The Sliding Mode Control about ASR of Vehicle with Four Independently Driven In-Wheel Motors Based On the Exponent Approach Law

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Abstract

Acceleration slip regulation control system is a new active safety technology. In this paper, through the research of the four-wheel independent drive electric vehicle, a sliding mode variable structure control algorithm based on exponent approach law is proposed, which is applied to the ASR system. This paper establishes a seven DOFs vehicle dynamics model, tests whether the ASR control strategy is efficient on the poor condition road. The simulation results show that the vehicle acceleration performance improvement rate increases by 43.5% and 58.5% with the control strategy. During the two simulation processes, the results indicate that the sliding mode variable structure control algorithm applied to ASR system has a good adaptation to good and slippery roads. The algorithm can greatly improve the four-wheel independent drive electric vehicle’s acceleration performance.

Keywords: ASR, sliding mode variable structure control, exponent approach law

1.1. INTRODUCTION

The main function of ASR (Acceleration Slip Regulation) is to prevent the driving wheels being in a slip state when the vehicle is in the process of starting or acceleration [1]. At the same time, the lateral adhesion coefficient values should not drop too much compared with the pure rolling state, thus the vehicle can meet the requirement of a turning state [2].

The four-wheel independent drive electric vehicle is a form of distributed drive system [3]. The in-wheel motor driven arrangement makes the structure more simplified, because the complicated
mechanical transmission link between the wheel and the power source is dismissed. Thus, not only the energy efficiency is greatly improved, but also the whole vehicle vibration and noise are greatly reduced [4]. Except the advantages above, the four-wheel independent drive is easily to make the electric control chassis reality, leading the dynamic control simple [5,6].

During the past years, the intelligent algorithms have developed rapidly [7]. The sliding mode variable structure control, one of the intelligent algorithms obtains quick application because of its good robustness [8]. Compared with other algorithms, the sliding mode algorithm essentially is a kind of nonlinear control and its biggest characteristic is discontinuity of control. In the process of dynamic, on the basis of the current state of the system, the algorithm changes the inputs to get the system follow the trajectory of the sliding mode state. According to many experiments past, the sliding mode control can be designed and validated to meet the control requirements. The coefficients of algorithm has nothing to do with the system parameters and the system noise, so the sliding mode variable structure control algorithm has a good robustness [9,10].

2. SEVEN FREEDOM DEGREES VEHICLE MODEL AND ASR CONTROL STRATEGY

2.1. The establishment of the seven freedom degrees vehicle dynamic model

The seven freedom degrees vehicle dynamic model takes of the coordinate system of the vehicle, including the vehicle's longitudinal movement, the lateral movement, the yaw movement and the four-wheel rotations [11]. As shown in Fig. 1, four motors are installed in the wheel hubs. The pitch, the roll and the vertical motion of the vehicle are ignored in the model.

The differential equation of the longitudinal motion:

\[ ma_x = m(v_x - \nu_x) = (F_{x1} + F_{x2}) \cos \delta + F_{x3} + F_{x4} - (F_{x1} + F_{x2}) \sin \delta \]  

(1)

The differential equation of the lateral motion:

\[ ma_y = m(v_y + \nu_y) = (F_{y1} + F_{y2}) \sin \delta + F_{y3} + F_{y4} + (F_{y1} + F_{y2}) \cos \delta \]  

(2)

The differential equation of the yaw motion:

\[ I \ddot{\delta} = A \alpha - (F_{y3} + F_{y4}) \beta + B \frac{D}{2} \]  

(3)

In the equations:

\[ A = (F_{x1} + F_{x2}) \sin \delta + (F_{y1} + F_{y2}) \cos \delta \]

\[ B = (F_{x2} - F_{x1}) \cos \delta + (F_{y1} - F_{y2}) \sin \delta + (F_{y4} - F_{x3}) \]
2.2. The establish of vehicle model

The whole simulation are divided into two parts and the selected road condition is joint road. The validity of the sliding mode variable structure control strategy is verified through the simulation below. The vehicle model parameters are shown in Table 1:

Table 1. Basic parameters of the vehicle

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Symbols</th>
<th>Units</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross mass</td>
<td>( m )</td>
<td>kg</td>
<td>1704</td>
</tr>
<tr>
<td>Wheelbase(front, rear)</td>
<td>( (l_f, l_r) )</td>
<td>m</td>
<td>(1.235, 1.455)</td>
</tr>
<tr>
<td>Track width(front, rear)</td>
<td>( (d_f, d_r) )</td>
<td>m</td>
<td>(1.535, 1.535)</td>
</tr>
<tr>
<td>Centroid height</td>
<td>( h )</td>
<td>m</td>
<td>0.45</td>
</tr>
<tr>
<td>Yaw moment of inertia.</td>
<td>( I_z )</td>
<td>kg*m²</td>
<td>3048</td>
</tr>
<tr>
<td>Initial slip rate</td>
<td>( \lambda )</td>
<td>--</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Simulation process is as follows. The initial velocity of vehicle was 5m/s in high adhesion road. The maximum adhesion coefficient of the ground is 0.9. After 1s, the vehicle arrives into the slippery road surface, and its maximum adhesion coefficient is 0.2. The total simulation time is 5s.

The simulation experiments with and without control strategy are carried out. The simulation model are established based on the magic formula tire model which is more precise in order to make the simulation more accurate and getting more close to the real car test data. According to the differential equation of the vehicle model and magic tire model, the vehicle ASR control model is gotted in the simulation.

2.3. The post-processing of simulation results

In the simulink environment, the first simulation does not exert the control strategy, so each wheel goes with the initial driving moment. The scopes of simulink can display the vehicle front and rear wheels’ slip ratio, velocity and the driving moment of each wheel. The second simulation is carried on with the drive torque control strategy.

The simulation results are shown in Fig. 2, 3 and 4.

Fig. 2. Slip rate changing with time
Fig. 3. Speed changing with time
Fig. 4. Front and rear torque changing over time

2.4. The simulation results analysis
Figure 2 shows the vehicle’s changes of the wheel slip rates with the application of sliding mode variable structure control strategy, along the joint road during acceleration.

For the first simulation, the vehicle runs without control. In 0~1s, the ground condition is good, during this period, the wheel’s slip rates are in a low range, and fails to maximize the use of ground adhesion. So the acceleration performance of the vehicle does not get the best state. After 1s, vehicle arrives into the slippery road, while the driving moment of the vehicle does not change. So the wheel’s slip rates grow fast. The acceleration performance of the vehicle is not good enough.

For the second simulation, the vehicle is attached to the sliding mode variable structure control algorithm. In the process of 0~1s, the slip rate is in low position of the slip ratio range beyond the best value. Therefore, by changing the driving moment of each wheel, the vehicle can make good use of the ground maximum adhesion, improving the speed of the vehicle. After the vehicle into the slippery road surface, reduce the driving moment to prevent the excessive wheel slip rates.

Figure 3 represents the vehicle's velocity changes over time before and after using sliding mode variable structure control algorithm.

By contrast, in the time of 0~1s and 1~5s, the vehicle velocity with control strategy is greater than that not exerts control strategy. This conclusion shows that the sliding mode variable structure control strategy has a good robustness for the good pavement with high adhesion coefficient and wet pavement with low adhesion coefficient.

Define the vehicle acceleration performance optimization rate as follows:

$$\eta = \frac{v_{ye} - v_{no}}{v_{no} - v_{0}}$$

In the formula: $\eta$ means vehicle acceleration performance optimization rate;
$v_{ye}$, the final speed with control strategy;
$v_{no}$, the final speed without control strategy;
$v_{0}$, the initial speed of the vehicle;

The vehicle velocity of the simulation is shown in Table 2.

<table>
<thead>
<tr>
<th>$t$(s)</th>
<th>1.000</th>
<th>5.000</th>
</tr>
</thead>
<tbody>
<tr>
<td>$v_{no}$(m/s)</td>
<td>9.069</td>
<td>14.300</td>
</tr>
<tr>
<td>$v_{ye}$(m/s)</td>
<td>10.840</td>
<td>19.140</td>
</tr>
</tbody>
</table>

During 0~1s, $\eta_1 = 43.5\%$ and during 1~5s, $\eta_2 = 58.7\%$.

The vehicle front and rear wheels’ drive torque changes over time in the two simulations are shown in Fig. 4.

It is not hard to find, after using the control strategy, the vehicle in good pavement can appropriately increases the driving moment of each wheel, make full use of the adhesion ability of road. So the vehicle achieves better acceleration performance. On the wet pavement, the algorithm can decrease the wheel driving moment to prevent excessive wheel slip.

3. CONCLUSION

Aiming at the vehicle ASR control system, this paper takes the sliding mode variable structure control algorithm with exponential reaching rate. Then the paper conducts a seven freedom degrees vehicle dynamic model. Finally the paper carries on the quantitative analysis to the simulation results.
show that without control algorithm, the vehicle in good road will not be able to make full use of the
ground adhesion; while on the slippery road surface, due to the driving moment is too big, the tire’s slip
rates are seriously beyond effective value. In both cases, the vehicle’s acceleration performance is poor.

During the second simulation with sliding mode variable structure control algorithm, whether the
adhesion of the road is high or low, the vehicle is able to achieve a better acceleration performance. The
algorithm maximizes the use of tire-road friction coefficient and the wheel slip rates are controlled in a
certain range. Through quantitative calculation, the driving performance of the two acceleration period
improves by 43.5% and 58.5%. The results indicate that the sliding mode variable structure control
algorithm in ASR system is effective and has a good robustness.

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Reference

[1] Du Z, Chen H, “Real vehicle drive test of four-wheel independent drive electric vehicle”, Automobile industry college
[5] Sakai S I, Sado H, Hori Y. Motion control in an electric vehicle with four independently driven in-wheel motors[J].
[10] Lin C, Cheng X. A sliding mode control strategy for a distributed driving electric vehicle[C]/ Transportation Electrification
Biography

Zhifu Wang received the M.E. degree and the Ph.D. degree from the Beijing Institute of Technology, Beijing, China, in 2003 and 2013, both in vehicle engineering. He is currently an Associate Professor with the National Engineering Laboratory for Electric Vehicles, Beijing Institute of Technology.