Research on Vehicle Steering Characteristic Based on MATLAB

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Abstract. The steering characteristic of the vehicle were researched, the equations of motion and state of the vehicle model were built on the basis of the theoretical cornering movement. The motion simulation based on MATLAB analysis of two degrees of freedom and three degrees of freedom for the vehicle models under the cornering wheel angle step input was carried out. The change laws of steering sensitivity, yaw velocity, lateral acceleration, front and rear lateral forces, and sideslip angle with different speeds were studied. The results show that the simulation analysis provides the basis for the forecast of vehicle cornering performance.

Keywords: Vehicle, steering characteristic, simulation, MATLAB.

1. Introduction

The steering characteristic of the vehicle have very important influence on the stability. Oversteer and understeer of the vehicle can make it difficult to control. The inappropriate choice of design parameters can lead to unexpected tail-flick or sharp turns and cause serious accidents [1-2]. That’s because some vehicles are under certain understeer at low centripetal acceleration, while are under drastic oversteer at high centripetal acceleration. Therefore, the research on the steering characteristic is an important aspect of vehicle handling and stability, and is of great significance.

In the early stage of research on vehicle steering characteristics, the analysis method of classical mechanics is commonly used to conduct some simple partial check calculations, but it can’t evaluate the overall performance of the vehicle. Later, the vehicle is studied as a complete control system, and some calculations and simulations based on a simplified model and the empirical model are adopted to get some cognition on steering characteristic rules. However, the model is too simple to directly analyze and optimize the design parameters. With the development of simulation technology and simulation software matures, the steering characteristics is analyzed by using more mature computer simulation theory and high performance simulation software. Guichun Hai et al. [3] researched the steering characteristics by changing suspension stiffness and stabilizer bar stiffness. Xiaochun Jian et al. [4] established two freedom model of the vehicle based on the ground coordinate system to analyze lateral and yaw motion. Jianhua Sun [5] investigated the overload effect on the automobile steering characteristics. Relevant foreign researchers [6-10] also conducted a series of in-depth study on the steering characteristics and handling stability.

2. Theory analysis of vehicle steering performance

According to d'Alembert principle, automotive steering balance equations can be listed, and transform them to obtain three degrees of freedom differential equations as follows [11-14].

$$\begin{aligned} & I_z \dot{r} + I_{xz} \dot{p} = N_r r + N_\beta \beta + N_\phi \phi + N_\delta \delta \\ & MV(\dot{\beta} + r) - M_s h \dot{p} = Y_r r + Y_\beta \beta + Y_\phi \phi + Y_\delta \delta \\ & I_x \dot{p} - M_s h V(\dot{\beta} + r) + I_{xz} \dot{r} = L_p p + L_\phi \phi \end{aligned} \tag{1}$$

where, $N_r = -2(\frac{k_f a^2 + k_r b^2}{V})$, $N_\beta = 2(-ak_f + k_r b + N_1 + N_2)$, $N_\phi = 2(-k_r b E_r + ak_f E_f)$, $N_\delta = -2(ak_f - N_1)$, $Y_r = 2(\frac{-k_f a + k_r b}{V})$, $Y_\beta = -2(k_f + k_r)$, $Y_\phi = 2(k_r E_r + k_f E_f)$, $Y_\delta = 2k_f$, $L_p = -(D_r + D_f)$, $L_\phi = -(C_{\phi 1} + C_{\phi 2} - M_s gh)$.

In order to facilitate computer analysis, the system can make the four-dimensional vector $(X) = \begin{Bmatrix} \gamma \\ \beta \\ p \\ \phi \end{Bmatrix}$ as the state variables, and the formula (1) is written as a first-order differential equation of variable X.

$$[M]\left\{\dot{X}\right\} = [C]\{X\} + \{n\}\delta \tag{2}$$

where,

$[M] = \begin{bmatrix} I_z & 0 & I_{xz} & 0 \\ 0 & MV & -M_s h & 0 \\ I_{xz} & -M_s hV & I_x & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ and $[C] = \begin{bmatrix} N_r & N_\beta & 0 & N_\phi \\ Y_r - MV & Y_\beta & 0 & Y_\phi \\ M_s hV & 0 & L_p & L_\phi \\ 0 & 0 & 1 & 0 \end{bmatrix}$ are four factorial square matrixes, $\{n\} = \begin{bmatrix} N_\delta \\ Y\delta \\ 0 \\ 0 \end{bmatrix}$ is four-dimensional vector.

In the simulation, the formula (2) can be written as follows.

$$\left\{\dot{X}\right\} = [M]^{-1}[C]\{X\} + [M]^{-1}\{n\}\delta \tag{3}$$

To facilitate the analysis, each instantaneous lateral acceleration and front and rear lateral force p_{y1} and p_{y2} are calculated. The formula is as follows.

$$\begin{aligned} \ddot{Y} &= \frac{V}{g}(X_1 + \dot{X}_2) \\ P_{y1} &= 2k_f(\frac{a}{V}X_1 + X_2 - E_f X_4 - \delta) \\ P_{y2} &= 2k_r(\frac{-b}{V}X_1 + X_2 - E_r X_4) \end{aligned} \tag{4}$$

3. MATLAB simulation analysis of vehicle steering angle input

3.1. Transient characteristics simulation of understeer characteristic.

The relevant parameters of vehicle model as follows:

The total mass: m=1818.2kg

Moment of inertia around oz axis: I=3885kg $\cdot m^2$

Wheelbase: L=3.048m

Distance between center of mass and front axle: a=1.4435m

Distance between center of mass and rear axle: b=1.6045m

Total cornering stiffness of the front wheel: k1=-62618N/rad

Total cornering stiffness of the rear wheel: k2=-1101185N/rad.

At this moment, δ is 0.1 rad, then the model is built by using MATLAB as shown in Figure 1.

Different curves can be drawn with MATLAB simulation as shown in figures.

When the speed is increased from 10km/h to 100km/h (in increments of 30km/h) and δ is 0.1rad, Figures 2, 3 and 4 are the changing curves of cornering sensitivity $\left.\frac{\omega_\gamma}{\delta}\right)_s$, yaw velocity ω_r and sideslip angle β.

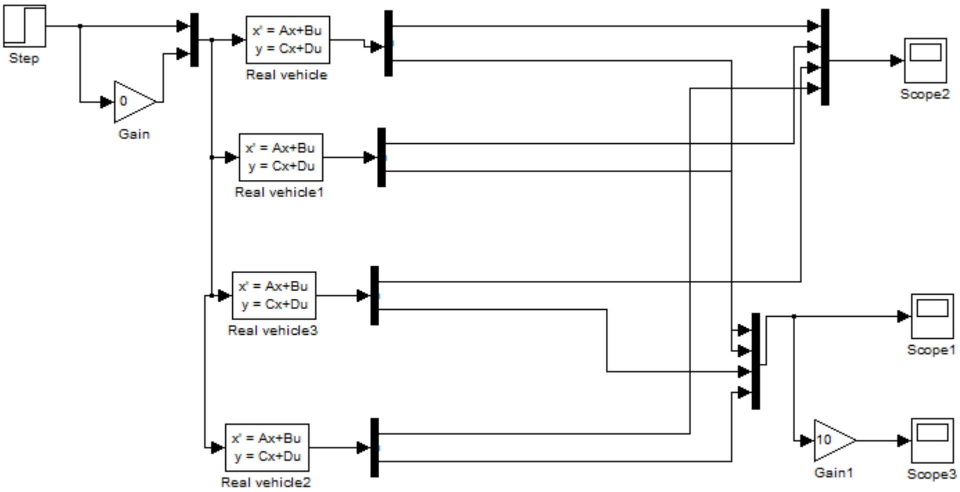

Fig.1 Simulation model with two degrees of freedom

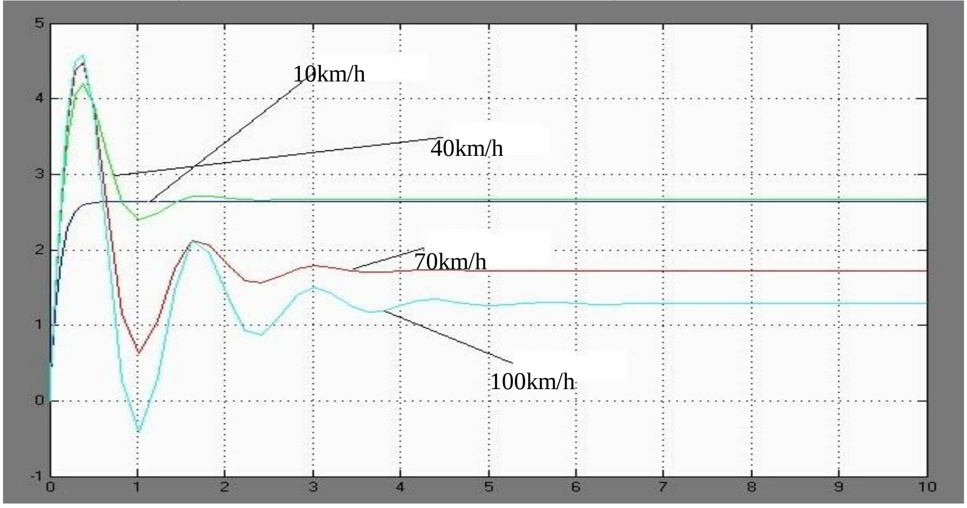

Fig.2 Cornering sensitivity changing curve

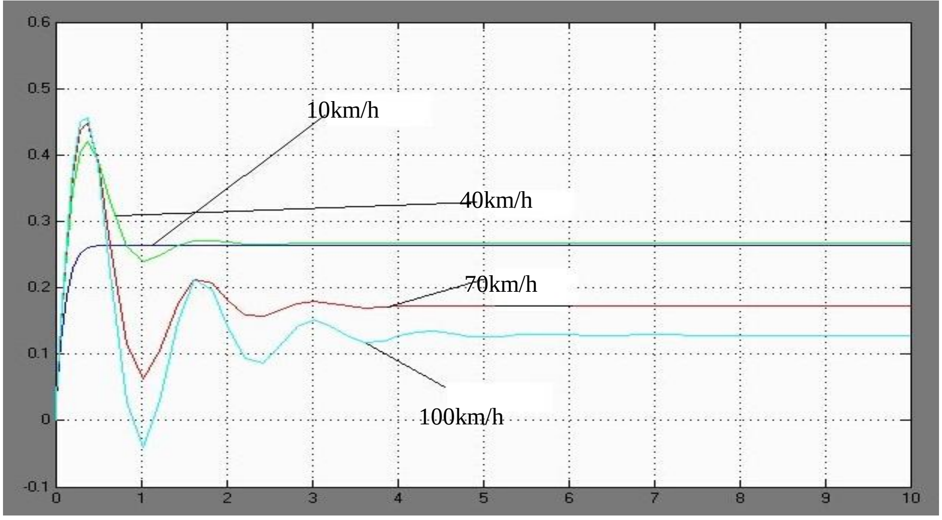

Fig.3 Yaw velocity changing curve

The conclusions can be gotten form the figures.

1) As δ is a constant, the cornering sensitivity changing curves and yaw velocity changing curves have the same trend in the same vehicle speed.

2) Characteristic speed is the turning point when cornering sensitivity and yaw velocity changes with the speed. And characteristic speed of under steer vehicle is 40km/h. It can be seen from Figure 2 and 3, when the speed is less than 40km/h, the steady-state value of cornering sensitivity and yaw velocity gradually increases along with the speed increases, when the speed is more than 40km/h, the steady-state value gradually decreases.

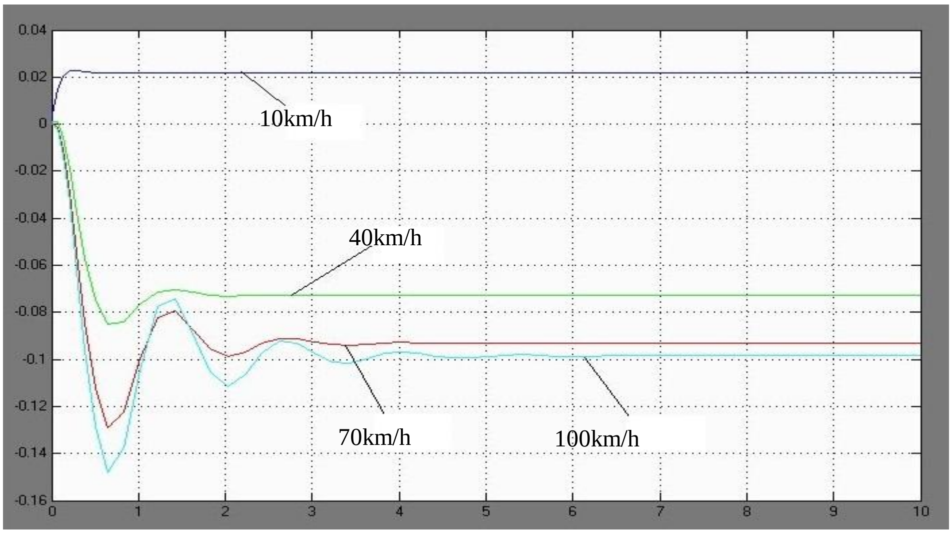

Fig.4 Sideslip angle changing curve

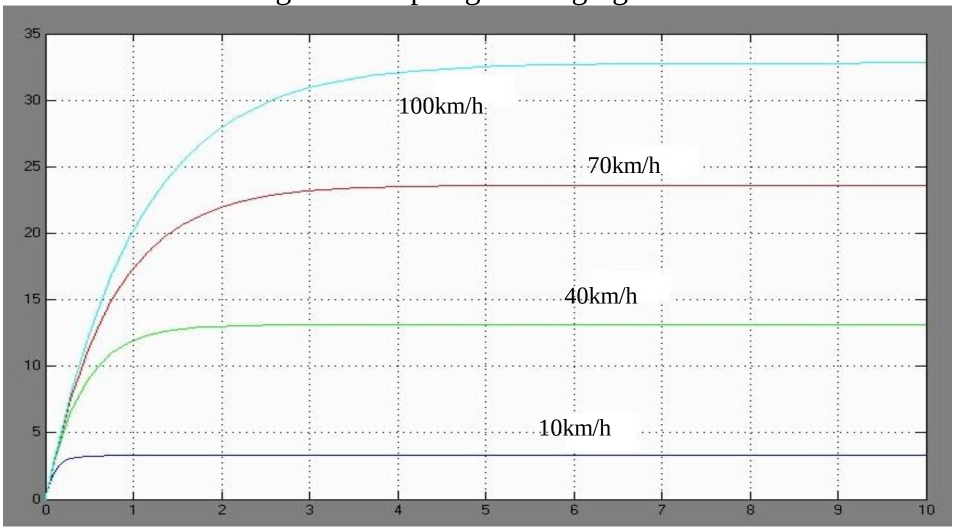

Fig.5 Cornering sensitivity changing curve

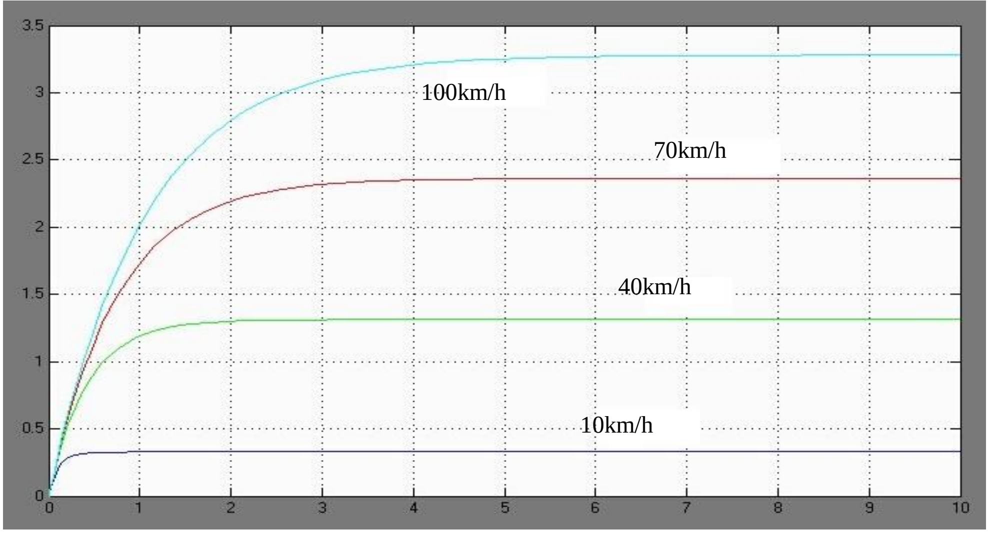

Fig.6 Yaw velocity changing curve

3) With the increase of the vehicle speed, yaw velocity overshoot gradually increases, and the time entering a steady state (i.e., the settling time) gradually lengthens. The first time reaching steady-state value (i.e., reaction time) gradually reduces, and then the vehicle becomes unstable and poor controllability.

4) As the speed increases, the vehicle sideslip angle changes from positive to negative, and gradually increases.

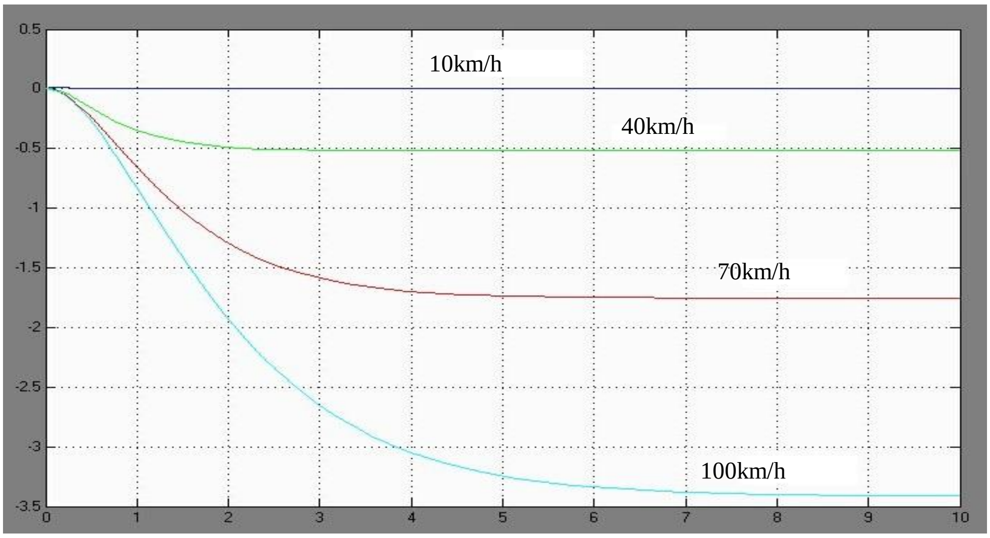

Fig.7 Sideslip angle changing curve

3.2 Transient characteristics simulation of neutral steer characteristic.

The relevant parameters of vehicle model as follows:

The total mass: m=1818.2kg

Moment of inertia around oz axis: I=3885 kg $\cdot m^2$

Wheelbase: L=3.048m

Distance between center of mass and front axle: a=1.9435m

Distance between center of mass and rear axle: b=1.1045m

Total cornering stiffness of the front wheel: k1=-62618N/rad

Total cornering stiffness of the rear wheel: k2=-1101185N/rad.

The specific model is similar to Figure 1, plug a and b into the model with other data unchanged. The following curves are obtained after the operation.

When the speed is increased from 10km/h to 100km/h (in increments of 30km/h) and δ is 0.1rad, Figures 5, 6 and 7 are the changing curves of cornering sensitivity $\left.\frac{\omega_\gamma}{\delta}\right)_s$, yaw velocity ω_r and sideslip angle β .

The conclusions can be obtained form the figures as follows.

1) Because δ is a constant, the cornering sensitivity changing curves and yaw velocity changing curves have the same trend in the same vehicle speed.

2) With the increase of the vehicle speed, the steady-state value of cornering sensitivity and yaw velocity gradually decreases. Namely, cornering sensitivity and yaw velocity are monotonically increasing with the speed.

3) There aren’t fluctuations for cornering sensitivity and yaw velocity. The yaw velocity overshoot is equal to 1. So the time entering steady state (the settling time) is equal to the first time reaching steady-state value (reaction time).

4) As the speed increases, the vehicle sideslip angle changes from positive to negative, and gradually increases. The time entering into steady state also lengthens.

3.3 Transient characteristics simulation of oversteer characteristic.

The relevant parameters of vehicle model as follows:

The total mass: m=1818.2kg

Moment of inertia around oz axis: I=3885 kg $\cdot m^2$

Wheelbase: L=3.048m

Distance between center of mass and front axle: a=2.4435m

Distance between center of mass and rear axle: b=0.6045m

Total cornering stiffness of the front wheel: k1=-62618N/rad

Total cornering stiffness of the rear wheel: k2=-1101185N/rad.

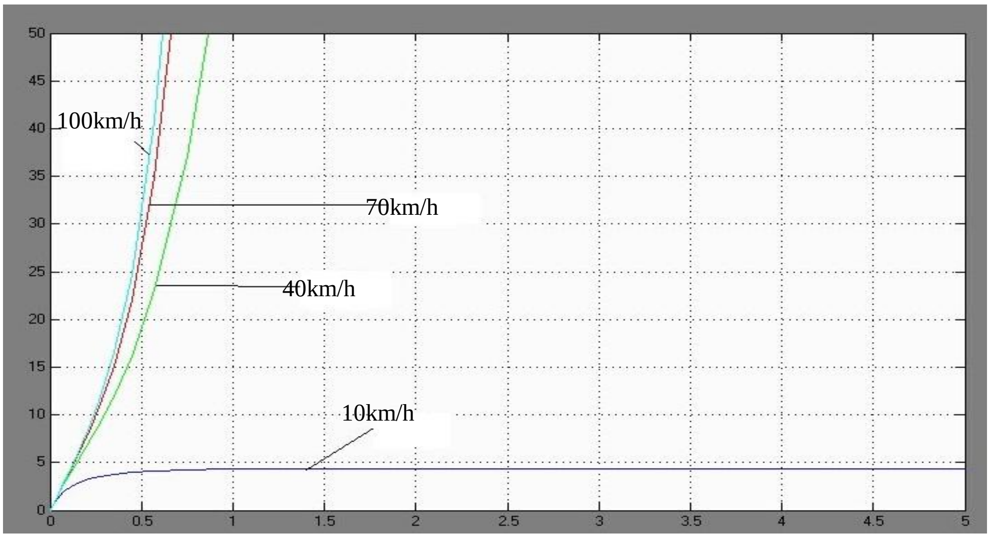

Fig.8 Cornering sensitivity changing curve

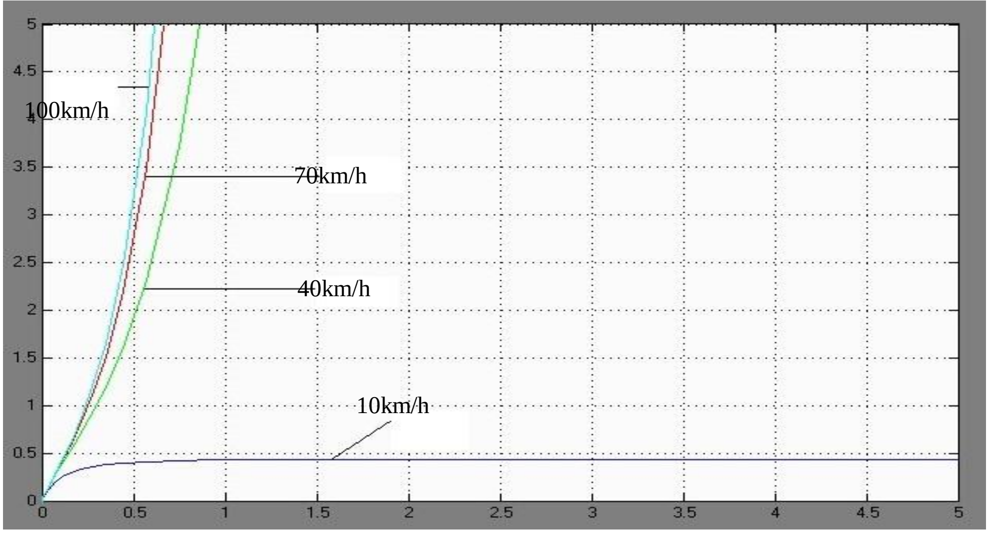

Fig.9 Yaw velocity changing curve

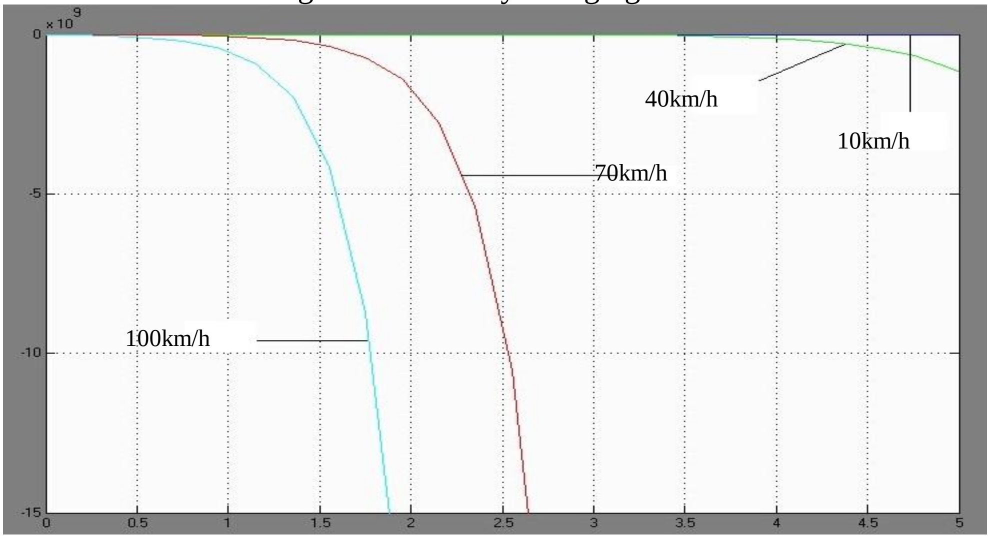

Fig.10 Sideslip angle changing curve

The specific model is similar to Figure 1, put a and b into the model with other data unchanged. The following curves are obtained after the operation.

When the speed is increased from 10km/h to 100km/h (in increments of 30km/h) and δ is 0.1rad, Figures 8, 9 and10 are the changing curves of cornering sensitivity $\left.\frac{\omega_r}{\delta}\right)_s$, yaw velocity ω_r and sideslip angle β.

The conclusions can be received form the figures.

1) As δ is a constant, the cornering sensitivity changing curves and yaw velocity changing curves have the same trend in the same vehicle speed. Both increase with the speed increases.

2) Critical speed is the turning point for vehicle entering the steady-state driving. And critical speed of oversteer vehicle is 40km/h. Figure 8 and 9 show that, when the speed is less than 40km/h, cornering sensitivity and yaw velocity can make the transition to steady state, when the speed is more than 40km/h, the small front wheel steering angle can cause great cornering sensitivity and yaw velocity. Then the vehicle can not enter the steady running, and occur sudden turn and then out of control.

3) With the increase of the speed, the vehicle sideslip angle changes from positive to negative, and gradually increases. When the speed exceeds the critical speed 40km/h, the sideslip angle rapidly increases. The vehicle becomes unstable and there will be sharp turn even roll.

3.4 Transient characteristics simulation of three freedom degree.

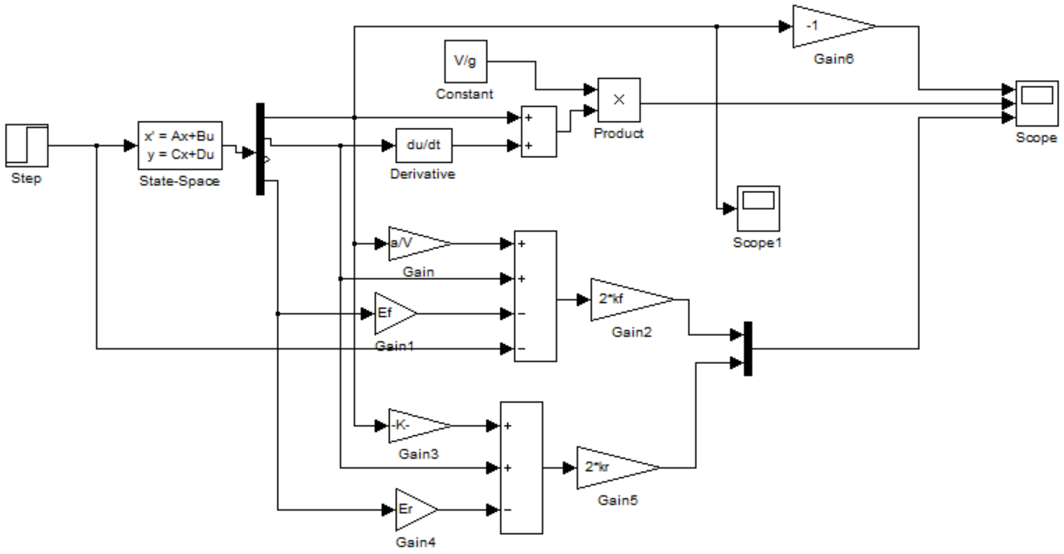

Fig.11 Simulation model with three degrees of freedom

MATLAB modeling is carried on through three degrees of freedom state equation and formula (4) as shown in Figure 1.

(1) When the speed is 20km/h, plug into the model for simulation.

In this case, the center of mass is in the front of neutral turning point. After running the curve is shown in Figure 12.

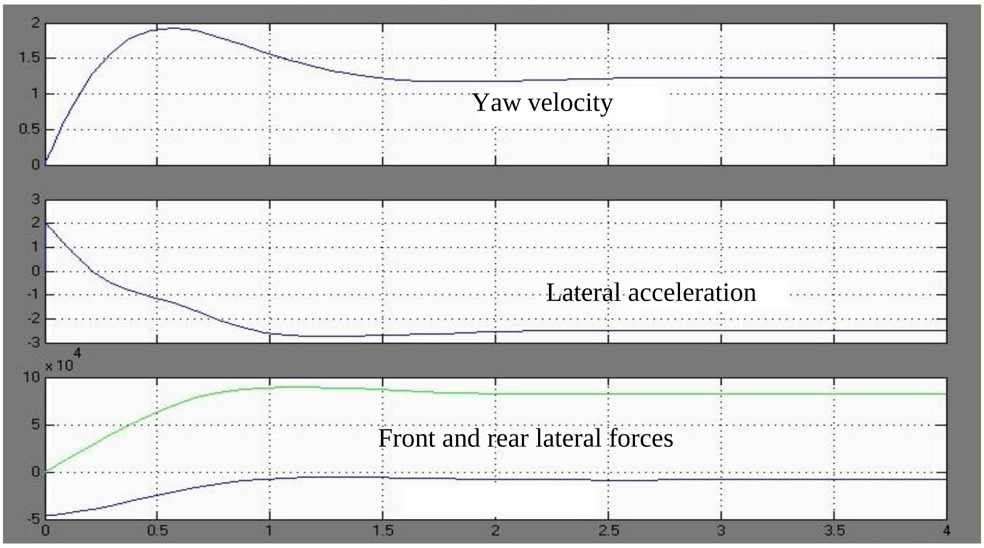

Fig.12 Simulation curve with v=20km/h

(2) When the speed is 60km/h, plug into the model and obtain the curve as shown in Figure 13.

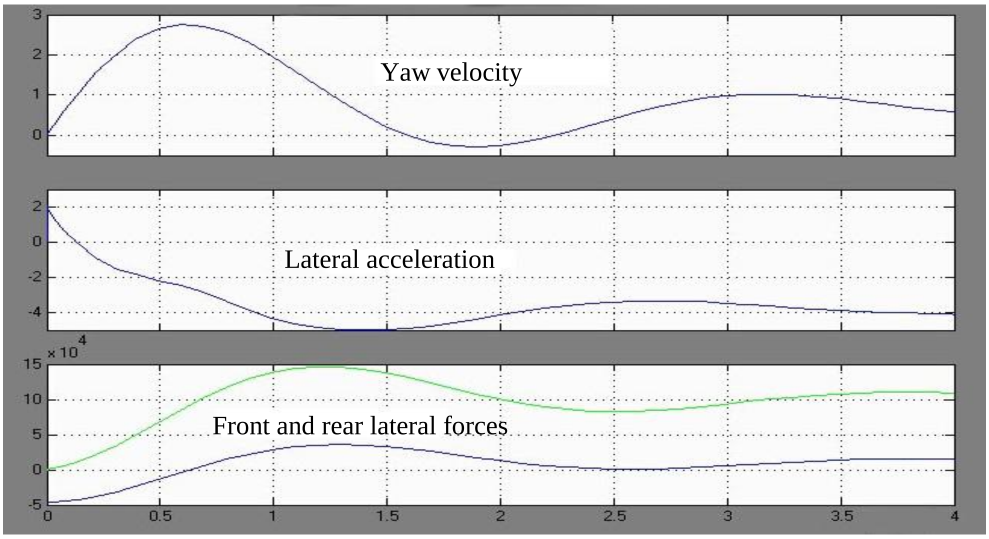

Fig.13 Simulation curve with v=60km/h

(3) When the speed is 100km/h, plug into the model and get the curve as shown in Figure 14.

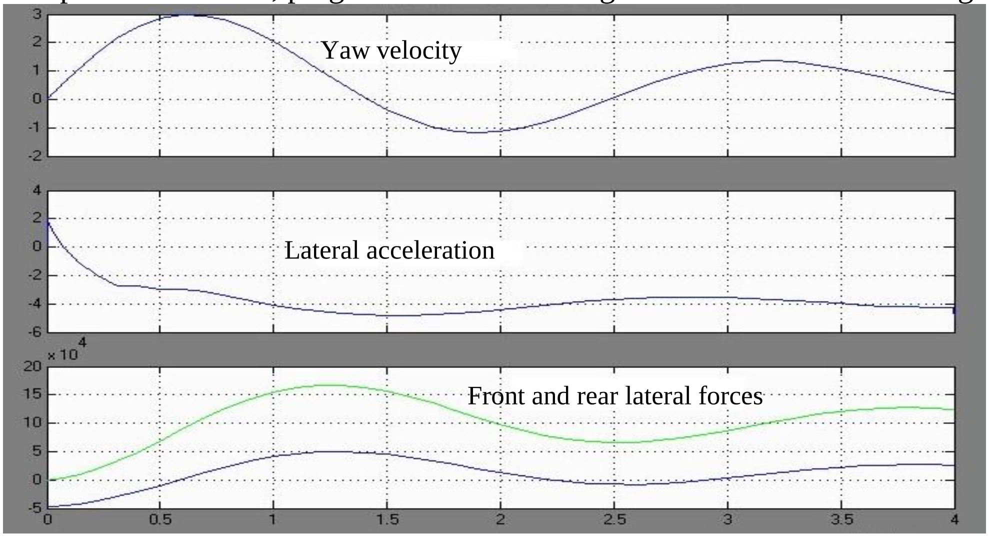

Fig.14 Simulation curve with v=100km/h

When the speed is 20km/h, 60km/h, and 100km/h, Figure 12, 13 and 14 are respectively the simulation curves of yaw velocity, lateral acceleration, and front and rear lateral forces. We can draw the following conclusions.

The center of mass is in the front of neutral turning point. As the speed increases, yaw velocity overshoot gradually increases, and the time entering a steady state (i.e., the settling time) gradually lengthens. The first time reaching steady-state value (i.e., reaction time) gradually reduces, and then the vehicle becomes unstable and poor controllability.

With the increase of the vehicle speed, lateral acceleration in steady state time gradually increases, and the vehicle becomes unstable and poor controllability.

4. Conclusion

The steering characteristic of the vehicle were researched, and the steering motions were simulated by using MATLAB. According to the simulation results, the change rules of steering sensitivity, yaw velocity, lateral acceleration, front and rear lateral forces, and sideslip angle with different speeds were obtained. The results show that the simulation analysis provides the basis for the forecast of vehicle cornering performance.

Acknowledgements

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