The Electronic Differential Terminal Sliding Mode Control Based on Genetic Algorithm*

Niaona Zhang, Xiaofang Zhang,Wenjing Niu
Electronic and Electrical Engineering Institute
Changchun University of Technology
Changchun, China
zhangniaona@163.com

***Abstract*—In order to realize the differential function of electric vehicle driven by two rear wheel-hub motors, by following the optimal slip ratio of each wheel and equalizing the slip ratio of both drive wheels as target, a electronic differential control strategy based on terminal sliding mode is proposed. First of all, according to the standard μ-λ curve, the optimal slip ratio of the pavement is determined. Then, the deviation between the actual slip ratio and the optimal one is selected as the input variables. Based on the terminal sliding mode variable structure control theory, the electronic differential control strategy is designed to control the two rear wheel drive torque to achieve the function of electronic differential. At the same time, in order to further improve the performance of the system, the genetic algorithm is used to optimize the parameters in the terminal sliding mode algorithm. The simulation results show that the method proposed in this paper can realize the differential function and improve the stability of the electric vehicle.**

Keywords—electronic differential; terminal sliding mode; genetic algorithm; slip ratio

I. INTRODUCTION

With the global environmental pollution and energy shortages, the electric vehicles with its no pollution and low energy consumption, has been rapid development in recent years. Compared with the traditional internal combustion engine, the drive control form of electric vehicle has undergone tremendous changes, which eliminates the transmission shaft, transmission and other transmission devices. In the simplified structure, reduce vehicle weight, to achieve a new form of chassis at the same time, electric vehicle is mainly based on drive control strategy to achieve the precise control of the wheel motor[1], so as to ensure the stability of the vehicle running. Vehicle control system is mainly used to complete the vehicle information collection, drive torque distribution and vehicle control program implementation, and it is the key to achieve the development of electric vehicle. At the same time, for the vehicle control system, the electronic differential technology is a very important part of the control system[2][3].

In order to ensure the electric vehicle to achieve safe and reliable steering running, many experts and scholars at home and abroad have done a deep research on electronic differential technology. Focusing on the consideration of active safety technology, Yee-pien Yang et al with two rear-wheel drive as the object of study, the first proposed two-layer control of the electronic differential strategy. B.Tabbach et al obtained the ideal rotational speed values for each drive wheel based on the Ackermann steering model, and then used the PI control algorithm to perform closed-loop control of the speed of the drive wheels[4]. Silun Peng designed the electronic differential controller based on direct torque control using BP neural network method[5]. Although the BP neural network-based control system also has a certain degree of robustness, it is not directly consider the system uncertainty control method, and thus can not fully guarantee the robust performance of the system. Liqiang Jin broke the traditional control of the wheel speed control strategy[6], the torque as a control variable of system, according to the driver's intention to reasonable distribution of the wheel torque to achieve the control of the vehicle.

The paper takes electric wheel vehicle of the front wheel steering and the rear wheel drive as the research object, builds 7 degree of freedom electric vehicle model. Through simplifying and linearizing the model, the paper gives the linear state equation. Considering the external interference and the measurement error and other factors make the system is not accurate enough, and then it takes the external disturbance uncertainty into the system state equation, and based on the terminal sliding mode variable structure control theory design electronic differential controller[7][8]. At the same time, the genetic algorithm is used to optimize the parameters in the terminal sliding mode to improve the reliability of the electronic differential controller[9][10].

II. THE ESTABLISHMENT OF ELECTRIC VEHICLE MODEL

A. Dynamic Model of Electric Vehicle

The vehicle dynamics model is shown in Figure 1, the ground reference coordinates is defined as *X-O-Y* and the vehicle reference coordinate is defined as *x-c-y*; ψ is the heading angle; The coordinate origin *c* of the vehicle reference is the center of mass of the vehicle; *c-x* represents the longitudinal direction of the vehicle; *c-y* represents the lateral

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direction of the vehicle[5]. (Ignoring front-wheel steering freedom and body roll freedom).

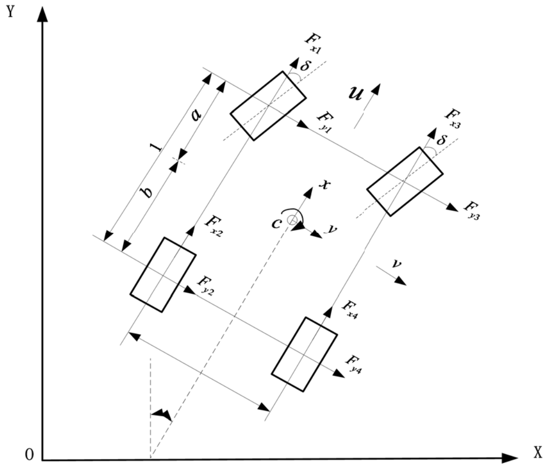

Fig. 1. The vehicle dynamics model

The dynamical model of electric vehicle is as follows:

$$\begin{cases} ma_x = \sum_{i=1}^{4} F_{xi} - mg\sin\theta - \frac{1}{2}C_D A_f \rho_a u^2 \\ ma_y = \sum_{i=1}^{4} F_{yi} \\ I_z \dot{r} = a(F_{y1} + F_{y3}) - b(F_{y2} + F_{y4}) \\ \qquad + \frac{B}{2}(F_{x1} + F_{x2}) - \frac{B}{2}(F_{x3} + F_{x4}) \\ J_m \dot{\omega}_i = T_{mi} i_m - F_{ti} R - F_{zi} d \quad i = 1...4 \end{cases} \tag{1}$$

Among them: F_{xi} and F_{yi} respectively is longitudinal force and lateral forces, i=1,2,3,4; m is the total weight of vehicle; g is the acceleration of gravity; a_x is the longitudinal acceleration; C_D is the automobile air resistance coefficient; θ is the road surface slope; A_f is the windward area; ρ_a is the air density; a_y is the lateral acceleration; r is the yaw velocity of vehicle; I_z is the moment of inertia of the vehicle around the z axis; B is the distance between wheels; l is the wheelbase; a、 b respectively is the horizontal distance between the center of mass and the front and rear axle; h is the height of the center of mass to the ground; δ_f is the front steering angle; J_m is the moment of inertia of electric wheel; ω_i is the wheel rotation speed; i_m is the transmission ratio between the wheel-hub motor and the wheel; T_{mi} is the motor drive torque; R is the radius of electric wheel; F_{ti} is the tire longitudinal force; F_{zi} is the ground support force; d is the eccentric distance of the ground support force from the wheel center.

B. Linearization of the Model

The mathematical model of electric vehicles is non-linear, in order to get the linear state equation, the original model is needed to be linearized. Assume that the speed of the vehicle does not change much, as defined below:

$$u = u_c + \Delta u \tag{2}$$

In the formula, u_c is defined as the initial speed of the vehicle; Δu is defined as the disturbance variable of the initial vehicle speed u_c.

The air resistance can be expressed as:

$$F_w = \frac{1}{2} C_D A_f \rho_a (u_c^{\,2} + 2u_c \Delta u) \tag{3}$$

The calculation formula of the vehicle longitudinal acceleration a_x and lateral acceleration a_y is defined as follows:

$$\begin{cases} a_x = \Delta\dot{u} \\ a_y = \dot{v} + u_c r \end{cases} \tag{4}$$

The ground support force can be defined as follows:

$$\begin{cases} F_{z1} = \left[\frac{mg}{2} + \frac{mh}{B}(\dot{v} + u_c r)\right]\frac{b}{l} - \frac{mh}{2l}\Delta\dot{u} \\ F_{z2} = \left[\frac{mg}{2} + \frac{mh}{B}(\dot{v} + u_c r)\right]\frac{a}{l} + \frac{mh}{2l}\Delta\dot{u} \\ F_{z3} = \left[\frac{mg}{2} - \frac{mh}{B}(\dot{v} + u_c r)\right]\frac{b}{l} - \frac{mh}{2l}\Delta\dot{u} \\ F_{z4} = \left[\frac{mg}{2} - \frac{mh}{B}(\dot{v} + u_c r)\right]\frac{a}{l} + \frac{mh}{2l}\Delta\dot{u} \end{cases} \tag{5}$$

Assume that the tire is working in the linear areas, the slip stiffness of each wheel is k_t; The lateral stiffness of two front wheels are k_{sf}, The lateral stiffness of two rear wheels are k_{sr}, The longitudinal force and lateral force calculation formula of the tire can be changed as below:

$$\begin{cases} F_{xi} = F_{ti} = k_t \lambda_i \\ F_{yi} = F_{si} = \begin{cases} k_{sf}\alpha_i & (i = 1,3) \\ k_{sr}\alpha_i & (i = 2,4) \end{cases} \end{cases} \tag{6}$$

Due to the front wheel angle will not be too large when normal driving, it can be approximated as $\cos\delta_{fi}\approx 1, \sin\delta_{fi}\approx\delta_{fi}$. The wheel core speed is expressed as:

$$\begin{cases} u_{t1} = u_{t2} = u + \frac{1}{2}Br \\ u_{t3} = u_{t4} = u - \frac{1}{2}Br \end{cases} \tag{7}$$

When calculating the sideway angle of the wheel, it can be approximated as $u_{ti}=u_c$, therefore, the calculation formula for the sideway angle can be defined as: