Research on Control Strategy of Two Independent Rear Wheels Drive Electric Vehicle

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Abstract

The 4 DOFS dynamic simulation model of two independent rear wheels drive electric vehicle was built by the Matlab/Simulink software. Asynchronous motors were used in the drive wheels. The motor vector control algorithm and the slip ratio differential control strategy are put forward in this paper. Simulation results showed that dynamic control of motor torque could be achieved with the vector control system and good steering stability of electric vehicle could be realized with differential algorithm.

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Keywords: electric vehicle; vector control; slip ratio; differential

1. Introduction

Electric vehicle is the inevitable development trend of the automotive industry in the future. Its key technologies include motor and drive technology, control technology, battery technology. These technologies have become the current hot research areas and some research results have also been introduced\(^{[1-3]}\). The two independent rear wheels drive is one of the new electric vehicle development forms, which is the important stage in the development of electric vehicles and makes the general concern of the academic and engineering\(^{[4-5]}\). If prototype be established through direct and extensive real tests to compare design schemes and practical effects of various control strategies, it would not only require a lot of financial and material resources, but also greatly extend the design cycle. Therefore, computer simulation technology is introduced in the preliminary theoretical study of electric vehicles. Dynamic simulation can effectively shorten the development cycle and reduce research costs. In this paper, the two independent rear-wheel drive control system model is finished by the Matlab/Simulink software and simulation analysis is done. It includes electrical motor simulation model, electrical motor control system
simulation model, 4DOFS steering dynamic simulation model and vehicle controller simulation model. Different methods were proposed in previous papers about the way of choice and control in the motor and two independent speed control of drive[6-8]. Vector control method for asynchronous motor and the slip ratio differential control strategy for two independent rear wheels drive are used in this paper. The simulation results showed that the methods are feasible.

2. Vehicle Dynamics Model

2.1. Motor model

Because the characteristics of asynchronous motor are low cost, durable, easy maintenance, reliability, larger output torque and higher output speed, it is widely used in the electric vehicles. The asynchronous motor torque is dynamic controlled through vector control method. Speed control system satisfies the need of dynamic performance of electric vehicles.

Asynchronous motor vector control equation:

\[
\begin{cases}
Te = p \frac{L_m}{L_r} \psi_r i_r \\
\psi_r = \frac{L_m}{1 + T_r \rho} i_M = L_n i_{slm}
\end{cases}
\]

\(T_e\) is electromagnetic torque. \(\psi_r\) is the total rotor flux. \(p\) is differential operator. \(L_m\) is stator and rotor mutual inductance. \(L_r\) is rotor inductance. \(i_{Mn}\) is rotor flux magnetizing current. \(T_r\) is Rotor time constant. \(i_M\) is DC motor field current, \(i_r\) is DC motor armature current. When the magnetic field is constant \(i_M\) can linearly control the size of the electromagnetic torque. In equation (1) \(i_M\) and \(i_r\) are completely decoupled. The asynchronous motors vector control system structure figure as shown in figure 1.

2.2. 4 DOFS dynamic electric vehicle model

The dynamic electric vehicle mode is simplified as shown in figure 4. There are four degrees of freedom. They are the car’s body lateral movement along the Y axis and Z axis yaw movement as well as two wheels rotational motion. 4 DOFS dynamic electric vehicle model is shown in figure 2. Parameters of 4 DOFs vehicle model is shown in table 1.

Figure 2. 4 DOFS dynamic electric vehicle model
TABLE I  PARAMETERS OF 4 DOFS CAR MODEL

| Symbol | Quantity                          | Values       |
|--------|----------------------------------|--------------|
| m      | vehicle mass                     | 2883kg       |
| a      | Distance from CG to front axle   | 1.68m        |
| b      | Distance from CG to rear axle    | 1.73m        |
| B      | Vehicle width                     | 2.91m        |
| m_s    | Spung mass                        | 2561kg       |
| Iz     | Moment of inertia about yaw axis | 9362kgm²     |
| Cf     | Front equivalent cornering stiffness | -21256N/rad |
| Cr     | Rear equivalent cornering stiffness | -35624N/rad |

The absolute acceleration and absolute angular of auto vehicle are decomposed in the coordinate system. The differential equations of motion are obtained.

\[ m(\dot{v} + uw_1) = Y_1 + Y_2 + Y_3 + Y_4 \]  \hspace{1cm} (2)

\[ J_1 \dot{\omega}_1 = a(Y_1 + Y_2) - b(Y_3 + Y_4) - B(X_1 + X_2)/2 + B(X_3 + X_4)/2 \]  \hspace{1cm} (3)

In the equation \( Y_i = F_{xi} \cos \delta_i - F_{yi} \sin \delta_i \) (\( i = 1, 2, 3, 4 \)), \( F_{xi} = \varphi_iN_i, F_{yi} = c_i\alpha_i \), \( \alpha_i \) is the wheel slip angle. \( v \) (m/s) is lateral velocity; \( u \) is longitudinal velocity; \( \omega_r \) (rad/s) is yaw velocity; \( J_1 \) (kg.m²) is Around the Z axis of inertia: \( N_i \) is vertical load. The velocity component:

\[
\begin{align*}
  u_1 &= \sqrt{(u - B\omega_r/2)^2 + (v + a\omega_r)^2} \cos \alpha_1 \\
  u_2 &= \sqrt{(u + B\omega_r/2)^2 + (v + a\omega_r)^2} \cos \alpha_2 \\
  u_3 &= \sqrt{(u - B\omega_r/2)^2 + (v - b\omega_r)^2} \cos \alpha_3 \\
  u_4 &= \sqrt{(u + B\omega_r/2)^2 + (v - b\omega_r)^2} \cos \alpha_4
\end{align*}
\]  \hspace{1cm} (4)

Vertical load of wheels change because of centrifugal force when vehicle is steering, centrifugal force is \( F_c = mV(\omega_r + \beta) \).

\( \beta \) is CG slip angle, \( \beta = \arctan(v/u) \), \( v \) is vehicle body speed. The tire vertical load:

\[
\begin{align*}
  N_1 &= \frac{b}{2L}(mg - \frac{2hF_c}{B}) \\
  N_2 &= \frac{b}{2L}(mg + \frac{2hF_c}{B}) \\
  N_3 &= \frac{a}{2L}(mg - \frac{2hF_c}{B}) \\
  N_4 &= \frac{a}{2L}(mg + \frac{2hF_c}{B})
\end{align*}
\]  \hspace{1cm} (6)

\( L = a + b \), \( h \) is CG height. Double rear wheels drive is adopted in the scheme. \( \delta_f \) is front wheel angle. Rear wheel angle is zero.
3. Control Strategy

Torque $T_e$ is input through accelerator pedal when electric vehicle is moving. When electric vehicle is steering, front wheel angle $\delta$ is input by steering wheel. Vehicle control system structure as shown in figure 3.

![Vehicle control system structure](image)

The new electronic differential program which controls the two driving wheels slip ratio to make good performance of stability is proposed in this paper. The vehicle controller schematic is shown in figure 4. First, the longitudinal velocity $u$ and lateral velocity $v$ are detected to calculate car sideslip angle $\beta$ and the speed $V$. Combined with vehicle yaw rate $\omega_y$, the two rear vertical load is calculated using formula (7):

$$\phi = \frac{F_w}{F_z}$$  \hspace{1cm} (7)

And defined the tire slip ratio:

$$s = \frac{u_w - r\omega_w}{u_w} \times 100\%$$  \hspace{1cm} (8)

Where $u_w$ is the speed of the wheel center and $\omega_w$ is the wheel angular velocity. Test showed that relationship between friction coefficient and slip ratio as shown in Figure 8. Different road conditions, the peak slip friction coefficient is very different. The $\phi(s) = \frac{2\mu \mu_p \phi_s}{\phi_p^2 + s^2}$ \hspace{1cm} (9) is used to fit the adhesion coefficient actual $\phi$ curve. $\phi$ is adhesion coefficient.

Relationship between friction coefficient and slip ratio is shown in figure 5.
The vehicle speed, vehicle quality and road conditions are used to calculate the ground reaction force required when moving. The force is equally distributed to two wheels. Adhesion coefficient can be calculated by equation (7). The two driving wheels slip ratio goals can be found by formula (9). The speed of two rear wheels center is calculated by equation (4). Two angular velocity goals are obtained by formula (8). The actual two wheels angular velocities are detected and input to PI regulator.

4. Simulation and Analysis

The following simulation experiments were carried out. Motors started with no load. The given speed \( n_s = 1350 \text{r/min} \). When \( t = 0.3s \), the sudden load \( T_L = 80 \text{Nm} \).

\[ t = 0.9s \], the speed \( n_s \) would reduced to \(-1350 \text{r/min}\). The speed response curves is shown in figure 6. Torque response curve is shown in figure 7. From the simulation curves, motor with no load started and at \( t = 0.3s \) motor speeded up to the given value. The maximum overshoot was only 0.8%. The torque fluctuated small after stabling, The speed only decreased by 0.2%.

Figure 6 Speed response curves; Figure 7. Torque response curve

Stator flux remained stable after the magnetic field was established during the speed process. In order to verify the effectiveness of the electric vehicle control system, the following simulation was finished. The positive steering inputted to the steering wheel when \( t = 25s \). The maximum steering angle was 9.8° and the time of turning process was 4s as shown in figure 8.

Figure 8. Steering wheel angle curve; Figure 9. Vehicle yaw rate curve
Simulation results showed that electric vehicle acceleration was finished in about 20s and driven in the uniform phase. In the steering process, both inside and outside wheel slip angle velocity were basically the same. The vehicle entered the stage of uniform driving after completing steering process. The larger wheel slip didn’t occur in the whole process and the vehicle yaw rate and lateral speed were controlled within the normal range as shown in figure 9.

5. Conclusion

The 4 DOFS dynamic electric vehicle model is built by the Matlab/simulink software. The simulation results showed that vector control for asynchronous motor is good stability, fast response, small overshoot and the control strategy based on the slip ratio can satisfy steering stability requirement.

Acknowledgment

The research is supported by the National High Technology Research and Development Program (863 Program) (2006AA11A112).

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Figure 4. Vehicle controller schematic