Simulation analysis on handling stability of virtual prototype vehicle of wheeled vehicle

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Abstract. In this paper, the steering stability of the Wheeled vehicle is evaluated by the response parameters characterizing the movement characteristics of the Wheeled vehicle. The steering stability of the virtual prototype of the Wheeled vehicle is simulated and analyzed. The steady state slewing characteristics, transient steering characteristics under angular pulse input of steering wheel steering portability response characteristics were investigated to obtain the pros and cons of each evaluation index of the Wheeled vehicle prototype. Then the strategies and suggestions for further optimization of the steering system model were proposed.

1. Introduction
There are many aspects in evaluating the steering stability index, such as steady-state steering characteristics, transient response characteristics, return normality, steering ease, typical driving performance and extreme driving capabilities [1-2]. The measured variables during simulation include: Wheeled vehicle yaw rate, body roll angle, Wheeled vehicle lateral acceleration, etc. We selected the steady-state slewing test, the transient response under the steering wheel angle pulse input, and the response of the sample car under three operating conditions to investigate the handling stability of the vehicle model.

2. Steady state rotation test
The steady-state swing test method is an important test method for studying the response characteristics of the Wheeled vehicle. The steady-state swing characteristic is a sufficient condition for whether the vehicle system is stable. Steady-state steering characteristics (understeer characteristics) of Wheeled vehicles have a very important influence on the direction control of Wheeled vehicles. Oversteerability and excessive understeerability will make it difficult to control Wheeled vehicles [3]. Some Wheeled vehicles have poor steering due to poor design parameters. Although they have a certain amount of understeer when the lateral acceleration is very small, they exhibit intense oversteer under a slightly larger centripetal acceleration, causing the Wheeled vehicle to accidentally flick or the violent turnaround caused a serious accident. Therefore, the study of steady-state steering characteristics is an important aspect of the research on the steering stability of Wheeled vehicles.

The continuous acceleration method of fixed steering wheel angle is: the Wheeled vehicle travels along the drawn circle at the lowest stable speed, and then the Wheeled vehicle starts, accelerates slowly and evenly (longitudinal acceleration does not exceed 0.25m/s), maintaining the steering wheel
angle No change [4], the lateral acceleration reaches 6.5m/s² (or the maximum lateral acceleration that can be achieved due to the limitation of engine power, or until the Wheeled vehicle appears unstable).

2.1. Steadystate rotation simulation test

The national standard GB/T6323.6-94 stipulates that the continuous acceleration method with a fixed turning radius is consistent with the requirements of the international standard ISO4138-82 steady-state rotation test. In this article, the simulation is based on the 6323.6-94 fixed steering wheel angle steady-state rotation test, simulation the middle-Wheeled vehicle starts to travel along a circle with an initial radius of 15m at the lowest speed, and the steering wheel angle is 167.8 degrees. Then accelerate (acceleration is 250mm/s) and fix the steering wheel angle. This test is a right-turn steering wheel group, and the simulation analysis results are as follows:

![Figure 1. Lateral acceleration response.](image1)

![Figure 2. Vehicle trajectory.](image2)

![Figure 3. Yaw rate response.](image3)

![Figure 4. Roll angle response.](image4)

2.2. Analysis of simulation results

According to the provisions of GB/T6323.6-94, each measurement value and lateral acceleration curve are made separately to examine its steady-state characteristics.
Figure 5. Response of yaw rate-lateral acceleration.

Figure 6. Body roll angle-lateral acceleration curve.

Figure 7. Slip angle difference-lateral acceleration curve.

Figure 8. Turning radius ratio \((R/R_c)\)-lateral acceleration curve.
2.2.1. **Body roll angle.** The turning angle of the body around the roll axis under the action of the lateral force is called the body roll angle. The body roll angle is an important parameter related to the steering stability and smoothness of the Wheeled vehicle. The value of the roll angle affects the steady-state response and the transient response of the yaw rate of the Wheeled vehicle. The roll angle itself is also an important indicator for evaluating the handling stability of Wheeled vehicles. Excessive roll angle makes the driver feel unstable and unsafe. At the same time, the body roll causes the front steering wheel to rotate around the kingpin, and the rear wheel rotates around an axis perpendicular to the ground, causing roll steering. When the wheels on one side of the Wheeled vehicle encounter bumps or pits, impact will be felt in the cabin. The poor rollability curve of the body can be seen Due to the large lateral acceleration, the roll angle at the center of mass of the body is small, which is not easy to cause roll steering, but the ride may be poor.

2.2.2. **The difference between the front and rear axles.** The curve of the relationship between the difference between the front and rear axles and the lateral acceleration. As can be seen from the curve in the figure, when the absolute value of the lateral acceleration is less than 3.5m/s², the deviation of the slip angle is approximately linear with respect to the lateral acceleration; when the lateral acceleration is absolutely greater than 3.5m/s², this is because The tire cornering characteristics have entered the obvious non-linear region. Many Wheeled vehicles have a significant change in steady-state response characteristics under large lateral acceleration, and cannot maintain circular driving, and the steering radius increases or decreases rapidly. It can be seen from Figures 5-7 that the slope deviation and lateral acceleration curve slope in the figure are greater than zero. As the lateral acceleration increases, the steering radius increases, and the Wheeled vehicle always has insufficient steering.

3. **Angle pulse input simulation test**

The steering wheel angle pulse input test method is an important test method for studying the transient response characteristics of Wheeled vehicles, especially a simple test method for studying the frequency response characteristics of Wheeled vehicles. The national standard GB/T6323.3-94 makes relevant regulations for the test. This test is usually used for frequency characteristic analysis.

According to the average value of the test data processing results, draw the amplitude-frequency characteristic and phase-frequency characteristic diagram respectively by turning the steering wheel to the left and right. The abscissa is logarithmic, or linear coordinates can also be used. In the steering stability of Wheeled vehicles, the dynamic characteristics of the Wheeled vehicle are often characterized by the frequency response characteristics of the Wheeled vehicle's yaw rate with the steering wheel angle as the input and the wheeled vehicle's yaw rate as the output.

3.1. **Angle pulse data processing**

The average value of resonance frequency \( f_p \), resonance peak level D and phase lag angle \( \alpha \) are determined according to GB/T 13047. According to the scoring criteria proposed in Guo Konghui's "Wheeled vehicle Handling Dynamics", the indicators are scored as follows:

- Evaluation score of resonance frequency \( f_p \)

\[
N_f = 60 + \frac{40(f_p - f_{60})}{f_{100} - f_{60}}
\]

Where: \( f_{100} \)-upper limit value of resonance frequency, 1.30 Hz

\( f_{60} \)—Lower limit value of resonance frequency, 0.70 Hz

\( f_p \)— In the steering wheel angle pulse test, the corresponding frequency at the resonance peak of the amplitude-frequency characteristic, Hz
Resonance peak level

\[ D = 20 \cdot \lg \frac{A_p}{A_0} \]  

(2)

Where: \( A_p = f' \cdot f \) — yaw rate gain at, \( s^{-1} \)

\( A_0 = f = 0 \) — Yaw rate gain at, \( s^{-1} \)

Resonance peak level D evaluation score value

\[ N_D = 60 + \frac{40(D_{60} - D)}{D_{60} - D_{100}} \]  

(3)

In the formula: \( D_{60} \) — the lower limit of the resonance peak level, 5.00dB

\( D_{100} \) — Upper limit value of resonance peak level, 2.00dB

D — Test value of resonance peak level, dB

Evaluation score of phase lag angle

\[ N_\alpha = 60 + \frac{40(\alpha_{60} - \alpha)}{\alpha_{60} - \alpha_{100}} \]  

(4)

Where: \( \alpha_{60} \) — the lower limit value of the phase lag angle, 60.0

\( \alpha_{100} \) — Upper limit value of phase lag angle, 20.0

\( \alpha \) — The test value of the phase lag angle at the input frequency of 1 Hz, (°)

The comprehensive evaluation score value of the steering wheel angle pulse input test

\[ N_M = \frac{N_f + N_D + N_\alpha}{3} \]  

(5)

3.2. Angle pulse test simulation

According to the steering wheel angle step input test requirements stipulated in the national standard GB/T6323.2-94, the simulation of the middle-wheel armored vehicle carried out the steering wheel angle step input test simulation at the initial speed of 70%-140km/H of the maximum speed of 195km/H. The pulse width is 0.4s. The steering wheel turns left. The maximum steering angle is 46d. The steering wheel rotation angle is controlled by a pulse function. The simulation results are shown in the following figure.

![Figure 9. Turning the steering wheel to the left.](image-url)
The various parameters of the armored vehicle will be given in the appendix program. According to the requirements, the simulink model is established.

4. Analysis of maneuverability simulation results

In the process of data analysis, the dynamic characteristics of the Wheeled vehicle are characterized by the frequency response of the yaw rate of the Wheeled vehicle with the steering wheel angle as the input and the yaw rate of the Wheeled vehicle as the output.

4.1. Steady yaw rate gain

The Wheeled vehicle research institutes of several universities in the Federal Republic of Germany have obtained the following statistical values through a large number of steering wheel step tests: the yaw rate gain of modern cars is 0.2-0.3 (1/s). It can be seen from the above figure that the steady-state yaw rate gain of the vehicle is 0.23 (1/s), which meets the requirements, but the gain at resonance is larger, reaching 0.5457 (1/s).

4.2. Resonance peak frequency
The higher the resonance frequency value, the better the steering stability. Car research results from the Japan Wheeled vehicle Research Institute [36]: The mean resonance frequency is 1.16 Hz. The resonance frequency of this prototype is 1.3672 Hz, which is slightly higher than the average.

4.3. The increase ratio at resonance
The increase is smaller than it should be. Car research results of the Japan Wheeled vehicle Research Institute: The average increase ratio at the resonance frequency is 2.41-2.51dB. The sample car has a large amplitude, reaching 7.6 dB, and the sample car has poor instantaneous stability.

5. Conclusions
In this paper, the handling stability of the virtual prototype of the car is analyzed by simulation. We mainly selects three aspects: steady-state turning characteristics, transient steering characteristics under steering wheel angle pulse input, and steering portability response characteristics. We use the scoring criteria proposed in Guo Konghui's Vehicle Handling Dynamics to analyze and score the simulation results. It can be seen that the evaluation indicators of this sample car are better, but the transient response stability is poor. Meanwhile, the steering system model also needs advanced optimization. This conclusion can directly guide the design and development of the wheeled vehicle test prototype.

References
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