INTERNATIONAL STANDARD

ISO
7401

First edition
1988-05-01

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION
ORGANISATION INTERNATIONALE DE NORMALISATION
МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ

Road vehicles — Lateral transient response test methods

Véhicules routiers — Méthodes d'essai en régime transitoire sous accélération latérale

Reference number
ISO 7401 : 1988 (E)

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 7401 was prepared by Technical Committee ISO/TC 22, *Road vehicles*.

Users should note that all International Standards undergo revision from time to time and that any reference made herein to any other International Standard implies its latest edition, unless otherwise stated.

Contents

Page

Annexes

This page intentionally left blank

Road vehicles — Lateral transient response test methods

0 Introduction

0.1 General

The road-holding ability of a road vehicle is a most important part of active vehicle safety. Any given vehicle, together with its driver and the prevailing environment, forms a unique closed-loop system. The task of evaluating road-holding ability is therefore very difficult because of the significant interaction of these driver-vehicle-road elements, each of which is in itself complex. A complete and accurate description of the behaviour of the road vehicle must necessarily involve information obtained from a number of tests of different types.

Because they quantify only a small part of the whole handling field, the results of these tests can only be considered significant for a correspondingly small part of the overall vehicle handling behaviour.

Moreover, nothing is known about the relationship between the results of these tests and accident avoidance. Considerable work is necessary to acquire sufficient and reliable data on the correlation between handling properties in general, and accident avoidance.

It is therefore not possible to use these procedures and test results for regulation purposes at the moment. The best that can be expected is that the transient response tests are used as some among many other mostly transient tests, which together cover the field of vehicle dynamic behaviour.

Finally, the role of the tyres is important and results may be strongly influenced by the type and condition of tyres.

0.2 Object of tests

The primary object of these tests is to determine the transient response behaviour of a vehicle. Characteristic values and functions in the time domain and frequency domain are considered necessary to characterize the transient response of vehicles.

Important criteria in the time domain are:

- time lags between steering-wheel angle, lateral acceleration and yaw velocity;
- response times of lateral acceleration and yaw velocity (see 6.1.1);
- lateral acceleration gain (lateral acceleration divided by steering-wheel angle);
- yaw velocity gain (yaw velocity divided by steering-wheel angle);
- overshoot values (see 6.1.3);
- vehicle TB factor (see 7.1.1.2).

The criteria listed above show some correlation with subjective evaluation during road driving.

Important criteria in the frequency domain are the frequency responses of

- lateral acceleration related to steering-wheel angle;
- yaw velocity related to steering-wheel angle;
- phase between input and output functions.

There are several test methods to obtain these criteria, the applicability of which depends in part on the size of the test track available, in the domains of time and frequency:

a) Time domain:
   - step input;
   - sinusoidal input (one period).

b) Frequency domain:
   - step input;
   - random input;
   - pulse input;
   - continuous sinusoidal input.

These test methods are optional. At least one of each domain type shall be performed. The methods chosen shall be indicated in the general data presentation (see annex A) and in the presentation of test results (see annex B).

It is necessary to measure

- steering-wheel angle;
- lateral acceleration;
- yaw velocity;
- steady-state sideslip angle;[1)]
- longitudinal velocity.

1) Steady-state sideslip angle is only necessary in the step input test.

It is desirable to measure

- lateral velocity or transient sideslip angle;[1]
- vehicle roll angle;
- steering-wheel torque.

The variables listed are not intended to comprise a complete list.

NOTE — Strictly speaking, test results based on lateral acceleration should not be used for comparison of the performance of different vehicles. This is because lateral acceleration, as precisely defined, is measured at right angles to the vehicle x-axis[2] and not at right angles to the tangent of the vehicle path.

To overcome this difficulty, lateral acceleration may be corrected for vehicle sideslip angle, which gives the quantity "centripetal acceleration". However, the extent of this correction is not likely to exceed a few percent and can generally be neglected.

1 Scope and field of application

This International Standard specifies test methods to determine transient response behaviour: it applies to passenger cars as defined in ISO 3833. The measurement of steady-state properties is defined in ISO 4138.

The open-loop manoeuvres specified in these test methods are not representative of real driving conditions but are useful to obtain measures of vehicle transient behaviour in response to several specific types of steering input under closely controlled test conditions.

NOTE — It is important to remember that the method of data analysis in the frequency domain is based on the assumption that the vehicle has a linear response. Over the whole range of lateral acceleration this may not be the case; the standard method of dealing with such a situation is to restrict the range of the input so that linear behaviour can be assumed, and if necessary to perform more than one test at different ranges of inputs which together cover the total input range that is of interest.

2 References

ISO 1176, *Road vehicles — Weights — Vocabulary.*

ISO 2416, *Passenger cars — Load distribution.*

ISO 3833, *Road vehicles — Types — Terms and definitions.*

ISO 4138, *Road vehicles — Steady state circular test procedure.*

ISO/TR 8725, *Road vehicles — Transient open-loop response test procedure with one period of sinusoidal input.*

ISO/TR 8726, *Road vehicles — Lateral transient response test procedure — Explanatory report on the random steering input method.*[3]

3 Instrumentation

3.1 Description

Those of the variables listed in 0.2 which are selected for test purposes shall be monitored, using appropriate transducers, and the data shall be recorded on a multi-channel recorder with a time base. The normal operating ranges and recommended maximum errors of the transducer/recording system are as shown in table 1.

NOTE — Some of the transducers listed are neither widely available nor in general use. Many such instruments are developed by users. If any system error exceeds the maximum values recommended, this fact and the actual maximum error shall be stated in the general data (see annex A).

The values in table 1 are tentative and provisional until more experience is available. To cover all the tests outlined in this International Standard, the minimum overall bandwidth of the entire measurement system including transducers and recorder shall be 8 Hz. If digitization is performed, it shall be at a rate sufficient for the required analysis.

3.2 Installation

Transducer installation and orientation will vary according to the type of instrumentation used. However, if a transducer does not measure the required variable directly, appropriate corrections for linear and angular displacement shall be made to its signals so as to obtain the required level of accuracy.

3.2.1 Steering-wheel angle

A transducer shall be installed as specified by the manufacturer so as to obtain the steering-wheel angle relative to the sprung mass.

3.2.2 Lateral acceleration

A transducer shall be installed as specified by the manufacturer and mounted either

a) on the sprung mass at the whole vehicle centre of gravity and aligned with the vehicle y-axis. In this case, it will measure "side acceleration" and its output shall be corrected for the component of gravity on the transducer axis due to both the vehicle roll angle and any track surface inclination; or

1) Alternatively this may be determined from other variables.

2) As referred to an axis system defined as follows:

axis system: Right-hand orthogonal axis system fixed in the vehicle such that its origin is at the centre of gravity of the vehicle. The x'-axis is longitudinal forward, the y'-axis is lateral and the z'-axis is vertical upwards.

3) At present at the stage of draft.

Table 1 — Variables

Variable	Range	Recommended maximum error of the combined transducer/recorder system
Steering-wheel angle	± 360° *	± 2° for angles < 180° ± 4° for angles > 180°
Lateral acceleration	± 15 m/s²	± 0,15 m/s²
Yaw velocity	± 50 °/s	± 0,5 °/s
Sideslip angle	± 15°	± 0,5°
Forward velocity	0 to 50 m/s	± 0,5 m/s
Lateral velocity	± 10 m/s	± 0,1 m/s
Vehicle roll angle	± 15°	± 0,15°
Steering-wheel torque	± 30 N·m	± 0,3 N·m

* Assuming a conventional steering system.

b) on the sprung mass at any position and aligned parallel to the vehicle *y*-axis. In this case, its output shall be corrected for its position relative to the centre of gravity, which will give "side acceleration", which in turn shall be corrected for the component of gravity on the transducer axis due to both vehicle roll angle and any track surface inclination.

3.2.3 Yaw velocity

A transducer shall be installed as specified by the manufacturer with its axis aligned with or parallel to the vehicle *z*-axis.

3.2.4 Sideslip angle

A transducer shall be installed as specified by the manufacturer so as to determine sideslip angle at the centre of gravity. If it does not measure directly at the centre of gravity, an appropriate correction shall be made. Its output shall also be corrected for roll motion influences.

Sideslip angle can be calculated from coincident measurements of other variables, for example, yaw, lateral and longitudinal velocity at any point on the vehicle.

The vehicle point to which the output of the transducer 1) is referred shall be indicated in the general data presentation (see annex A).

3.5.2 Forward velocity

A velocity transducer shall be installed as specified by the manufacturer. If it is not aligned so as to operate in the *x-z* plane, and parallel to the test track surface, its output shall be corrected for any linear or angular displacement from this.

3.2.6 Lateral velocity

A velocity transducer shall be installed as specified by the manufacturer. If it is not aligned so as to operate in the *y-z* plane, and parallel to the test track surface, its output shall be corrected for any linear or angular displacement from this, especially for roll motion influences.

The vehicle point to which the output of the transducer 1) is referred shall be indicated in the general data presentation (see annex A).

3.2.7 Vehicle roll angle

A transducer shall be installed as specified by the manufacturer so as to measure the angle between the vehicle *y*-axis and the track surface.

3.2.8 Steering-wheel torque

A transducer shall be installed, as specified by the manufacturer, so as to measure the torque applied to the steering-wheel about its axis of rotation.

3.2.9 Steering machine

If a steering machine is used, it shall be installed as specified by the manufacturer.

3.2.10 Steering-wheel stop

For step input tests (see 5.4), a steering-wheel stop may be used.

4 Test conditions

4.1 Test track

All tests shall be carried out on a uniform hard surface which is free of contaminants and has no more than 2 % gradient as measured over a distance between 5 and 25 m in any direction. For standard test conditions, a smooth dry pavement of asphalt or cement concrete or a high-friction test surface is recommended.

1) It is recommended that the centre of gravity or the point of intersection between a line connecting the rear wheel centres and the vehicle longitudinal median plane is used as a reference point.

For the random input test, the test surface shall be maintained over a track of 8 m minimum width for a length sufficient to permit at least 30 s running at the test speed, in addition to the run-up and stopping requirements.

The ambient wind speed shall not exceed 7 m/s. For test speeds above 30 m/s, a lower maximum wind speed is desirable. If the lateral component exceeds 4 m/s it shall be noted in the general data presentation (see annex A).

4.2 Tyres

The tests may be performed with tyres in any state of wear so long as a minimum of 1,5 mm of tread depth remains over the whole width and circumference of the tyres at the end of the tests (see note).

However, for standard tyre conditions, new tyres shall be used after being run-in for 150 to 200 km in the appropriate position on the test car without excessive harsh use, for example braking, accelerating, cornering, hitting the kerb, etc.

Tyres shall be inflated to the pressure specified by the vehicle manufacturer for the test vehicle configuration. The tolerance for setting the cold pressure is ± 0,05 bar[1)] for pressures up to 2,5 bar and ± 2 % for pressures above 2,5 bar.

NOTE — As in certain cases, the tread depth has a significant influence on test results, it is recommended that it should be taken into account when comparing vehicles or tyres.

The width is that part of the tyre which contacts the road surface when the vehicle is stationary and the steered wheels are in the straight-ahead position.

4.3 Operating components

All operating components likely to influence the results of this test (for example, condition and setting of shock absorbers, springs and other suspension components) shall be inspected to determine whether they meet the manufacturer's specifications. The results of these inspections and measurements shall be recorded and in particular any deviations from manufacturer's specifications shall be noted in the general data presentation (see annex A).

4.4 Vehicle loading conditions

4.4.1 General conditions

In no case shall the manufacturer's maximum total mass and the manufacturer's maximum axle load, both as defined in ISO 1176, be exceeded. The complete vehicle kerb mass as defined in ISO 1176 shall be regarded as the minimum mass.

Care shall be taken to give minimum error in the location of the centre of gravity and in the values of the moments of inertia as compared to the loading conditions of the vehicle in normal use.

4.4.2 Minimum loading conditions

The total vehicle mass for the minimum loading condition shall consist of the complete vehicle kerb mass (see 4.4.1), plus the masses of the driver and instrumentation. The load distribution shall be equivalent to that produced by two occupants in the front seats.

4.4.3 Maximum loading conditions

For the maximum loading condition, the total mass of a fully laden vehicle shall consist of the complete vehicle kerb mass (see 4.4.1), plus 68 kg for each seat in the passenger compartment, and the maximum luggage mass equally distributed over the luggage compartment according to ISO 2416. Loading of the passenger compartment shall be such that the actual wheel loads are equal to those obtained by loading each seat with 68 kg according to ISO 2416. The mass of the driver and instrumentation shall be included in the vehicle mass.

5 Test method

5.1 Tyre warm-up

The tyres shall be warmed up prior to the tests by a procedure equivalent to driving 500 m at a lateral acceleration of 3 m/s^2 (left and right turn each) or to driving at the test speed for a distance of 10 km.

5.2 Test speed

All tests shall be carried out at a test speed of 80 km/h (depending on vehicle capability). If higher or lower test speeds are selected they shall be in 20 km/h steps.

5.3 Steering-wheel angle amplitude

The steering-wheel angle amplitude shall be determined by steady-state driving on a circle the radius of which gives the preselected lateral acceleration at the required test speed.

5.4 Step input

The vehicle shall be driven at the test speed (see 5.2) in a straight line. Starting from 0 ± 0,5 °/s yaw velocity equilibrium condition, a steering input shall be applied as rapidly[2)] as possible to a preselected value and maintained at that value for several seconds or until the measured vehicle motion variables reach a steady state. No change in throttle position shall be made, even though speed may decrease.

Data shall be taken for both left and right turns. All the data may be taken in one direction followed by all the data in the other direction. As an alternative, data may be taken successively in each direction for each acceleration level going from the lowest to the highest. The method chosen shall be noted in the general data.

1) 1 bar = 10^5 Pa = 10^5 N/m^2

2) Depending on the lateral acceleration desired and the existing vehicle parameters. Values between 200 °/s and 500 °/s are considered suitable for the turning speed of the steering-wheel.

Data shall be taken through the desired range of steering inputs and response variable outputs.

The required lateral acceleration level is 4 m/s^2. Optional lateral acceleration levels of 2 m/s^2 and 6 m/s^2 are recommended.

All test runs shall be performed at least three times.

5.5 Sinusoidal input (one period)

The vehicle shall be driven at the test speed (see 5.2) in a straight line. Starting from 0 ± 0,5 °/s yaw velocity equilibrium condition, one full period sinusoidal steering-wheel input shall be applied with a steering frequency of 0,5 Hz. Optional steering frequency of 1 Hz is recommended. The allowable amplitude error compared to the true sine wave is ±5 % of the first peak value.

Required lateral acceleration level is 4 m/s^2. Optional acceleration levels of 2 m/s^2 and 6 m/s^2 and up to the adhesion limit (see ISO/TR 8725) are recommended. No change in throttle position shall be made, even though speed may decrease.

Data shall be taken for both left and right turns. All the data may be taken in one direction followed by all the data in the other direction. As an alternative, data may be taken successively in each direction for each acceleration level going from the lowest to the highest. The method chosen shall be noted in the general data presentation (see annex A).

All test runs shall be performed at least three times in order to obtain mean values and standard deviations.

5.6 Random input

Test runs shall be made by driving the vehicle at the required test speed (see 5.2) and making continuous inputs to the steering-wheel up to predetermined limits of steering-wheel amplitude (see 5.3). This limit is determined according to 5.3 for a lateral acceleration level within the range in which the vehicle exhibits linear behaviour (see the note to clause 1). The recommended value of lateral acceleration is 2 m/s^2, but the value used should not normally exceed 4 m/s^2 (see ISO/TR 8726).

Any mechanical limitations of steering-wheel angle shall not be used because of their effect on the harmonic content of the input. It is also important that the input is continuous because periods of relative inactivity will seriously reduce the signal/noise ratio.

In order to ensure adequate high-frequency content, the input must be energetic; to ensure enough total data, at least 12 min of data is desirable unless indicated confidence limits permit a shorter time.

Ideally, this should be a continuous run, but practical considerations may prevent this for two reasons. Firstly, the test track may not be sufficiently long to permit a continuous run of such a length at the required lateral acceleration and secondly, the computer used to analyse the data may not be large enough to handle all the data at one go. In either case, it is permissible to use a number of shorter runs of at least 30 s duration: having calculated the power spectral densities for each run, they can then be averaged. The averaging function used shall be noted in the general data presentation (see annex A).

5.7 Pulse input

The vehicle shall be driven at the test speed (see 5.2) in a straight line. Starting from 0 ± 0,5 °/s yaw velocity equilibrium condition, a triangular waveform steering-wheel input shall be applied followed by 3 to 5 s neutral steering-wheel position.

The pulse width of 0,3 to 0,5 s is required. Efforts shall be made to minimize the overshoot of steering-wheel angle input. The amplitude of steering-wheel angle is determined according to 5.3 for a lateral acceleration level of 4 m/s^2.

The test shall be performed at least three times.

5.8 Continuous sinusoidal input

The vehicle shall be driven at the test speed (see 5.2) in a straight line. Starting from 0 ± 0,5 °/s yaw velocity equilibrium condition, at least three periods of sinusoidal steering-wheel input shall be applied with the predetermined steering-wheel angle amplitude (see 5.3) and frequency.

The required lateral acceleration level is 4 m/s^2. Optional lateral acceleration levels of 2 m/s^2 and 6 m/s^2 are recommended.

The steering frequency shall be increased in steps. It is recommended that the frequency range covered is up to 4 Hz.

6 Data analysis

6.1 Step input

6.1.1 Response time

The transient response data reduction shall be carried out as follows: the origin for each response is that time when the steering-wheel angle change is 50 % completed. This is the reference point from which all response time data are measured. Response time is thus defined as the time, measured from this reference, for a vehicle transient response first to reach 90 % of its new steady-state value (see figure 1).

6.1.2 Peak response time

The peak response time is the time, measured from the origin for a vehicle transient response to reach its peak value[1)] (see figure 1).

1) In some instances, system damping may be so high that a peak value cannot be determined. If this occurs, data sheets should be marked accordingly.

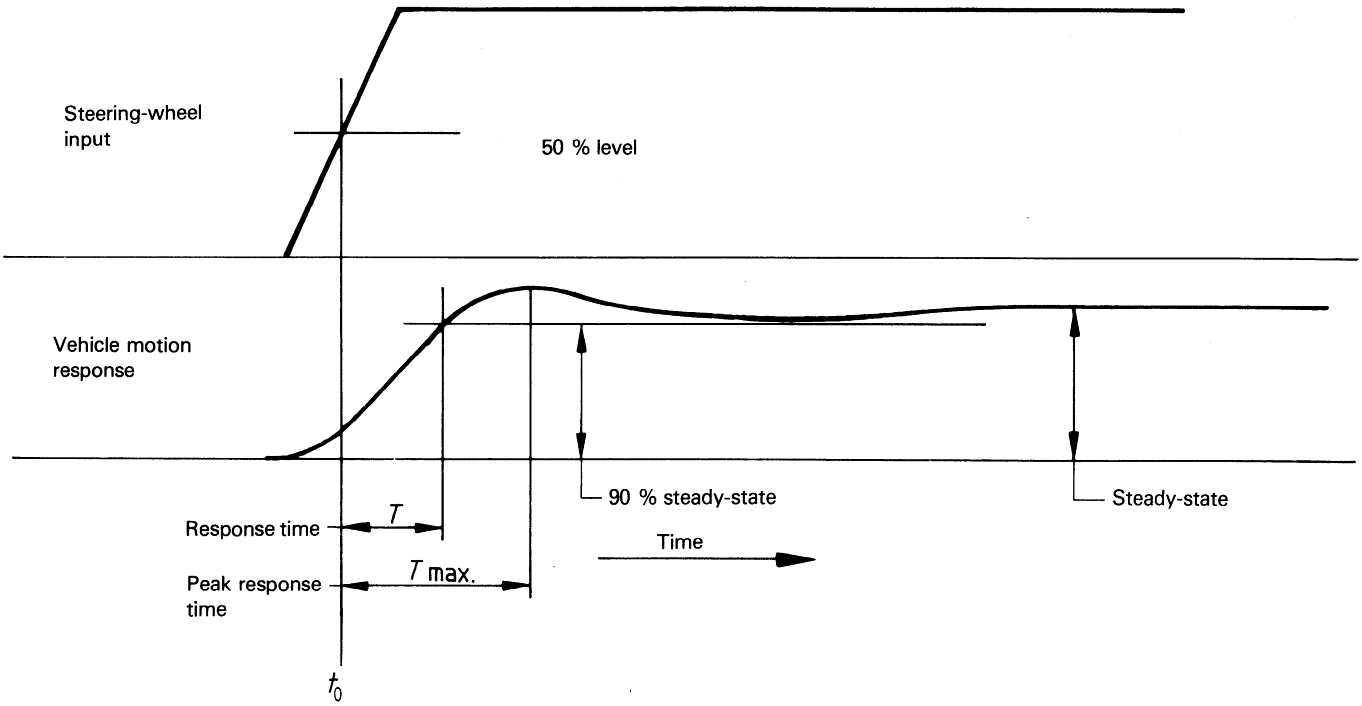

Figure 1 — Response time and peak response time

6.1.3 Overshoot values

The overshoot values are calculated as a ratio: difference of peak value minus steady-state value/steady-state value.

6.2 Sinusoidal input (one period)

6.2.1 General

The test results may be sensitive to the method of data processing. It is therefore recommended that the procedure given in ISO/TR 8725 be used.

6.2.2 Lateral acceleration

Lateral acceleration in this test is defined as the first peak value of the lateral acceleration corrected for vehicle roll angle at the vehicle centre of gravity.

6.2.3 Yaw velocity

Yaw velocity in this test is defined as the first peak value of the yaw velocity.

6.2.4 Time lags

The time lags between the variables steering-wheel angle, lateral acceleration and yaw velocity are calculated for the first and second peaks by means of cross-correlation of the first and second halfwaves respectively (positive and negative parts of the time history).

6.2.5 Lateral acceleration gain

Lateral acceleration gain per unit of steering-wheel angle is calculated as the ratio between the lateral acceleration according to 6.2.2 and the corresponding steering-wheel angle maximum amplitude.

6.2.6 Yaw velocity gain

Yaw velocity gain per unit of steering-wheel angle is calculated as the ratio between the yaw velocity according to 6.2.3 and the corresponding steering-wheel angle maximum amplitude.

6.3 Random input

6.3.1 General

The data processing can be carried out most rapidly by using a multi-channel real time analyser, or by using a computer with the appropriate software (see ISO/TR 8726).

6.3.2 Preliminary analysis

The recorded time history of forward velocity shall be displayed and examined visually to ensure that it is within 5 % of the nominal value.

A Fourier analysis shall be made of the steering-wheel angle time history, and the result shall be displayed as a graph of the input level relative to that at the lowest frequency versus frequency as shown in figure 4 (see annex B, clause B.3).

This graph shall be examined visually to ensure adequate frequency content. The recommended ratio between maximum and minimum steering-wheel angle shall not be greater than 4 : 1 (12 dB). If the ratio is greater, the results may be discarded or, if used, the extent of the ratio shall be noted in the general data presentation (see annex A).

6.3.3 Further processing

The data shall then be processed using appropriate equipment to produce the transfer function amplitude and phase information together with the coherence function for the following combinations of input and output variables:

- lateral acceleration per unit of steering-wheel angle;
- yaw velocity per unit of steering-wheel angle.

6.4 Pulse input

6.4.1 General

See 6.3.1.

6.4.2 Preliminary analysis

The recorded time history of longitudinal velocity shall be displayed and examined visually to ensure that it is within 5 % of the nominal value.

NOTE — Although it is desirable to have such data so that the zero reference before steering and the zero reference after the steering operation become the same, the line connecting the point of initiation of changes and the point of completion of changes shall be made as zero reference, if the zero references before and after the changes differ from one another.

A Fourier analysis shall be made of the steering-wheel angle time history, and the result shall be displayed as a graph of the input level relative to that at the lowest frequency versus frequency as shown in figure 4 (see annex B, clause B.3).

6.4.3 Further processing (see 6.3.3)

The transfer functions of at least three test runs shall be averaged.

6.5 Continuous sinusoidal input

6.5.1 Steering-wheel angle amplitude

Steering-wheel angle amplitude is defined as the mean value of the amplitudes following the first period.

All amplitudes shall be taken during the manoeuvre when the vehicle is in a periodic steady-state condition.

6.5.2 Lateral acceleration amplitude

Lateral acceleration amplitude is defined as the mean value of the amplitudes following the first period.

All amplitudes shall be taken during the manoeuvre when the vehicle is in a periodic steady-state condition.

6.5.3 Yaw velocity amplitude

Yaw velocity amplitude is defined as the mean value of the amplitudes following the first period.

All amplitudes shall be taken during the manoeuvre when the vehicle is in a periodic steady-state condition.

6.5.4 Lateral acceleration gain

Lateral acceleration gain per unit of steering-wheel angle is calculated as the ratio between lateral acceleration amplitude according to 6.5.2 and the steering-wheel angle amplitude according to 6.5.1.

6.5.5 Yaw velocity gain

Yaw velocity gain per unit of steering-wheel angle is calculated as the ratio between yaw velocity amplitude according to 6.5.3 and the steering-wheel angle amplitude according to 6.5.1.

6.5.6 Phase angle

Phase angles between the steering-wheel angle and the variables lateral acceleration and yaw velocity shall be determined from the time histories after the first period when the vehicle is in a periodic steady-state condition.

7 Data presentation

General data shall be presented as shown on the summary form given in annex A.

Time histories of variables used in data reduction shall be plotted. If a curve is fitted to any set of data, the method of curve fitting shall be described in the results presentation in accordance with annex B.

7.1 Data presentation in the time domain

7.1.1 Step input

7.1.1.1 Time histories

Plot time histories of steering-wheel angle, lateral acceleration, yaw velocity and sideslip angle for the lateral acceleration level of 4 m/s^2 in the form as shown in figure 2 (see annex B, clause B.1).

7.1.1.2 Time response data summary

For the test speed of 80 km/h and the lateral acceleration level 4 m/s^2 determined from figure 2, record the following values in table 2 (see annex B, clause B.1):

a) steady-state yaw velocity response gain, $(\dot{\Psi}/\delta_H)_{ss}$

b) lateral acceleration response time, T_{a_y}

c) yaw velocity response time, $T_{\dot{\Psi}}$