Study of TCS for All Electric Independent Driving and Braking Electric Vehicle of Dual Axles

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Abstract. In this study, a new configuration for all electric independent driving and braking electric vehicle of dual axles is proposed based on the driving ability requirement of dual axle independent driving electric vehicle on the weak adhesion pavement and the advantage of electromechanical brake system (EMB). The working principle and scheme of traction control system (TCS) for this configuration is given. The TCS control scheme is proposed based on BP neural network PID algorithm. The simulation platform is developed and it includes vehicle model, motor model, driveline model, EMB model, tire model and so on. The acceleration performance is verified by simulation on the separated pavements. The results show that the speed of wheels which are on the low adhesion pavement can be controlled near the target value. The vehicle driving ability is improved effectively. For example, the acceleration time with TCS control can be reduced by 64.04% compared with no TCS situation, when the adhesion coefficient of separated pavement is 0.7/0.1.

1. Introduction

With the increasingly serious environmental pollution and energy security issues, electric vehicles have become the main developing trend of automotive industry. Among them, the dual axle independent driving electric vehicle has become one of the research focuses since it has advantages of reasonable distribution of front and rear axle load, good dynamic performance and so on[1-3]. Tesla, which is known for its excellent dynamic performance, is a typical application case of this configuration. In recent years, with the gradual maturity of electric vehicle control technology, the traction control system (TCS) for electric vehicles is studied deeply, because the motor has characteristics of fast response, small lag and high precision. For example, document [4] studies the traction control algorithm for ISG hybrid electric vehicle based on dynamic coordinated control. Document [5] studies the traction control method for full hybrid electric vehicle. Document [6] studies the hardware of TCS controller for single axle driving electric vehicle. Document [7] studies the TCS control system for electric vehicles with in-wheel-motors and the fuzzy control is adopted. Document [8] studies the TCS controller of four wheel independent driving electric vehicle based on ADRC. The research for the dual axle independent driving electric vehicle mainly focuses on how to improve the vehicle power and economy performance by reasonably allocating the motor driving force and motor braking force between front and rear axle [9-11]. With the gradual mature of above researches, how to
improve the acceleration performance of the dual axle independent driving electric vehicle on the weak adhesion pavement gradually becomes the focus of future research.

In this paper, a new configuration for all electric independent driving and braking electric vehicle of dual axles is proposed based on the research status of dual axle independent driving electric vehicle and the demand for TCS. The TCS control scheme based on BP neural network PID is proposed. The simulation platform is developed and the acceleration performance is verified by simulation. This research can provide a solution for giving full play to the driving potential of dual axle independent driving electric vehicle on the weak adhesion pavement.

2. Working principle

As shown in figure 1, all electric independent driving and braking electric vehicle of dual axles includes the following parts: front and rear motor driving system, vehicle control unit (VCU), TCS controller, battery (including BMS), electronic accelerator pedal, electronic brake pedal, four wheel speed sensors and four sets of electromechanical brake system (EMB). The front and rear motor driving systems include motor, motor control unit (MCU), inverter, gear box and main reducer respectively. This paper chooses EMB as the braking system, and the reasons are as follows: first, as the next generation of brake system, EMB has the advantages of known braking force, small hysteresis and precise control, and it is easy to integrate ABS/TCS/ESP and other control systems [12, 13]. Second, the large parts such as vacuum booster and hydraulic pipes are discarded, and the chassis layout of vehicle can be more simple and flexible after adopting EMB. Third, the demand for higher voltage power supply limits the application of EMB in traditional vehicles, while electric vehicles can solve this problem easily and this provides a new opportunity for EMB [13].

During working, the wheel speed sensors are used to measure the speed of four wheels and the wheel speeds are transferred to TCS controller through signal wiring. Based on the speed of four wheels, the vehicle speed, wheel slip rate and vehicle status can be estimated by TCS controller. The VCU accepts the displacement of electronic accelerator pedal and electronic brake pedal to identify the driving and braking demand of driver. The MCU, BMS and VCU are connected through CAN bus1. The TCS controller, VCU and the EMB controllers are connected through CAN bus2. The VCU and TCS controller also have the role of gateway. When TCS is triggered to work, the target driving
torque of motor and the target braking torque of EMB can be calculated by TCS controller according to the wheel speeds, the estimated vehicle speed, the displacement of electronic accelerator pedal and the actual braking force from EMB controllers. The target driving torque of motor are transferred to corresponding MCU and the target braking force are transferred to corresponding EMB controller through CAN bus, respectively. Finally, the slip rate and speed of wheels are controlled to the target value through the control for motor driving force and EMB braking force. The function of TCS is realized, which achieves the driving ability improvement of vehicle on the weak adhesion pavement.

3. Control scheme

![Flow chart for TCS](image)

The control flow chart for the TCS based on all electric independent driving and braking electric vehicle of dual axles is shown in figure 2. The vehicle speed estimation, road identification and driver intention recognition are computed according to the wheel speed, displacement of accelerator pedal, displacement of brake pedal and other signals. Whether the vehicle is in a straight line or not is judged by the TCS controller based on those signals. If the vehicle is driving under a straight line, whether the TCS is triggered or not is judged according to the vehicle and wheel movement state. After triggering TCS, the corresponding control strategy is adopted according to different pavement. If the vehicle is on the uniform pavement, the TCS aims at improving the driving capability and driving stability of vehicle. When the driving control is normal, the driving force control is adopted. This can make full use of the advantages of small lag and accurate control of motor driving force. When the driving
control fails, the braking force control is adopted to ensure the vehicle stability. If the vehicle is on the separated pavement and the vehicle speed is less than the set threshold value of $V_t$, the braking force control is adopted to ensure the driving capacity of vehicle. When the vehicle speed is higher than the set threshold value of $V_t$, the driving force control is adopted to reduce the wear of braking system.

Based on the above, it is known that the driving and braking control strategies are the key of TCS. For the two control strategies, the neural network PID control [14] is applied and the structures are the same. The driving control strategy is selected as an example to illustrate the working principle. The principle diagram for driving force control is shown in figure 3. $S$ is the wheel slip rate. $S_0$ is the target value of wheel slip rate, and it is determined by the pavement. The BP neural network takes the wheel speed, vehicle speed and $S$ as input. The incremental digital PID controller takes the difference between $S_0$ and $S$ as input. Its output is the target load signal of motor, which is used to adjust the motor torque. The incremental digital PID control parameters are the output of BP neural network. The specific structure of this BP neural network is shown in figure 4. The input layer has three nodes, the hidden layer has five nodes, and the output has three nodes (PID control parameters $k_p$, $k_i$, $k_d$).

**Figure 3.** Principle diagram for driving force control

**Figure 4.** Structure diagram of BP neural network for driving force control

### 4. Simulation platform

In order to verify the TCS performance of all electric independent driving and braking electric vehicle of dual axles, the simulation platform is developed using Matlab/Simulink according to the configuration shown in figure 1. Its scheme is shown in figure 5.
5. Simulation and analysis

Table 1. Simulation results for TCS on the separated pavement

| Adhesion coefficient of pavement | (1m/s-6m/s) Acceleration time(s) | Reduction ratio of acceleration time (%) |
|---------------------------------|---------------------------------|----------------------------------------|
|                                 | No control | Control |                                 |
| 0.7/0.1                         | 5.272      | 1.896   | 64.04                                |
| 0.7/0.2                         | 2.612      | 1.617   | 38.09                                |
| 0.7/0.3                         | 1.782      | 1.407   | 21.04                                |

The simulation results on three separated pavements are shown in table 1. During the simulation process, the opening of accelerator pedal remains 100% unchanged. The right wheel is on the low adhesion pavement and the left wheel is on the high adhesion pavement. As shown in table 2, the maximum decrease of acceleration time can reach 64.04%. As the decrease of adhesion coefficient on low adhesion side (right wheel), the adhesive force proportion of high adhesion side becomes larger. This brings more obvious effect of TCS. In order to show the control effect in detail, the front wheel control with adhesion coefficient of 0.7/0.2 is selected as an example. For facilitate analysis, this paper illustrates the control effect by comparing actual wheel speed with target wheel speed. The target wheel speed is calculated according to vehicle speed and target slip rate.

Figure 5. Scheme for simulation platform

Figure 6. Front wheel speed and vehicle speed without control

As shown in figure6, wheel speed on high adhesion pavement is the same with vehicle speed and wheel speed on low adhesion pavement is increased rapidly when TCS does not work. The wheel
speed on low adhesion pavement becomes much larger than the target wheel speed and vehicle speed. This indicates that the wheel is over sliding. According to the tire characteristics [16], this will lead to a small wheel longitudinal adhesion coefficient and lateral adhesion coefficient, weak driving ability of vehicle, and poor lateral stability of vehicle.

![Figure 7. Front wheel speed and vehicle speed with control](image1)

![Figure 8. Clamping force of front EMB](image2)

When the TCS works, the wheel speed on low adhesion pavement is quickly controlled near the target speed (as shown in figure 7). According to the tire characteristics [16], the longitudinal adhesion and lateral adhesion of tire can be controlled to a larger value, which implies that the longitudinal driving ability and lateral stability of vehicle can be improved effectively. At the same time, the driving force on the high adhesion side can be improved too, and the acceleration time of vehicle is shortened. In addition, the overshoot of wheel speed in the initial stage is large, this is because the EMB needs to eliminate brake clearance, and the lag of motor is small. The corresponding clamping force of EMB is shown in figure 8.

6. Conclusion

Based on the research status of dual axle independent driving electric vehicle and its demand for TCS, a new configuration for all electric independent driving and braking electric vehicle of dual axles is proposed. The main contribution is listed as follows:

1) The control scheme for TCS based on BP neural network PID is proposed and the simulation platform is developed using Matlab/Simulink. The simulation platform includes vehicle model, motor model, driveline model, EMB model, tire model and so on.

2) On low adhesion pavement and separated pavement, the speed of wheels which are on the low adhesion pavement can be controlled near the target value (computed using vehicle speed and target slip rate). The longitudinal driving ability and lateral stability can be improved effectively. For
example, the acceleration time with TCS control can be reduced by 64.04% compared with no TCS situation, when the adhesion coefficient of separated pavement is 0.7/0.1.

3) The TCS for all electric independent driving and braking electric vehicle of dual axles not only provides a solution to give full play to the driving potential of dual axle independent driving electric vehicle on the weak adhesion pavement, but also provides a reference for further exploration of EMB application in electric vehicles.

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