Research on Control Strategy of Hybrid Electric Vehicle

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Abstract. Focusing on optimizing the energy management strategy of the hybrid power system and improving the fuel economy, this paper mainly studies the determination of the optimal control target driving comfort, and obtains the optimal control law according to the optimal control theory, and designs the controller. Finally, in order to make the system control indicators reach the research goals, an observer is established for tracking observation.

1. Introduction
The environmental and resource problems brought about by the global industrialization process have caused the development and production of hybrid electric vehicles to reach a peak in the past ten years. More and more countries place the development of hybrid electric vehicles in an important strategic position. In the near future, it will completely replace traditional cars and achieve a major leap in the development of new energy vehicles. At the International Conference on Electric Vehicles in December 1997, most automotive engineers believed that in the next ten years, at least 40% of the world’s newly produced vehicles will be hybrid vehicles. Therefore, when the development of pure electric vehicles has not been able to solve the challenges of huge expenses and construction difficulties, the research and development of hybrid electric vehicles is particularly important.

2. Optimal control theory
In modern automatic control technology, optimal control theory is mainly used to optimize various control systems, and designing optimal solutions from multiple control schemes is an important component of control theory. In 1948, Wiener first proposed the concepts of information, feedback, and control. The most widely used are the dynamic programming proposed by Bellman and Pontryagin’s principle of maximum value. Based on the state variable method, the system can achieve the maximum Excellent indicators. The optimal control principle used in this article is the principle of maximum value, which is an algorithm for establishing the optimal control index through the extreme value.

From a mathematical point of view, optimal control is to obtain extreme values, that is, to use equations or inequalities as constraints to make the objective function of the system reach the required maximum or minimum value. From a practical point of view, optimal control is to maximize the efficiency of the system and minimize the consumption under certain resource constraints.

To make the system reach the optimal control goal, a mathematical model describing the motion process of the system must be established. Through the change of control variables, the system can reach the specified target state during operation, and a parameter index that can judge the quality of the system is used as standard. By comparing the performance of the system with the reference index, it is ensured
that its motion state is constrained by the controller, so as to achieve the maximum or minimum value of the system performance index function within the allowable control range.

3. Controller Design of Hybrid Electric Vehicle

In the process of shifting the gears of a hybrid electric vehicle, the pros and cons of driving comfort will fluctuate as the system basically does not see output changes. In order to make the change of the vehicle system ride comfort within a certain target range, this paper establishes the following performance index parameters:

$$ J = \int_{t_0}^{t_f} (j^2 + V + \mu u^2) \, dt $$

In the objective function, $t_f$ is the shift time, $V$ is the weight coefficient between the impact of the vehicle and the shift time index, which is defined by the driver's pedal opening; $\mu$ represents the weight coefficient related to control. $j$ represents the change of longitudinal acceleration, that is, the driving comfort studied in this article. The specific expression is as follows:

$$ j = r_w \left( -\frac{w_1}{l_w} x_1 - \frac{w_2}{l_w} x_2 + \frac{w_2}{l_w} x_3 + \frac{c_d}{i_g l_m l_w} x_4 \right) $$

It can be seen from the above that if the driving comfort is the control goal, the optimal control problem of the vehicle control system driving comfort can be transformed into the minimum value problem of formula (1).

$$ \min \left[ J = \int_{t_0}^{t_f} (j^2 + V + \mu u^2) \, dt \right] $$

And the initial state and final state satisfy:

$$ \begin{align*}
  x(t_0) &= x_0 \\
  N(x(t_f), t_f) &= 0
\end{align*} $$

Under unconstrained control conditions, the system satisfies the optimal control trajectory:

$$ \frac{\partial H}{\partial u} = 0 $$

According to the above formula, the optimal control law of the system can be calculated using the initial test conditions, terminal conditions and transversal conditions of the system:

$$ u^* = -\frac{\lambda_4}{2\mu} $$

4. Observer Design Based on Control Law

In modern control theory, there are generally two control goals, one is to make the system more stable, and the other is to make the system reach the target value under the condition of parameter changes and interference. In order to achieve such control requirements, modern control uses internal state feedback to design feedback control systems, and state feedback is the basis of modern control theory.

Observer is also called filter or estimator. It has two main ideas, one is based on modern control theory, and the other is based on disturbance estimation. In the early 1960s, in order to achieve state feedback and other control requirements for the control system, DG Luenberg, RW Bass, and JE
Bertrand proposed the concept and construction method of the state observer, which solved the inability of the state through reconstruction. The problem of direct measurement. The emergence of state observers not only provides practical possibilities for the technical realization of state feedback, but also has practical applications in many aspects of control engineering, such as duplicating disturbances to achieve complete compensation for disturbances. The observer design used in this article is based on the output state observer.

The optimal control law is a function of time and belongs to open-loop control. Therefore, its stability and anti-interference ability are relatively poor. Therefore, based on the objective function, the optimal control law can ensure that the system When the control index reaches the specified research goal, it is necessary to construct an observer to track and control the above optimal control law. The control law of optimal control is difficult to measure directly. Therefore, in order to obtain the optimal control law of system driving smoothness, it is necessary to design a state observer based on optimal control to obtain the numerical solution of the optimal control law.

5. Simulation implementation

In order to verify whether the designed observer can better track the change process of the optimal control law of the original system, this paper is implemented by Matlab simulation. Through simulation, the change process of gearbox input speed and driving comfort during the gear shifting process of the whole vehicle system is obtained, as shown in Figure 1 and Figure 2:

![Figure 1. Transmission speed change graph](image-url)
In this article, the ride comfort is defined as the degree of shock experienced by the car when shifting gears. For the entire vehicle system, to improve the comfort during shifting and reduce the degree of shock, it must first be tracked and controlled, and the transmission system input The change of the speed directly affects its driving comfort, so it is necessary to control the speed change within a certain range, and Figure 1 clearly shows that the change of the input speed does not substantially fluctuate within a certain range.

Figure 2 reflects the changes in driving comfort. It can be seen that when the input torque changes gradually decrease to no change, the driving comfort also remains stable within a certain range, reaching the expected research goal of this paper.

During the entire shifting process, since the optimal control term $\lambda_4$ is difficult to directly measure, the tracking error of the observer is used to determine whether the change process of the optimal control law of the Uehara system can be tracked. Figure 3 shows the estimation error process of the optimal control of the system.
Obviously, it can be seen from Fig. 3 that the observer designed based on the optimal control law of
the original system can well track the change process of the optimal control law \( u^* \) in the original system,
and the observation error gradually tends to within the expected time. It is close to zero, which has
achieved the research goal of this article.

In summary, the driving simulation results of hybrid electric vehicles under the optimal control
strategy show that the controller based on the optimal control law can effectively control the
transmission input torque and maintain better driving comfort, and the state observer can also control
The law is tracked, and the simulation results have a good verification of the research objectives.

6. Conclusion
According to the mathematical model of automobile driving established in this paper, the optimal control
target driving comfort is determined, and the optimal control law of driving comfort during the shifting
process of hybrid electric vehicle is obtained through the optimal control principle. Then, in order to
track and observe the optimal control law, a state observer is designed and simulated, and the control
results are studied and verified through simulation.

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