^{n_2 \cdot \omega \cdot \tau}}{n_2 \cdot \omega \cdot \tau} \]  

(3)

Where, \( a_i \): average acceleration after sampling \( n_2 \) times.

(2) Judgment of driver’s status and analysis of the vehicle’s status

Select appropriate \( \sigma_1 \) and \( \sigma_2 \) as threshold parameters. Assume that the previous sampled accelerator opening is \( \alpha_{i-1} \). Take \( p_{\alpha i} \) as the ratio of the current opening value to the previous opening value. When \( p_{\alpha i} \) is less than \( \sigma_2 \) and greater than \( \sigma_1 \), it is marked as state 1, otherwise it is marked as state 2.

If it is the state 2, the counter 1 is incremented. When the state 1 occurs, the counter 1 does not change.

There are three states for setting the accelerator opening: large opening, middle opening, and small opening. State 1 includes the middle opening, which is less changeable than the original accelerator pedal opening. The state 2 includes a large opening and a small opening which change more greatly than the original accelerator opening. \( \sigma_1 \) is the critical value of small opening and middle opening. Therefore, the value of \( \sigma_1 \) must ensure that when \( p_{\alpha i} \) is less than \( \sigma_1 \), the accelerator pedal opening is at a smaller opening compared to the original. \( \sigma_2 \) is the critical value of middle opening and large opening. Therefore, the value of \( \sigma_2 \) must ensure that when \( p_{\alpha i} \) is greater than \( \sigma_2 \), the accelerator pedal opening is at a larger opening compared to the original.

When the input current acceleration is \( \alpha_i \), which is less than \( \sigma_3 \) and greater than \( \sigma_4 \), it is marked as state 1, otherwise it is marked as state 2. If it is the state 2, the counter 1 is incremented. When the state 1 is present, the counter 2 is not changed. \( \sigma_3 \) and \( \sigma_4 \) are also suitable threshold parameters.

There are three states for setting the acceleration: rapid deceleration, steady, and rapid acceleration. State 1 includes the steady, relatively small change from the original speed. State 2 includes rapid acceleration and rapid deceleration, and this is a relatively large change from the original vehicle speed. \( \sigma_2 \) is the critical value of rapid deceleration and steady, so the value of \( \sigma_2 \) must ensure that if \( \alpha_i \) is smaller than \( \sigma_3 \), the vehicle has a larger deceleration trend. \( \sigma_4 \) is the critical value for rapid acceleration and steady, so the value of \( \sigma_4 \) must ensure that the vehicle has greater acceleration when \( \alpha_i \) is greater than \( \sigma_4 \).

(3) Whether to choose flexible shift

Counter 1 is reset to zero when counter 1 is in state 1 for \( k_1 \) consecutive times. Counter 2 is reset to zero when counter 2 is in state 1 for \( k_3 \) consecutive times. This phenomenon shows that the speed does not change too much and road conditions are good. When the counter 1 accumulates to \( k_2 \) and the counter 2 accumulates to \( k_5 \), it proves that the vehicle is driving on a congested road. TCU will decide to choose the flexible shift strategy.

(4) Flexible shift control

The control system calculates \( V_i \) as the ideal speed for the driver by averaging the speed of the previous cycles. The ideal vehicle speed is compared with the threshold value. When the ideal vehicle speed is high, it is hoped that the transmission gear will remain in the second gear, and the control strategy of delay downshift will be entered. Through the vehicle speed correction, the downshift curve is shifted to the left, allowing the transmission to shift at a lower speed. The revised vehicle speed calculation is shown in Eq.4.

\[ V_{in} = (1 + \alpha \cdot \mu_1) \cdot V \]  

(4)

Where, \( \alpha \): accelerator pedal opening, \( \mu_1 \): compensation coefficient. The value of \( \mu_1 \) is determined by the amount of leftward shift of the downshift curve.

Once the transmission is downshifted from second gear to first gear, TCU will choose the delayed
upshift. When the ideal vehicle speed is low, it is hoped that the transmission gear will remain in the first gear, and the control strategy of delay upshift will be chosen. Through the vehicle speed correction, the upshift curve is shifted to the right, allowing the transmission to shift at a higher speed. The revised vehicle speed calculation is shown in Eq. 5.

\[ V_{in} = (1 + \alpha \cdot \mu_2) \cdot V \]  

(5)

Where, \( \mu_2 \): compensation coefficient. The value of \( \mu_2 \) is determined by the amount of rightward shift of the downshift curve.

Once the transmission is upshifted from first gear to second gear, TCU will choose the delayed downshift.

(5) Exit the flexible shift strategy

The calculator 3 starts counting after entering the flexible shift. Taking the pedal opening degree \( \alpha_i \) as an input, it is assumed that the accelerator pedal opening degree \( \alpha_1 \) is maintained at the state 1. The state of the accelerator opening value is analysed by the next sampling data. If it remains in state 1, counter 3 is incremented by one, otherwise the counter is set to zero. When the counter is greater than \( k_{\alpha} \), the control system defaults that the vehicle has exited the complex condition and TCU exits the flexible shift.

4. Simulation results and analysis

Flexible shifting is mainly aimed at operating conditions in which the accelerator pedal opening degree constantly changes and the driver wants the vehicle speed to change continuously. In the FTP-75 (federal test procedure) [12] operating condition, the range of vehicle speed change is large and the working conditions are more complicated. Therefore, this operating condition is selected as a simulation condition for flexible shifting, as is shown in figure 4.

![Figure 4 The speed-time curve of FTP](image)

As can be seen from the figure, the change of vehicle speed with time is complex and close to the actual traffic conditions of the city, so it is reasonable to select this condition to test the effect of flexible shifting.

When shifting using the traditional look-up table, the shift curve during the entire FTP cycle is shown in figure 5. With flexible shifting, the shift curve for the entire FTP cycle is shown in figure 6.
According to figure 5 and figure 6, it can be seen that when choosing the traditional look-up table shift strategy, the number of shifts is 74 times. With the flexible shifting control strategy, the number of shifts is 62 on the same road segment, and 12 cycles can be reduced in one cycle. Especially in the period of 600s~1000s, which is less than 7 minutes, when using the traditional look-up table shift strategy, the number of shifts is 21 times, and the number of shifts when using flexible shifts is 16 times, which can reduce 5 times of shifts. This proves that choosing flexible shifting under complex conditions can effectively reduce the number of vehicle shifts, increase the service life of the gearbox and increase comfort.

When using the traditional table look-up mode to shift gears, the battery SOC curve during the entire FTP cycle is shown in figure 7. With flexible shifting, the battery SOC curve during the entire FTP cycle is shown in figure 8.

As can be seen from the figure, after the flexible shift is adopted, the number of shifts of the transmission is significantly reduced, and the SOC curve is not significantly different. This shows that the flexible shift strategy can reduce the number of shifts and improve comfort while ensuring economic efficiency.

5. Conclusion
For traffic congestion in the city, this paper proposes a flexible shift strategy to solve the problem of frequent shifts. By using the vehicle speed, acceleration, and accelerator pedal opening as the basis for the system to judge whether to switch the flexible shift, a complete entry and exit flexible shifting standard and a control principle in the shifting process are proposed. FTP-75 is selected as the simulation condition for flexible shifting. The simulation model established by Matlab proves that flexible shifting significantly improves the number of shifts of the vehicle and comfort in FTP condition. At the same time, economical efficiency is not reduced. So this strategy has a good application prospect in future urban traffic.

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