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Controllability and Stability Test Procedure for Automobile

汽车操纵稳定性试验方法

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Controllability and Stability Test Procedure for Automobile

1 Scope

This Standard specifies the pylon course slalom test procedure, steering transient response test procedure (steering wheel angle step input and steering wheel angle pulse input), returnability test procedure, steering efforts test procedure, steady static circular test procedure, and controllability and stability test procedure for the central area of steering wheel for automobile.

The pylon course slalom test procedure, steering transient response test procedure (steering wheel angle step input and steering wheel angle pulse input), returnability test procedure, and steering efforts test procedure are applicable to Type-M, Type-N and Type-G vehicles. The steady static circular test procedure is applicable to bi-axial Type-M, Type-N and Type-G vehicles. The controllability and stability test procedure for the central area of steering wheel is applicable to Type-M_1 and Type-N_1 vehicles. Other types of vehicles may take them as a reference.

2 Normative References

The following documents are indispensable to the application of this document. In terms of references with a specified date, only versions with a specified date are applicable to this document. In terms of references without a specified date, the latest version (including all the modifications) is applicable to this document.

GB/T 3730.1 *Motor Vehicles and Trailers - Types - Terms and Definitions*

GB/T 3730.2 *Road Vehicles - Masses - Vocabulary and Codes*

GB/T 12534-1990 *Motor Vehicles - General Rules of Road Test Method*

GB/T 12549 *Terms and Definitions for Vehicle Controllability and Stability*

GB/T 15089 *Classification of Power-driven Vehicles and Trailers*

3 Instruments and Equipment

3.1 The instruments required for the test are as follows:

a) Speedometer;

b) Steering wheel torque and steering wheel angle measuring instrument;

3.4 The bandwidth of the entire measurement system, including the sensor and recording system, is not less than 3 Hz.

3.5 The various sensors are installed in accordance with their respective instruction manuals. Specifically speaking, the speedometer shall be installed on the longitudinal symmetry plane of the vehicle; the controllability and stability tester shall be as close to the center of mass of the vehicle as possible.

4 Test Conditions

4.1 Test Vehicles

4.1.1 Before the test, determine the wheel positioning parameters. Check, adjust and tighten the steering system and suspension system; lubricate them as required. The test can only be carried out if it is determined that the test vehicle has met the technical conditions specified by the manufacturer. The values of the relevant parameters being determined and checked are recorded in Appendix A and Appendix B.

4.1.2 If new tires are used for the test, before the test, they shall at least go through 200 km of normal running. If used tires are used for the test, after the test is completed, the residual tire crown pattern depth shall be not less than 1.6 mm. The tire pressure shall comply with the exit-factory technical requirements of the vehicle.

4.1.3 Before the test, at the test speed, run straight for 10 km, or, along the circumference of a radius of 15 m, and a corresponding speed with a lateral acceleration of 3 m/s^2, run for 500 m (one time for left turn, one time for right turn), so as to warm up the tires.

4.1.4 In pylon course slalom test, the load state is the maximum design total mass of the vehicle. In steering transient response test (steering wheel angle step input and steering wheel angle pulse input), returnability test, steering efforts test, steady static circular test, and controllability and stability test for the central area of steering wheel, the load state is the maximum design total mass and light load. The light load refers to the state of the vehicle's kerb weight, except for the driver, the tester and instrument, there is no other load. In terms of vehicles with a small load capacity, if the light load mass has exceeded 70% of the maximum total mass, then, it is unnecessary to conduct a light load test. The load of Type-N vehicles (sandbags recommended) is evenly distributed in the cargo box. The load (or dummies) of Type-M vehicles is distributed on the seats and the floor, and the ratio shall comply with the exit-factory technical requirements of the vehicle. The mass of the axle load must comply with the manufacturer's regulations.

4.2 Test Site and Environment

4.2.1 Test site shall be dry, flat and clean, with cement concrete or asphalt pavement. The slope in any direction shall not be greater than 2%. In terms of the controllability

$\bar{r}_i$---the average yaw velocity of the i^th test, expressed in (°)/s;

r_{ij}---within the effective staking area, the peak value of the time-history curve of the yaw velocity (see Figure 2), expressed in (°)/s.

5.4.4 Average roll angle of vehicle body

The average roll angle of vehicle body of the i^th test shall be determined in accordance with Formula (4):

$$\bar{\phi}_i = \frac{1}{4}\sum_{j=1}^{4} |\phi_{ij}| \quad \cdots\cdots (4)$$

Where,

$\bar{\phi}_i$---the average roll angle of vehicle body of the i^th test, expressed in (°);

ϕ_{ij}---within the effective staking area, the peak value of the time-history curve of the roll angle of vehicle body (see Figure 2), expressed in (°).

5.4.5 Average lateral acceleration

5.4.5.1 In accordance with one of the following methods, determine the true value of lateral acceleration:

a) In terms of lateral acceleration measurement, the output axis shall be aligned or parallel to the *Y*-axis. If the acceleration sensor rolls with the vehicle body, then, it shall be corrected in accordance with Formula (5):

$$a_y = \frac{a'_y - g \cdot \sin\phi}{\cos\phi} \quad \cdots\cdots (5)$$

Where,

a_y---the true lateral acceleration, expressed in m/s^2;

a'_y---the lateral acceleration indicated by the acceleration sensor, expressed in m/s^2;

g---the acceleration of gravity, expressed in 9.81 m/s^2;

ϕ---the roll angle of vehicle body, expressed in (°).

b) Transient yaw velocity (expressed in rad/s) multiplied by the transient forward speed of the vehicle (expressed in m/s).

5.4.5.2 In accordance with Formula (6), determine the average lateral acceleration of the i^th test:

6.2 Measurement Parameters

a) Vehicle forward speed;

b) Steering wheel angle;

c) Yaw velocity;

d) Roll angle of vehicle body;

e) Lateral acceleration;

f) Slip angle of vehicle.

6.3 Test Methods

6.3.1 The test speed is determined in accordance with 70% of the maximum speed of the tested vehicle (rounded off to an integer multiple of 10). However, the maximum test speed should not exceed 120 km/h.

6.3.2 Before the test, at the test speed, run for 10 km, so as to warm up the tires.

6.3.3 Turn on the instrument power to reach the normal working temperature. In the stopping state, perform signal zero calibration.

6.3.4 In accordance with the steady-state lateral acceleration values of 1.0 m/s^2, 1.5 m/s^2, 2.0 m/s^2, 2.5 m/s^2 and 3.0 m/s^2, pre-select the position of the steering wheel angle (input angle).

6.3.5 The vehicle runs in a straight line at the test speed. Firstly, in accordance with the input direction, gently approach the steering wheel, eliminate the free stroke of the steering wheel and start recording the zero line of the various measurement variables. After (0.2 ~ 0.5) s, at the fastest speed (the jump time is not more than 0.2 s, or the jump speed is not lower than 200°/s), turn the steering wheel, so as to reach the pre-selected position and fixate it for a few seconds (until the measurement variables transit to new steady-state values), then, stop the recording. During the recording process, maintain the vehicle speed unchanged.

6.3.6 The test is carried out in two directions: turning left and turning right. It may also be carried out alternately in two directions, or, it may be continuously carried out in one direction, then, in the other direction.

6.4 Test Data Processing

6.4.1 The steady-state values of the various measurement variables shall adopt the mean value after entering the steady state. If the rate of change of the vehicle's forward speed is greater than 5%, or if the change of the steering wheel angle exceeds 10% of the mean value, then, this test is invalid.

r_0---the steady-state value of yaw velocity response (see Figure 7), expressed in (°)/s;

r_{max}---yaw velocity response peak (see Figure 7), expressed in (°)/s.

6.4.6 The total square deviation of yaw velocity shall be determined in accordance with Formula (8):

$$E_r = \sum_{k=0}^{n}\left(\frac{\delta_{swk}}{\delta_{sw0}} - \frac{r_k}{r_0}\right)^2 \times \Delta t \qquad \cdots\cdots (8)$$

Where,

E_r---total square deviation of yaw velocity, expressed in s;

δ_{swk}---transient value of steering wheel angle input, expressed in (°);

r_k---transient value of yaw velocity output, expressed in (°)/s;

δ_{sw0}---end value of steering wheel angle input, expressed in (°);

r_0---steady-state value of yaw velocity response, expressed in (°)/s;

n---the number of sampling points, till the vehicle's yaw velocity response reaches a new steady-state value;

Δ_t---time interval of sampling, expressed in s; it shall not be more than 0.2 s.

6.4.7 The total square deviation of lateral acceleration shall be determined in accordance with Formula (9):

$$E_{ay} = \sum_{k=0}^{n}\left(\frac{\delta_{swk}}{\delta_{sw0}} - \frac{a_{yk}}{a_{y0}}\right)^2 \times \Delta t \qquad \cdots\cdots (9)$$

Where,

E_{ay}---total square deviation of lateral acceleration, expressed in s;

a_{yk}---transient value of lateral acceleration response, expressed in m/s^2;

a_{y0}---steady-state value of lateral acceleration response, expressed in m/s^2.

6.4.8 "Vehicle factor" (TB) is obtained by multiplying the peak response time of yaw velocity by the steady-state vehicle slip angle.

6.5 Test Result Expression

6.5.1 At the test vehicle speed, and the lateral acceleration of 2 m/s^2, record the following data in Table 5:

a) Speedometer;

b) Steering wheel torque and steering wheel angle measuring instrument;

c) Controllability and stability tester;

d) Multi-channel data acquisition system.

7.2 Measurement Parameters

a) Vehicle forward speed;

b) Steering wheel angle;

c) Vehicle's lateral acceleration;

d) Vehicle's yaw velocity.

7.3 Test Methods

7.3.1 The test speed shall be 70% of the maximum design speed of the tested vehicle and rounded off to an integer multiple of 10.

7.3.2 Before the test, at the test speed, run for 10 km to warm up the tires.

7.3.3 Turn on the instrument power to let it reach the normal working temperature.

7.3.4 The vehicle runs in a straight line at the test speed; its yaw velocity is 0 ± 0.5°/s. Make a mark, note the central position of the steering wheel (straight-running position). Then, offer a triangular pulse angle input to the steering wheel (see Figure 16). During the test, turn the steering wheel to the left (or the right), then, quickly turn it back to the previous position (timely correction is allowed) and maintain stationary; record the whole process, until the vehicle returns to the straight-running state. The input pulse width of the steering wheel angle is (0.3 ~ 0.5) s, and the maximum steering angle shall make the maximum lateral acceleration during the transition of this test to be 4 m/s^2. When turning the steering wheel, the overshoot of the steering angle shall be minimized. During the recording time, the position of the accelerator pedal shall remain unchanged.

d) Multi-channel data acquisition system.

8.2 Measurement Parameters

a) Vehicle forward speed;

b) Yaw velocity;

c) Lateral acceleration.

8.3 Test Methods

8.3.1 Low-speed returnability test

8.3.1.1 On the test site, use bold colors to draw a circle with a radius of not less than 15 m.

8.3.1.2 Turn on the instrument power to let it reach the normal working temperature.

8.3.1.3 The test vehicle runs in a straight line. Record the zero line of the various measurement variables. Then, adjust the steering wheel angle, so that the vehicle runs along a circle with a radius of 15 m. Adjust the vehicle speed, so that the lateral acceleration can reach (4 ± 0.2) m/s^2. Fixate the steering wheel angle; stabilize the vehicle speed and start recording. After 3 s, quickly release the steering wheel and make a mark (it is recommended to use a micro-switch and a signal channel for simultaneous recording). Record the vehicle movement process within at least 4 s after the release. During the recording time, the accelerator pedal position shall remain unchanged.

8.3.1.4 In terms of vehicles with a lateral acceleration of less than (4 ± 0.2) m/s^2, in accordance with the highest lateral acceleration that the tested vehicle can reach, conduct the test; indicate this in the test report (remarks in Table 8).

8.3.1.5 The test shall be conducted in two directions: left-turn and right-turn; three times in each direction.

8.3.2 High-speed returnability test

8.3.2.1 This test shall be carried out for vehicles whose maximum speed exceeds 100 km/h.

8.3.2.2 The test vehicle speed shall be 70% of the maximum speed of the tested vehicle and rounded off to an integer multiple of 10.

8.3.2.3 Turn on the instrument power to let it reach the normal working temperature.

8.3.2.4 The tested vehicle runs in a straight line at the test speed along the test section; record the zero line of the various measurement variables. Then, turn the steering

$\overline{F}_{max}$---the mean value of the maximum applied force of the steering wheel, expressed in N;

D---the diameter of the previous steering wheel of the tested vehicle, expressed in m.

9.4.4 Work function of steering wheel

9.4.4.1 The work function of every week of running along the lemniscate path shall be determined in accordance with Formula (27):

$$W_i = \frac{1}{57.3}\sum_{j=1}^{n_i-1} M_{swij} \cdot (\delta_{swi(j+1)} - \delta_{swij}) \quad \cdots\cdots (27)$$

Where,

W_i---the work function of the steering wheel in the i^{th} week (i = 1 ~ 3) of running along the lemniscate path, expressed in J.

M_{swij}---the applied torque of the steering wheel at the j^{th} (j = 1 ~ n_i - 1) sampling point in the i^{th} week (i = 1 ~ 3) of running along the lemniscate path, expressed in N•m;

n_i---the number of sampling points in the i^{th} week of running along the lemniscate path;

$\delta_{swi(j+1)}$---the steering wheel angle at the j + 1 (j = 1 ~ n_i - 1) sampling point in the i^{th} week (i = 1 ~ 3) of running along the lemniscate path, expressed in (°);

δ_{swij}---the steering wheel angle at the j (j = 1 ~ n_i - 1) sampling point in the i^{th} week (i = 1 ~ 3) of running along the lemniscate path, expressed in N•m.

9.4.4.2 The mean value of the work function of the steering wheel shall be determined in accordance with Formula (28):

$$\overline{W} = \frac{\sum_{i=1}^{3} W_i}{3} \quad \cdots\cdots (28)$$

Where,

$\overline{W}$---the mean value of the work function of the steering wheel, expressed in J.

9.4.5 Average friction torque and average friction of steering wheel

9.4.5.1 The average friction torque of the steering wheel of every week of running along the lemniscate path shall be determined in accordance with Formula (29):

$$\overline{M}_{swfi} = \frac{57.3W_i}{2(|-\delta_{swmax}| + |+\delta_{swmax}|)} \quad \cdots\cdots (29)$$

Where,

in 10.3.2 ~ 10.3.6 may be adopted to conduct the test. Or, the test method specified in Appendix D may be adopted to conduct the test.

10.3.2 On the test site, use bold colors to draw a circle with a radius of not less than 15 m.

10.3.3 Turn on the instrument power to let it warm up to the normal working temperature.

10.3.4 Before the test starts, the vehicle shall run at a speed corresponding with the lateral acceleration of 3 m/s^2 along the drawn circle for 5 circles, so as to warm up the tires.

10.3.5 Operate the vehicle to run along the drawn circle at the lowest stable speed. When the speed sensor installed on the longitudinal symmetry plane of the vehicle can be aligned with the drawn circle on the ground within half a circle, fixate the steering wheel, stop the vehicle and start recording; record the zero line of the various variables. Then, the vehicle starts, slowly and evenly accelerates (the longitudinal acceleration does not exceed 0.25 m/s^2), until the lateral acceleration of the vehicle reaches 6.5 m/s^2 (or the maximum lateral acceleration that can be achieved due to engine power limitation, or when the vehicle manifests an unstable state). Record the entire process.

10.3.6 The test shall be conducted in two directions: left-turning and right-turning; test 3 times in each direction. At the beginning of each test, it shall be ensured that the longitudinal symmetry plane of the vehicle body is in the center of the drawn circumferential line.

10.4 Test Data Processing

10.4.1 Lateral acceleration

The lateral acceleration of the various points shall be determined in accordance with the method specified in 5.4.5.1 b).

10.4.2 Turning radius ratio

In accordance with the recorded yaw velocity and vehicle forward speed, the turning radius of the various points shall be determined in accordance with Formula (33):

$$R_k = \frac{57.3 \cdot v_k}{r_k} \qquad \cdots\cdots (33)$$

Where,

R_k---the turning radius of the kth point, expressed in m;

v_k---the transient value of vehicle speed at the kth point, expressed in m/s;

reference value, and the allowable peak deviation is ± 10%. In order to obtain good test data when the lateral acceleration is 1 m/s^2, and ensure that the operating range of the vehicle and its subsystems exceeds the hysteresis zone, the reference value of the lateral acceleration peak value is 2 m/s^2, or, a smaller value, or other values not exceeding 4 m/s^2 may also be adopted.

11.3.4 Throughout the test process, the angular amplitude of the steering wheel and the angular velocity of passing through the central area shall be as consistent as possible. On the premise of ensuring that the longitudinal speed of the vehicle is within the specified range, the change of the accelerator pedal position shall be as small as possible. In the data segment used for data analysis, the longitudinal vehicle speed variation shall not exceed ± 3% of the test vehicle speed.

11.3.5 Throughout the test, record all measurement parameters, including the various measurement variables in the initial driving state. In order to ensure that the test is not affected by the use of the instruments, the data recording shall continue for more than 1 s after the completion of all tests.

11.3.6 The steering input during the test can be implemented through manual or steering robot. When manual input of steering signal is adopted, the test shall last at least 40 s, so as to ensure that at least 8 input cycles of data are obtained. When due to the limitation of the test site, it is impossible to obtain sufficient continuous data with good consistency, it is allowed to combine a series of short data for test analysis. Under this circumstance, it shall be ensured that there are at least 20 cycles of data, and appropriate mathematical statistical methods shall be adopted to process the test data; the statistical methods shall be included in the test report. When a steering robot is adopted to input steering signal, the test shall last at least 20 s, so as to ensure that at least 4 input cycles of data are obtained.

11.4 Test Data Processing

11.4.1 The lateral acceleration value shall be determined in accordance with the method specified in 5.4.5.1 a) or 5.4.5.1 b).

11.4.2 Meticulously analyze the time-history of the variables listed in 11.2, especially the steering wheel angle, steering wheel yaw velocity, vehicle longitudinal speed and lateral acceleration; at least select four cycles with good control indicators for data analysis.

11.4.3 As it is shown in Figure 29, plot the data filtered in accordance with the requirements of 11.5.1 ~ 11.5.5 in a rectangular coordinate system. The graph is a loop group formed by the superposition of multiple hysteresis loops; the number of loops equals to the number of the filtered loops.

11.4.4 The loop group shall be averaged in an appropriate mode. The recommended method is to perform poly-nominal fitting on the upper and the lower parts of the test

b) Abscissa hysteresis interval;

c) Slope.

11.5 Test Result Expression

11.5.1 The relation curve of steering wheel torque and steering wheel angle

In Figure 30, draw the relation curve of steering wheel torque and steering wheel angle. In addition, in accordance with the method described in 11.4.4 and 11.4.5, obtain the following parameters:

a) Average steering stiffness---average slope of the curve in the interval of ± 10% of the peak steering angle in Figure 30;

b) Steering stiffness of the central area of steering wheel---the slope when the steering wheel angle is at the zero point in Figure 30;

c) Steering friction torque---the ordinate hysteresis interval when the steering wheel angle is at the zero point in Figure 30;

d) Steering angle hysteresis of steering wheel---the abscissa hysteresis interval when the steering wheel torque is at the zero point in Figure 30.

11.5.2 The relation curve of yaw velocity and steering wheel angle

In Figure 31, draw the relation curve of yaw velocity and steering wheel angle; obtain the following parameters:

a) Yaw velocity gain---the average slope of the curve in the interval of ± 20% of the peak steering wheel angle in Figure 31 obtained in accordance with the method described in 11.4.4 and 11.4.5;

b) Yaw velocity response hysteresis time---the hysteresis time of the yaw velocity response to the steering wheel angle input in the time-domain curve corresponding to each loop in Figure 31.

11.5.3 The relation curve of yaw velocity and steering wheel torque

In Figure 32, draw the relation curve of yaw velocity and steering wheel torque. In addition, in accordance with the method described in 11.4.4 and 11.4.5, obtain the yaw velocity response hysteresis, namely, the ordinate hysteresis interval.

11.5.4 The relation curve of lateral acceleration and steering wheel angle

In Figure 33, draw the relation curve of lateral acceleration and steering wheel angle. In addition, in accordance with the method described in 11.4.4 and 11.4.5, obtain the following parameters:

a) Average steering sensitivity---the average slope of the curve in the interval of ± 20% of the peak steering wheel angle in Figure 33;

b) Minimum steering sensitivity---the minimum slope of the curve in the interval of ± 1 m/s^2 of lateral acceleration in Figure 33;

c) When lateral acceleration is ± 1 m/s^2, the steering sensitivity---the slope of the curve at 1 m/s^2 of lateral acceleration in Figure 33;

d) Lateral acceleration hysteresis---the ordinate hysteresis interval in Figure 33;

e) Steering wheel angle hysteresis---the abscissa hysteresis interval in Figure 33;

f) Steering hysteresis---the area of the loop in the interval of ± 1 m/s^2 of lateral acceleration in Figure 33, divided by 2 m/s^2.

11.5.5 The relation curve of steering wheel torque and lateral acceleration

In Figure 34, draw the relation curve of steering wheel torque and lateral acceleration. In addition, in accordance with the method described in 11.4.4 and 11.4.5, obtain the following parameters:

a) When lateral acceleration is 0, the steering wheel torque---the positive and negative steering wheel torque at 0 lateral acceleration in Figure 34;

b) When lateral acceleration is ± 1 m/s^2, the steering wheel torque---the positive and negative steering wheel torque at ± 1 m/s^2 of lateral acceleration away from the center position direction of the steering wheel in Figure 34;

c) When steering wheel torque is 0, the lateral acceleration---the positive and negative lateral acceleration at 0 steering wheel torque in Figure 34;

d) When lateral acceleration is 0, the steering wheel torque gradient---the slope of the curve at 0 lateral acceleration in Figure 34;

e) When lateral acceleration is ± 1 m/s^2, the steering wheel torque gradient---the slope of the curve at ± 1 m/s^2 of lateral acceleration away from the center position direction of the steering wheel in Figure 34;

f) Steering wheel torque hysteresis---the ordinate hysteresis interval in Figure 34;

g) Lateral acceleration hysteresis---the abscissa hysteresis interval in Figure 34.

11.5.6 Fill the test vehicle speed, waveform type of steering wheel input and lateral acceleration amplitude into Table 12. Fill the parameters obtained in 11.5.1 ~ 11.5.5 into Table 13. The characteristic parameters obtained through different input

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