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Research on the stability performances of the vehicle dynamics equivalent system based on the unsteady constraints

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1. Introduction

The experiments of vehicle stability control performances commonly use the road test method [1-4], which can truly reflect the actual effects of the vehicle stability control performances, is a necessary and effective test verification method in the developing process of the vehicle ESP system. Limited by safety condition, test field and technical equipment, the road test is usually only done on the specific conditions, it is difficult to fully test the vehicle stability control performance. Especially the road test on vehicle stability control performances under the tire adhesion limit is still hard to be done fully and effectively at the present because it is very dangerous, and the traffic accidents easily occur under the tire adhesion limit, so it is more significant that the vehicles have reliable and effective stability control performances under the tire adhesion limit. It is an important method of researching and testing the vehicle stability control performances to do experiments based on safe test platform system, wealth of research has been done at home and abroad [5-8], but technology is not mature enough and it still can not meet the needs of system development and test for vehicle stability control.

To solving these problems, we establish the stability control dynamics system equivalent with independent vehicle system based on the unsteady constraints vehicle dynamics system using the artificial neural network, it can effectively prevent vehicle instability and avoid occurrence of dangerous working conditions to test the vehicle stability control performances based on the equivalent system. Using the ESP control principle based on the integrated control of brake and drive, based on the Matlab/Simulink establish the stability performances simulation test system of the vehicle dynamics equivalent system for the Chery A3 car. Using the simulation model, we respectively simulate the stability performances of the vehicle dynamics equivalent system and the independent vehicle system on steady-state conditions of neutral steering, under steering and over steering. The study results indicate that the stability performances of the vehicle dynamics equivalent system based on the unsteady constraints and the independent vehicle system show remarkable consistency, it will provide a theoretical basis and technical support for establishing the safe and efficient test platform for vehicle stability control based on the unsteady constraints vehicle stability control dynamics equivalent system to research the vehicle stability control performances.

2. The unsteady constraints vehicle dynamics system

The test system for vehicle stability control performances based on the unsteady constraints, shown in Fig. 1, consists of the experiment table system and the test vehicle system. The experiment table system mainly consists of fixed axis, traction bar, traction rope, tie rod, the fifth wheel, front/rear tension gauge, front/rear pull rod,

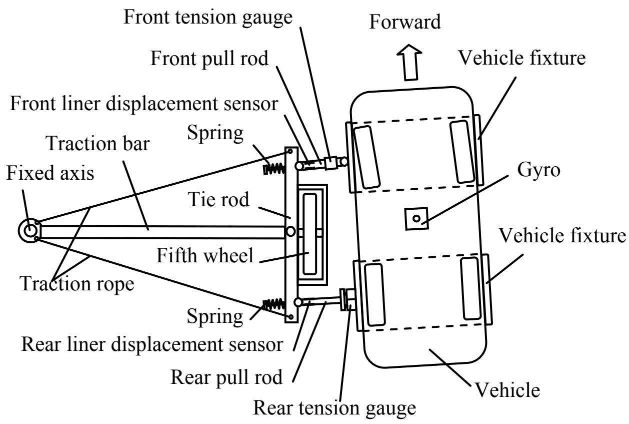

Fig. 1 The test system for vehicle stability control performances based on the unsteady constraints

front/rear liner displacement sensor and spring. The test vehicle system consists of the vehicle fixture, the gyro and the vehicle with the ESP system. The traction bar and the fixed axis are connected by a bearing, the traction bar and the tie rod are vertically articulated in the place of the vehicle's centroid, the fifth wheel is fixed in the tie rod; one end of the rear pull rod is fixed in the vehicle fixture by two tension gauges that could measure the pull rod's pull force; the other end of the rear pull rod connects with the tie rod by vertical pin; the front tension gauge is fixed in the pull rod, one end of the front pull rod connects to tie rod and the other to the vehicle fixture by vertical pins; the front and the rear pull rod which can stretch and pull back to change its length go through the horizontal holes of vertical pin that connects with the tie rod, preloading by the spring; the liner displacement sensor that fixed between the pull rod and the tie rod can measure the length of the front and the rear pull rod; the vehicle fixture make that the two pull rods are above the vehicle front and the rear wheels on the high of the vehicle's centroid; the pull rod's variable length makes it easy to revise the turning radius. The test system by using the relationship of the experiment table system's location and test vehicle system's location, combined with the signals of the fifth wheel, the steering angle of the front wheel and the gyro can measure the longitudinal and lateral speed of the vehicle centroid and the four wheels' center, side slip angle ,etc. The parameters of the vehicle body state are helpful to test vehicle stability control performances and study the control strategy.

The dynamics analysis of the test system for vehicle stability control performances based on the unsteady constraints is shown in Fig. 2. The dynamics model of test system for vehicle stability control performances based on the unsteady constraints can be built by adding the pull forces of the front/rear pull rod F_{fx}, F_{fy}, F_{rx}, F_{ry} in the independent vehicle system dynamics model. The pull forces of the front/rear pull rod F_{fx}, F_{fy}, F_{ry} are flexible constraint forces, so the test system for vehicle stability control performances is unsteady constraints vehicle dynamics system.

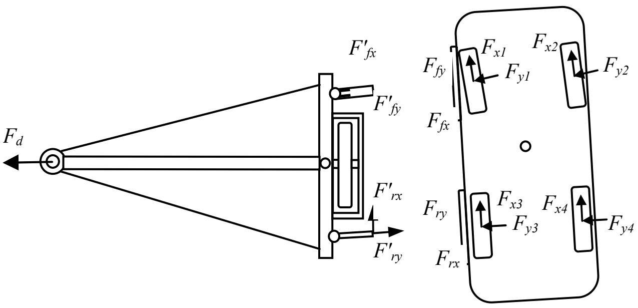

Fig. 2 The test system dynamics model for vehicle stability control performances based on the unsteady constraints

The test table dynamics equation is

$$I_t \dot{\omega}_t = M_{F_f} + M_{F_r} + M_f \tag{1}$$

where I_t is the rotational inertia of the experiment table system around the fixed axis, kg·m^2; ω_t is the rotation velocity of the experiment table system around the fixed axis, it can be calculated according to the wheel speed signal measured by the fifth wheel, rad/s; M_{Ff} is the torque of the front pull rod's forces F_{fx}, F_{fy} to the fixed axis, N·m; M_{Fr} is the torque of the rear pull rod's forces F_{rx}, F_{ry} to the fixed axis, N·m; the torque arms that the forces F_{fx}, F_{fy}, F_{rx}, F_{ry} to the fixed axis can be calculated according to the location of the experiment table system and the test vehicle; M_f is the friction torque in kinematic pairs of experiment table system, it can be tested, N·m.

3. The vehicle dynamics equivalent system based on the unsteady constraints

The establishment method of the vehicle dynamics equivalent system based on the unsteady constraints is shown in Fig. 3. Respectively using the same stability control system and input in the unsteady constraints vehicle dynamics system and the independent vehicle dynamics system to get the state-spaces of two systems, obtain the equivalent state-space with the independent vehicle dynamics system from the unsteady constraints vehicle dynamics system using the artificial neural network mapping algorithm, and use it as the output state feedback of the unsteady constraints vehicle dynamics system to establish the vehicle stability control dynamics equivalent system. On the same conditions of the stability control system and input, the vehicle stability control performances of the equivalent system are same as the independent vehicle stability control performances, then it will provide a theoretical basis and technical support for establishing the safe and efficient test platform for vehicle stability control based on the unsteady constraints vehicle stability control dynamics equivalent system to research the vehicle stability control performances.

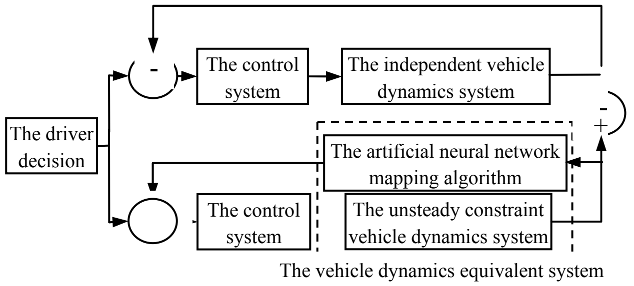

Fig. 3 The establishment method of the vehicle dynamics equivalent system based on the unsteady constraints

We establish the vehicle equivalent system using the artificial neural network and the ESP control based on the integrated control of brake and drive. The vehicle ESP control principle based on the integrated control of brake and drive uses the hierarchical control, the upper controller is the state controller of car body, which uses the PID controller, the lower controller is including the ABS controller to the nondriving wheel and the ASR controller to the driving wheel [9, 10]. We use the BP neural network to research the state-space mapping algorithm from the unsteady constraints vehicle dynamics system to the independent vehicle dynamics system. The architecture of mapping neural network is shown in Fig. 4, which is two layers BP neural network. The hide layer transfer function is the hyperbolic tangent sigmoid (tansig) function and the output layer transfer function is the linear (purelin) function. The inputs and outputs of mapping neural network are two same parameters, the vehicle centroid slip angle and yaw rate, so neurons number of output layer is 2 same as network inputs layer. Number of neurons in hidden layer is selected as 500 by comparing different number. Use the Matlab/Neural Network Toolbox to train the mapping neural network, the network training inputs P and the target outputs T are the output state parameter values of the unsteady constraints vehicle dynamics system and the independent vehicle dynamics system using the same stability control system and input on three simulation conditions of neutral steering, under steering and over steering.

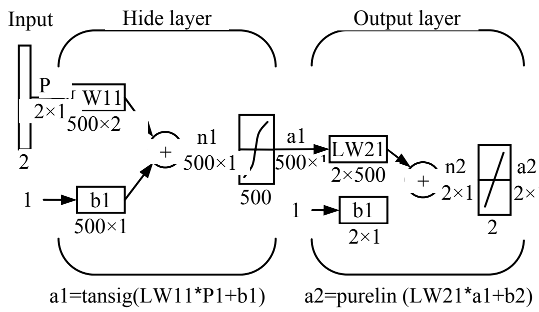

Fig. 4 The mapping neural network architecture

4. The stability control performances analysis of the vehicle dynamics equivalent system based on the unsteady constraints

To verify the consistency of the stability performances between the vehicle dynamics equivalent system based on the unsteady constraints and the independent vehicle system, based on the Matlab/Simulink establish the stability performances simulation test system of the vehicle dynamics equivalent system for the Chery A3 car. Using the simulation model, we respectively simulate the stability performances of the vehicle dynamics equivalent system and the independent vehicle dynamics system on steady-state conditions of neutral steering, under steering and over steering. Use the vehicle centroid slip angle and yaw rate to measure the control effect of vehicle ESP system, Figs. 5, 7, 9 show the slip angle change of the vehicle centroid, where X-axis represents the time and Y-axis represents the slip angle of the vehicle centroid. Figs. 6, 8, 10 show the yaw rate change of the vehicle centroid, where X-axis represents the time and Y-axis represents the yaw rate

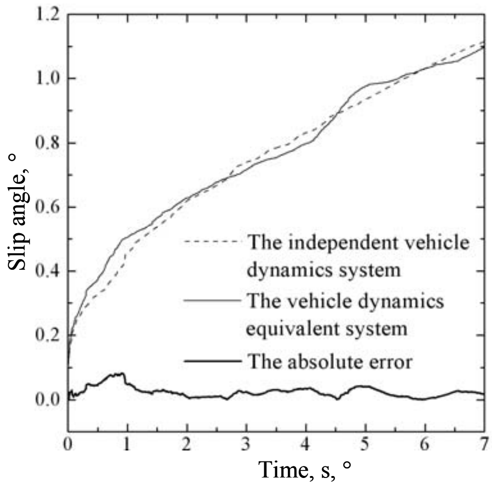

Fig. 5 The vehicle centroid slip angle on neutral steering

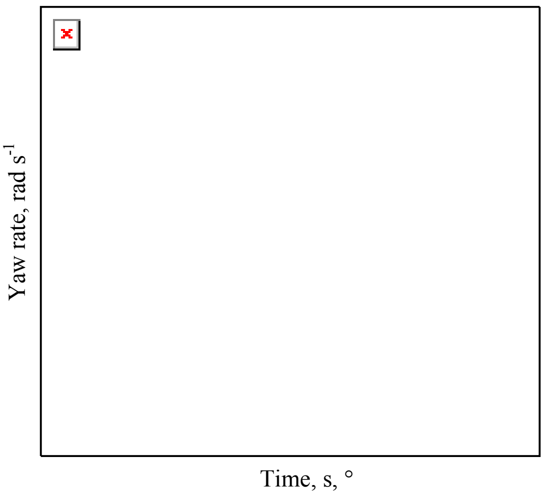

Fig. 6 The vehicle centroid yaw rate on neutral steering

of the vehicle centroid. In Figs. 5-10, the thin dashed line is characteristic curve of the independent vehicle dynamics system; the thin solid line is characteristic curve of the vehicle dynamics equivalent system based on the unsteady constraints; the thick solid line is the absolute error curve between the vehicle dynamics equivalent system and the independent vehicle dynamics system.

4.1. The neutral steering characteristic analysis

Simulation condition: the steer angle of vehicle left-front wheel is 15°; the initial vehicle velocity $v_0 = 5$ km/h, the stop simulating vehicle velocity $v_t = 60$ km/h; bisectional road, the ground adhesion coefficient of inside two wheels is 0.8, the ground adhesion coefficient of outside two wheels is 0.2; the front pull rod stiffness $K_{bc} = 100$ N/m, the rear pull rod stiffness $K_{ad} = 10000$ N/m; the initial length of front/rear pull rod $L_{bc} = L_{ad} = 0.785$ m; through strength design and press pole stability design, the rotational inertia of the experiment table system around the fixed axis $I_t = 3000$ kg·m^2. The vehicle dynamics equivalent system and the independent vehicle dynamics system are controlled by ESP.

Fig. 5 shows the vehicle centroid slip angle on neutral steering; Fig. 6 shows the vehicle centroid yaw rate on neutral steering. It can be seen that, on the same simulation condition, the characteristic curves of the vehicle dynamics equivalent system and the independent vehicle dynamics system are very close, the maximum errors of the vehicle centroid slip angle and yaw rate between the two systems respectively are 0.084° and 0.025 rad·s^{-1}, the mean square errors respectively are 0.029° and 0.01rad·s^{-1}, so the vehicle dynamics equivalent system can well reflect the ESP control performances of the independent vehicle dynamics system.

4.2. The under steering characteristic analysis

Simulation condition is same as the neutral steering characteristic test, the vehicle dynamics equivalent system and the independent vehicle dynamics system are not controlled by ESP.

Fig. 7 shows the vehicle centroid slip angle on under steering, Fig. 8 shows the vehicle centroid yaw rate on under steering. It can be seen that, on the same simulation condition, the characteristic curves of the vehicle dynamics equivalent system and the independent vehicle dynamics system are very close, the maximum errors of the vehicle centroid slip angle and yaw rate between the two systems respectively are 0.32° and 0.031 rad·s^{-1}, the mean square errors respectively are 0.103° and 0.015 rad·s^{-1}.

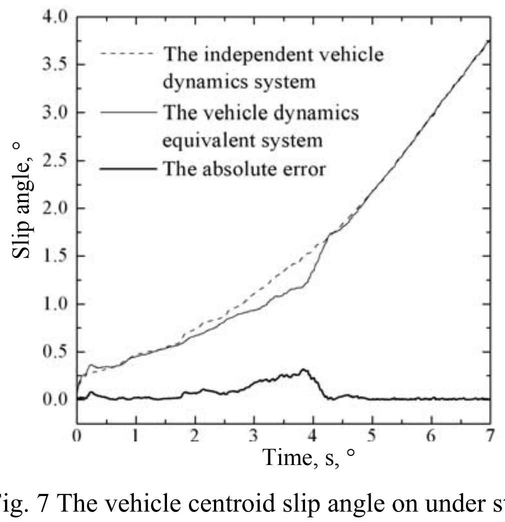

Fig. 7 The vehicle centroid slip angle on under steering

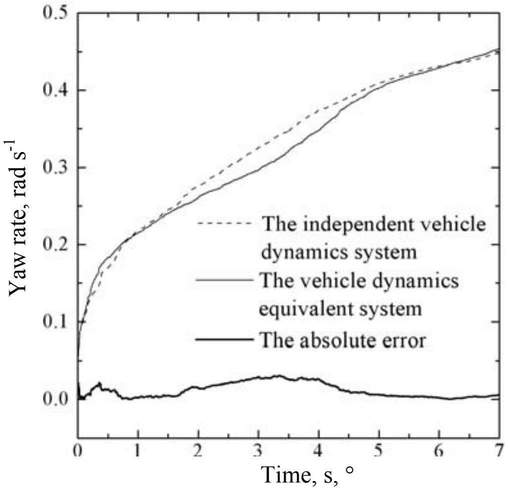

Fig. 8 The vehicle centroid yaw rate on under steering

4.3. The over steering characteristic analysis

Simulation condition: the steer angle of vehicle left-front wheel is 15°; the initial vehicle velocity v_0 = 5km/h, the stop simulating vehicle velocity v_t = 60 km/h; bisectional road, the ground adhesion coefficient of two inside wheels is 0.1, the ground adhesion coefficient of two outside wheels is 0.9; the front and rear pull rod stiffness $K_{bc} = K_{ad}$ = 10 N/m; other parameters are same as above. The vehicle dynamics equivalent system and the independent vehicle dynamics system are not controlled by ESP.

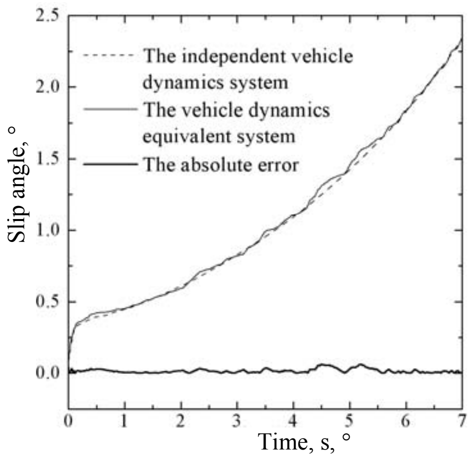

Fig. 9 The vehicle centroid slip angle on over steering

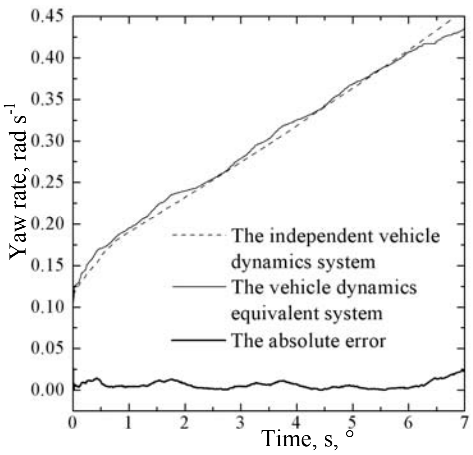

Fig. 10 The vehicle centroid yaw rate on over steering

Fig. 9 shows the vehicle centroid slip angle on over steering, Fig. 10 shows the vehicle centroid yaw rate on over steering. It can be seen that, on the same simulation condition, the characteristic curves of the vehicle dynamics equivalent system and the independent vehicle dynamics system are very close, the maximum errors of the vehicle centroid slip angle and yaw rate between the two systems respectively are 0.063° and 0.027 rad·s^{-1}, the mean square errors respectively are 0.022° and 0.007 rad·s^{-1}.

5. Conclusion

Set up the vehicle stability control dynamics system based on the unsteady constraints. Establish the vehicle stability control dynamics equivalent system based on the unsteady constraints using the artificial neural network and the ESP control principle based on the integrated control of brake and drive. Based on the Matlab/Simulink establish the stability performances simulation test system of the vehicle dynamics equivalent system for the Chery A3 car. Using the simulation model, we respectively simulate the stability performances of the vehicle dynamics equivalent system and the independent vehicle system on steady-state conditions of neutral steering, under steering and over steering.

The study results indicate that, on steady-state conditions of neutral steering, under steering and over steering, the stability performances of the vehicle dynamics equivalent system and the independent vehicle dynamics system show remarkable consistency, the error range between the two systems is smaller, it shows that, on a variety of typical conditions that may occur and based on the same stability control system and input, the state-spaces of the vehicle dynamics equivalent system based on the unsteady constraints and the independent vehicle dynamics system have remarkable consistency, the stability control based on the vehicle dynamics equivalent system based on the unsteady constraints and the independent vehicle dynamics system can achieve the same control effect, it will provide a theoretical basis and technical support for establishing the safe and efficient test platform for vehicle stability control based on the unsteady constraints vehicle stability control dynamics equivalent system to research the vehicle stability control performances.

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TRANSPORTO PRIEMONIŲ DINAMIKOS EKVIVALENTINIŲ SISTEMŲ SU KINTAMOMIS JĖGOMIS STABILUMO PROCESŲ TYRIMAS

R e z i u m ė

Straipsnyje pateikiamas transporto priemonių dinaminių sistemų su kintamais jėgų ryšiais stabilumo tyrimas. Naudojant dirbtinius neuroninius tinklus ir ESP kontrolės principus, pritaikytus integruotai stabdžių ir važiuoklės kontrolei, sudaryta transporto priemonių ekvivalentinių sistemų su kintamais jėgų ryšiais dinaminio stabilumo kontrolės sistema. Naudojantis MATLAB/Simulink, sukurta stabilumo proceso imitavimo bandymo sistema, ekvivalentinė automobilio „Chery A3" dinaminei sistemai. Naudojant imitavimo modelį imituoti dinaminės automobilio ekvivalentinės sistemos stabilumo procesai ir realaus automobilio sistema analogiškose sąlygose jį vairuojant. Tyrimo rezultatai rodo, kad automobilio ekvivalentinės dinaminės sistemos stabilumo rodikliai, matuojant kintamus jėgų ryšius ir realios sistemos yra analogiški. Tai suteikia teorinę ir praktinę bazę sukuriant saugią ir efektyvią automobilio stabilumo tyrimų programą, naudojant stabilumo kontrolės dinamikos ekvivalentinę sistemą.

Guoye Wang, Juanli Zhang

RESEARCH ON THE STABILITY PERFORMANCES OF THE VEHICLE DYNAMICS EQUIVALENT SYSTEM BASED ON THE UNSTEADY CONSTRAINTS

S u m m a r y

Set up the vehicle stability control dynamics system based on the unsteady constraints. Establish the vehicle stability control dynamics equivalent system based on the unsteady constraints using the artificial neural network and the ESP control principle based on the integrated control of brake and drive. Based on the Matlab/Simulink establish the stability performances simulation test system of the vehicle dynamics equivalent system for the Chery A3 car. Using the simulation model, respectively simulate the stability performances of the vehicle dynamics equivalent system and the independent vehicle system on steady-state conditions of neutral steering, under steering and over steering. The study results indicate that the stability performances of the vehicle dynamics equivalent system based on the unsteady constraints and the independent vehicle system show remarkable consistency, it will provide a theoretical basis and technical support for establishing the safe and efficient test platform for vehicle stability control based on the unsteady constraints vehicle stability control dynamics equivalent system to research the vehicle stability control performances.

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