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Road vehicles — Lateral transient response test methods — Open-loop test methods

Véhicules routiers — Méthodes d'essai de réponse transitoire latérale — Méthodes d'essai en boucle ouverte

Reference number
ISO 7401:2003(E)

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Contents

Page

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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 7401 was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 9, *Vehicle dynamics and road-holding ability*.

This second edition cancels and replaces the first edition (ISO 7401:1988), which has been technically revised.

Introduction

The dynamic behaviour of road vehicles 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 the dynamic behaviour is therefore very difficult since there is a significant interaction between these driver–vehicle–environment elements, each of which is complex in itself. 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. Since 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 dynamic behaviour.

Moreover, insufficient knowledge is available concerning the relationship between accident avoidance and the dynamic characteristics evaluated by these tests. A substantial amount of effort is necessary to acquire sufficient and reliable data on the correlation between accident avoidance and vehicle dynamic properties in general and the results of these tests in particular. Therefore it is not possible to use these methods and test results for regulation purposes at present. The best that can be expected is that the transient response tests are used as some among many other tests, which together cover the field of vehicle dynamic behaviour.

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

Road vehicles — Lateral transient response test methods — Open-loop test methods

1 Scope

This International Standard specifies open-loop test methods for determining the transient response behaviour of road vehicles. It is applicable to passenger cars, as defined in ISO 3833, and to light trucks.

NOTE The open-loop manoeuvre specified in this International Standard is not representative of normal driving conditions, but is nevertheless useful for obtaining measures of vehicle transient behaviour in response to several specific types of steering input under closely controlled test conditions. For measurements of steady-state properties, see ISO 4138.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 1176:1990, *Road vehicles — Masses — Vocabulary and codes*

ISO 2416:1992, *Passenger cars — Mass distribution*

ISO 3833:1977, *Road vehicles — Types — Terms and definitions*

ISO/TR 8725:1988, *Road vehicles — Transient open-loop response test method with one period of sinusoidal input*

ISO/TR 8726:1988, *Road vehicles — Transient open-loop response test method with pseudo-random steering input*

ISO 8855:1991, *Road vehicles — Vehicle dynamics and road-holding ability — Vocabulary*

ECE Regulation No. 30, *Uniform provisions concerning the approval of pneumatic tyres for motor vehicles and their trailers*

3 Principle

IMPORTANT — 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 is unlikely to be the case, the standard method of dealing with such a situation being 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 that together cover the total range of interest.

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

Important characteristics 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 8.2.1),
- lateral acceleration gain (lateral acceleration divided by steering-wheel angle),
- yaw velocity gain (yaw velocity divided by steering-wheel angle), and
- overshoot values (see 8.2.3).

These characteristics show correlation with subjective evaluation during road driving.

Important characteristics in the frequency domain are the frequency responses, i.e. amplitudes and phases of

- lateral acceleration related to steering-wheel angle, and
- yaw velocity related to steering-wheel angle.

There are several test methods for obtaining these characteristics in the domains of time and frequency, as follows, the applicability of which depends in part on the size of the test track available.

a) Time domain:

   1) step input;

   2) sinusoidal input (one period).

b) Frequency domain:

   1) random input;

   2) pulse input;

   3) continuous sinusoidal input.

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

NOTE It is possible that the characteristic values of lateral acceleration gain and yaw velocity gain, obtained by the different test methods, may not be comparable, owing to one or more of the following circumstances:

- linear versus non-linear vehicle behaviour;
- periodic versus non-periodic steady state condition;
- steady state versus dynamic vehicle behaviour.

4 Reference system

The variables of motion used to describe the vehicle behaviour in a test-specific driving situation relate to the intermediate axis system (X, Y, Z) (see ISO 8855).

The location of the origin of the vehicle axis system (X_V, Y_V, Z_V) is the reference point and therefore should be independent of the loading condition. It is fixed in the longitudinal plane of symmetry at half-wheelbase and at the same height above the ground as the centre of gravity of the vehicle at complete vehicle kerb mass (see ISO 1176).

5 Variables

The following variables shall be determined:

— steering-wheel angle, δ_H;

— lateral acceleration, a_Y;

— yaw velocity, $\dot{\psi}$;

— longitudinal velocity, v_X.

The following variables may be determined:

— roll angle, ϕ;

— sideslip angle, β;

— lateral velocity, v_Y;

— steering-wheel torque, M_H.

These variables, defined in ISO 8855, are not intended to comprise a complete list.

6 Measuring equipment

6.1 Description

The variables to be determined in accordance with Clause 5 shall be measured by means of appropriate transducers. Their time histories shall be recorded on a multi-channel recording system having a time base.

The typical operating ranges and recommended maximum errors of the transducers and the recording system are given in Table 1.

6.2 Transducer installation

The transducers shall be installed according to the manufacturer's instructions, where such instructions exist, so that the variables corresponding to the terms and definitions of ISO 8855 can be determined.

If the transducer does not measure the variable directly, appropriate transformations into the reference system shall be carried out.

6.3 Data processing

6.3.1 General

The frequency range relevant to these tests is between 0 Hz and the maximum utilized frequency f_{max} = 5 Hz. Depending on the data processing method chosen (analog or digital data processing), the provisions of 6.3.2 or 6.3.3 shall be observed.

6.3.2 Analog data processing

The bandwidth of the entire combined transducer/recording system shall be no less than 8 Hz.

In order to execute the necessary filtering of signals, low-pass filters of order four or higher shall be employed. The width of the passband (from 0 Hz to frequency f_0 at –3 dB) shall be not less than 9 Hz. Amplitude errors shall be less than ± 0,5% in the relevant frequency range of 0 Hz to 5 Hz. All analog signals shall be processed with filters having phase characteristics sufficiently similar to ensure that time delay differences due to filtering lie within the required accuracy for time measurement.

NOTE During analog filtering of signals with different frequency contents, phase shifts can occur. Therefore a digital data processing method, as described in 6.3.3, is preferable.

Table 1 — Variables, their typical operating ranges and recommended maximum errors

Variable	Range	Recommended maximum error of combined transducer and recorder system
Steering-wheel angle	− 180° to + 180 [a]	± 1°
Lateral acceleration	− 15 m/s² to + 15 m/s²	± 0,15 m/s²
Yaw velocity	− 50 °/s to + 50 °/s	± 0,5°/s
Sideslip angle	− 15° to + 15°	± 0,3°
Longitudinal velocity	0 m/s to 50 m/s	± 0,5 m/s
Lateral velocity	− 10 m/s to + 10 m/s	± 0,1 m/s
Roll angle	− 15° to + 15°	± 0,15°
Steering-wheel torque	− 30 N·m to + 30 N·m	± 0,3 · m
Transducers for some of the listed variables are not widely available and are not in general use. Many such instruments are developed by users. If any system error exceeds the recommended maximum value, this and the actual maximum error shall be stated under general data in the test report (see Annex A).		
[a] Assuming a conventional steering system.		

6.3.3 Digital data processing

6.3.3.1 General considerations

Preparation of analog signals includes consideration of filter amplitude attenuation and sampling rate in order to avoid aliasing errors, filter phase lags and time delays. Sampling and digitizing considerations include pre-sampling amplification of signals so as to minimize digitizing errors, the number of bits per sample, the number of samples per cycle, sample and hold amplification, and timewise spacing of samples. Considerations for additional phaseless digital filtering include the selection of passbands and stopbands, and the attenuation and allowable ripple in each, as well as correction of anti-alias filter phase lags. Each of these factors shall be considered so that an overall data-acquisition accuracy of ± 0,5 % is achieved

6.3.3.2 Aliasing errors

In order to avoid uncorrectable aliasing, the analog signals shall be appropriately filtered before sampling and digitizing. The order of filters used and their passband shall be chosen according to both the required flatness in the relevant frequency range and the sampling rate. The minimum filter characteristics and sampling rate shall be such that

— within the relevant frequency range of 0 Hz to f_{max} = 5 Hz the attenuation is less than the resolution of the data acquisition system, and

— at one-half the sampling rate (i.e. the *Nyquist* or “folding” frequency) the magnitudes of all frequency components of signal and noise are reduced to less than the system resolution.

For 12-bit data acquisition systems with a resolution of 0,05 % the filter attenuation shall be less than 0,05 % to 5 Hz, and the attenuation shall be greater than 99,95 % at all frequencies greater than one-half the sampling frequency.

NOTE For a Butterworth filter the attenuation is given by

$$A^2 = \frac{1}{1 + \left(\frac{f_{max}}{f_0}\right)^{2n}}$$

and

$$A^2 = \frac{1}{1 + \left(\frac{f_N}{f_0}\right)^{2n}}$$

where

n is the order of the filter;

f_{max} is the relevant frequency range (5 Hz);

f_0 is the filter cut-off frequency;

f_N is the Nyquist or “folding” frequency;

f_s is the sampling frequency $= 2 \times f_n$.

For example, for a fourth-order filter:

— for $A = 0{,}9995$, $f_0 = 2{,}37 \times f_{max} = 11{,}86$ Hz;

— for $A = 0{,}0005$, $f_s = 2 \times (6{,}69 \times f_0) = 158$ Hz.

6.3.3.3 Phase shifts and time delays for anti-aliasing filtering

Excessive analog filtering shall be avoided, and all filters shall have sufficiently similar phase characteristics to ensure that time delay differences lie within the required accuracy for the time measurement.

NOTE In the frequency range in which the filter amplitude characteristics remains flat, the phase shift, ϕ, of a Butterworth filter can be approximated by

— $\phi = 81° \ (f/f_0)$ for 2nd order,

— $\phi = 150° \ (f/f_0)$ for 4th order,

— $\phi = 294° \ (f/f_0)$ for 8th order.

The time delay for all filter orders is $t = (\phi/360°) \times (1/f_0)$

6.3.3.4 Data sampling and digitizing

At 5 Hz the amplitude changes by up to 3 % per millisecond. To limit dynamic errors caused by changing analog inputs to 0,1 %, sampling or digitizing time shall be less than 32 µs. All pairs of sets of data samples to be compared shall be taken simultaneously or over a sufficiently short time period.

6.3.3.5 Data acquisition system requirements

The data acquisition system shall have a resolution of 12 bits or more (± 0,05 %) and an accuracy of 2 LSB (± 0,1 %). Anti-aliasing filters shall be of order four or higher and the relevant frequency range shall be from 0 Hz to f_{max}.

For fourth-order filters, f_0 shall be greater than 2,37 f_{max} if phase errors are subsequently adjusted in digital data processing, and greater than 5 f_{max} otherwise, and the data sampling frequency f_s shall be greater than 13,4 f_0.

For filters of orders other than the fourth order, f_0 and f_s shall be selected for adequate flatness and prevention of alias error.

Amplification of the signal before digitizing shall be such that in the digitizing process the additional error is less than 0,2 %. Sampling and digitizing time for each data channel sampled shall be less than 32 µs.

6.3.3.6 Digital filtering

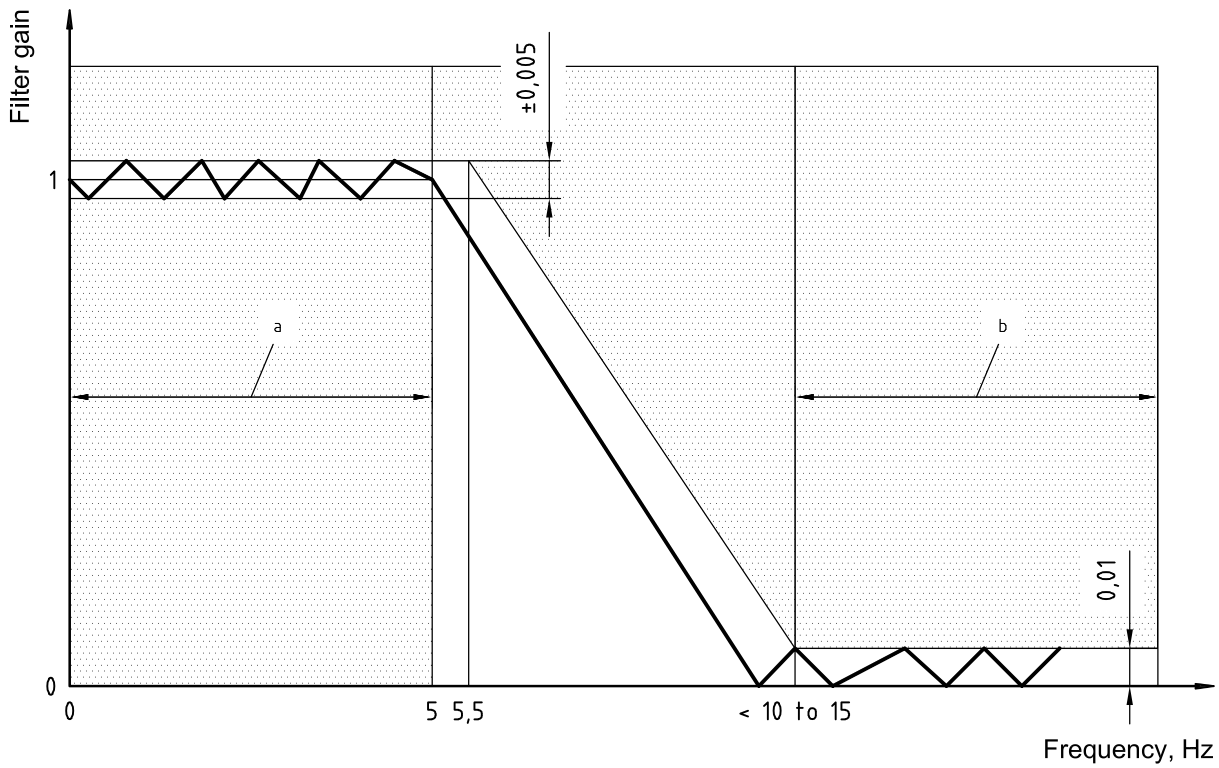
For filtering of sampled data in data evaluation, phaseless (zero-phase-shift) digital filters shall be used, in accordance with the following (see Figure 1):

— the passband shall range from 0 Hz to 5 Hz;

— the stopband shall begin at between 10 Hz and 15 Hz;

— the filter gain in the passband shall be ± 0,005 (100 ± 0,5) %;

— the filter gain in the stopband shall be ⩽ 0,01 (⩽ 1 %).



a Passband

b Stopband

Figure 1 — Required characteristics of phaseless digital filters

7 Test conditions

7.1 General

Limits and specifications for the ambient wind and vehicle test conditions are established in 7.3 to 7.4, and shall be maintained throughout each test. Any deviations shall be shown in the test report (see Annex A), including the individual diagrams of the presentation of results (see Annex B).

7.2 Test track

All tests shall be carried out on a smooth, clean, dry and uniform paved road surface. The gradient of the paved surface shall not exceed 2,5 % in any direction when measured over any distance interval between that corresponding to the vehicle track and 25 m. For each test the road surface conditions and paving material shall be recorded in the test report (see Annex A).

For the standard test conditions, a smooth, dry pavement of asphalt or cement concrete or a high-friction test surface should be used.

For the random input test, the test surface shall be maintained over a minimum track width of 8 m for a length sufficient to permit at least 30 s running at the test speed.

7.3 Weather conditions

During the measurements, ambient wind velocity shall not exceed 5 m/s, regardless of wind direction.

The component of the wind velocity perpendicular to the vehicle path shall not exceed 4 m/s.

For each test procedure, weather conditions shall be recorded in the test report (see Annex A).

7.4 Test vehicle

7.4.1 Tyres

For the standard test conditions, new tyres shall be fitted on the test vehicle according to the manufacturer's specifications. They shall have a tread depth of at least 90 % of the original value in the principal grooves within 0,75 of the tread breadth (in accordance with specifications for tread-wear indicators given in ECE Regulation No. 30) and shall not have been manufactured more than one year prior to the test. The date of manufacture shall be noted in the test report (see Annex A).

NOTE The tread breadth is the width of that part of the tread which, with the tyre correctly inflated, is in contact with the road in normal straight-line driving.

If not otherwise specified by the tyre manufacturer, the tyres shall be run in for at least 150 km on the test vehicle or an equivalent vehicle without excessively harsh use such as severe braking, acceleration, cornering or hitting the kerb. After running in, the tyres shall be maintained at the same position on the vehicle throughout the tests.

Tyres shall be inflated to the pressure specified by the vehicle manufacturer for the test vehicle configuration at the ambient temperature of the test. The tolerance for setting the cold inflation pressure is ± 5 kPa[1)] for pressures up to 250 kPa and ± 2 % for those above 250 kPa.

Inflation pressure and tread depth of the tyres before the tyre warm-up and after completion of the test shall be recorded in the test report (see Annex A).

The tests may also be performed in other than the standard condition. The details shall be recorded in the test report (see Annex A).

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1) 1 kPa = 10^2 bar = 10^3 N/m^2

As tread depth or uneven tread wear can have a significant influence on test results, these should be taken into account when making comparisons between vehicles or between tyres.

7.4.2 Other operating components

For the standard test conditions, any operating component likely to influence the results of a test (e.g. shock absorbers, springs and other suspension components and suspension geometry) shall be as specified by the manufacturer. Any deviations from the manufacturer's specifications shall be recorded in the test report (see Annex A).

7.4.3 Vehicle loading conditions

7.4.3.1 General

Tests shall be carried out at the minimum loading condition and at the maximum loading condition defined below, and at other loading conditions of interest.

The maximum authorized total mass (Code: ISO-M08) and the maximum authorized axle load (Code: ISO-M13), in accordance with ISO 1176:1990, 4.8 and 4.13, shall not be exceeded.

Care shall be taken to minimize the difference of both the location of the centre of gravity and the moments of inertia as compared to the loading conditions of the vehicle in normal use (see ISO 2416:1992, Clause 5). The resulting static wheel loads shall be determined and recorded in the test report (see Annex A).

7.4.3.2 Minimum loading condition

For the minimum loading condition, the total vehicle mass shall consist of the complete vehicle kerb mass (Code: ISO-M06) in accordance with ISO 1176:1990, 4.6, plus the masses of the driver and the instrumentation. The mass of the driver and the instrumentation should not exceed 150 kg. The load distribution shall be equivalent to that of two occupants in the front seats, in accordance with ISO 2416.

7.4.3.3 Maximum loading condition

For the maximum loading condition, the total mass shall be equal to the maximum authorized total mass.

For the maximum loading condition, the total mass shall be equivalent to the complete vehicle kerb mass, plus 68 kg for each seat in the passenger compartment and with the remaining maximum mass of transportable goods equally distributed over the luggage compartment in accordance with 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.

NOTE The transient lateral response is strongly influenced by the moments of inertia and by the height of the centre of gravity. Wheel loads define only one of several factors contributing to the dynamic properties of vehicles.

7.5 Warm-up

The tyres and other relevant vehicle components shall be warmed up prior to the tests in order to achieve a temperature representative of normal driving conditions.

To warm up the tyres, a procedure of driving at the test speed (see 7.6) for a distance of at least 10 km or equivalent to driving 500 m at a lateral acceleration of 3 m/s^2 (left and right turn each) could be appropriate.

7.6 Test speed

The test speed is defined as the nominal value of the longitudinal velocity. The standard test speed is 100 km/h. Other test speeds of interest may be used (preferably in 20 km/h steps).

8 Step input

8.1 Test procedure

Drive the vehicle at the test speed (see 7.6) in a straight line. The initial speed shall not deviate by more than 2 km/h from the test speed. Starting from a 0°/s ± 0,5°/s yaw velocity equilibrium condition, apply a steering input as rapidly as possible to a preselected value and maintain at that value for several seconds after the measured vehicle motion variables have reached a steady state. In order to keep the steering input short relative to the vehicle response time, the time between 10 % and 90 % of the steering input should not be greater than 0,15 s. No change in throttle position shall be made, although speed may decrease. A steering wheel stop may be used for selecting the input angle.

Take data for both left and right turns. All data shall be taken in one direction followed by all data in the other direction. Alternatively, take data successively in each direction for each acceleration level, from the lowest to the highest level, this being preferable with respect to tyre wear and symmetrical vehicle stress. Record the method chosen in the test report (see Annex A).

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

Determine the steering-wheel angle amplitude by steady-state driving on a circle the radius of which gives the preselected steady-state lateral acceleration at the required test speed. The standard steady-state lateral acceleration level is 4 m/s^2. Additional levels of 2 m/s^2 and 6 m/s^2 may be used.

Perform all test runs at least three times.

8.2 Data analysis

8.2.1 Response time

The transient-response data reduction shall be carried out such that the origin for each response is the time at which the steering-wheel angle change is 50 % complete. This is the reference point from which all response times are measured. Response time is thus defined as the time, measured from this reference, for the vehicle transient response to first reach 90 % of its new steady-state value (see Figure 2).

8.2.2 Peak response time

The peak response time is the time, measured from the reference point, for a vehicle transient response to reach its peak value (see Figure 2).

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

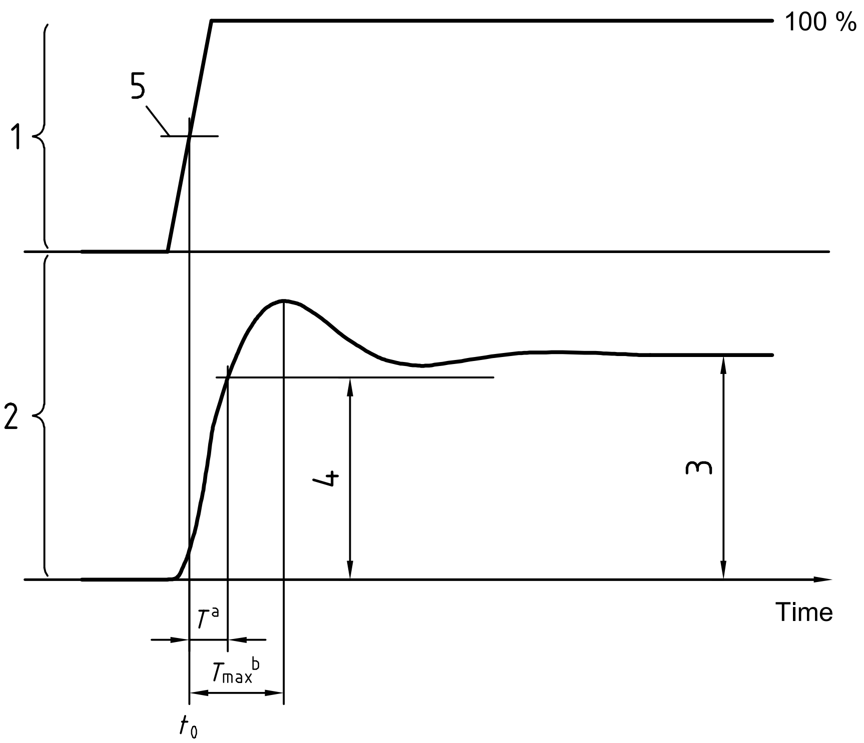
8.2.3 Overshoot values

The overshoot values are calculated as a ratio: the difference of peak value and steady-state value divided by steady-state value.

8.3 Data presentation

8.3.1 General

General data shall be presented in accordance with Annex A.



Key

1 steering wheel input

2 vehicle response motion

3 steady state

4 90 % steady state

5 50 % level

a Response time

b Peak response time

Figure 2 — Response time and peak response time

8.3.2 Time histories

The time histories of variables used for data evaluation shall be plotted. If a curve is fitted to any set of data, the method of curve fitting shall be described in the presentation of results in Annex B.

Plot the time histories of steering-wheel angle, lateral acceleration and yaw velocity for each measured lateral acceleration level in the form, as shown in Figure B.1.

8.3.3 Time response data summary

Record the following values in accordance with Table B.1 for each combination of test speed and lateral acceleration:

a) steady-state yaw velocity response gain, $\left(\frac{\dot{\psi}}{\delta_{\text{H}}}\right)_{\text{ss}}$;

b) lateral acceleration response time, T_{aY};

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

d) lateral acceleration peak response time, $T_{aY,\text{max}}$;

e) yaw velocity peak response time, $T_{\dot{\psi},\text{max}}$;

f) overshoot value of lateral acceleration, U_{aY};

g) overshoot value of yaw velocity, $U_{\dot{\psi}}$.

9 Sinusoidal input — One period (see ISO/TR 8725)

9.1 Test procedure

Drive the vehicle at the test speed (see 7.6) in a straight line. The initial speed shall not deviate by more than 2 km/h from the test speed. Starting from a 0°/s ± 0,5°/s yaw velocity equilibrium condition, apply one full period sinusoidal steering-wheel input with a frequency of 0,5 Hz. An additional frequency of 1 Hz should also be used. The amplitude error of the actual waveform compared to the true sine wave shall be less than 5 % of the first peak value. No change in throttle position shall be made, although speed may decrease.

Take data while the steering wheel is rotated initially both to the left and to the right. All data shall be taken in one direction followed by all data in the other direction. Alternatively, take data successively in each direction for each acceleration level, from the lowest to the highest level. Record the method chosen in the test report (see Annex A).

Increase the steering-wheel input stepwise up to a magnitude sufficient to produce the desired lateral acceleration in accordance with 9.2.2. The standard lateral acceleration level is 4 m/s^2. Additional acceleration levels of 2 m/s^2 and 6 m/s^2 and up to the adhesion limit (see ISO/TR 8725) may be used.

Perform at least three test runs for each combination of speed and steering.

9.2 Data analysis

9.2.1 General

The test results can be sensitive to the method of data processing. The procedure given in ISO/TR 8725 should therefore be used.

9.2.2 Lateral acceleration

Lateral acceleration in this test is defined as the first peak value of the lateral acceleration time history, corrected for vehicle roll angle.

9.2.3 Yaw velocity

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

9.2.4 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 half-waves, respectively (positive and negative parts of the time history).

9.2.5 Lateral acceleration gain

Lateral acceleration gain is calculated as the ratio of the lateral acceleration (in accordance with 9.2.2) to the corresponding peak value of the steering-wheel angle.

9.2.6 Yaw velocity gain

Yaw velocity gain is calculated as the ratio of the yaw velocity (according to 9.2.3) to the corresponding peak value of the steering-wheel angle.

9.3 Data presentation

9.3.1 General

General data shall be presented in accordance with Annex A.

The time histories of variables used for data evaluation shall be plotted. If a curve is fitted to any set of data, the method of curve fitting shall be described in the presentation of results in accordance with Annex B.

9.3.2 Time histories

Plot the time histories of steering-wheel angle, lateral acceleration and yaw velocity for each measured lateral acceleration level as shown in Figure B.2.

9.3.3 Time response data summary

Calculate the following test data (see Table B.2) as mean values ± standard deviation:

a) time lags between steering-wheel angle and lateral acceleration

   1) first peak, $T\left(\delta_{\mathrm{H}} - a_Y\right)_1$

   2) second peak, $T\left(\delta_{\mathrm{H}} - a_Y\right)_2$

b) time lags between steering-wheel angle and yaw velocity

   1) first peak, $T\left(\delta_{\mathrm{H}} - \dot{\psi}\right)_1$

   2) second peak, $T\left(\delta_{\mathrm{H}} - \dot{\psi}\right)_2$

c) lateral acceleration gain, $\frac{a_Y}{\delta_{\mathrm{H}}}$

d) yaw velocity gain, $\frac{\dot{\psi}}{\delta_{\mathrm{H}}}$

9.3.4 Data as functions of lateral acceleration

If optional lateral acceleration levels are measured, it is useful to present data as functions of lateral acceleration.

9.3.5 Asymmetry factors

The justification for making two initial turn directions is that an asymmetry can exist. This asymmetry can be presented in terms of asymmetry factors. See ISO/TR 8725.

10 Random input (see ISO/TR 8726)

10.1 Test procedure

Make the test runs by driving the vehicle at the required test speed (see 7.6) while making continuous inputs to the steering-wheel, up to predetermined limits of steering-wheel angle.

The test shall cover a minimum frequency range of 0,2 Hz to 2 Hz. Optionally, the frequency range may also be extended above and below these limits.

Do not use mechanical limiters of the steering-wheel angle, if existing, because of their effect on the harmonic content of the input. It is also important that the input be continuous, as periods of relative inactivity will seriously reduce the signal-to-noise ratio.

To ensure adequate high-frequency content, the input should be energetic (see 10.2.2 and 10.3.2).

To ensure enough total data, capture at least 12 min of data, unless confidence limits indicate that a shorter time is sufficient. Ideally, all data should be accomplished in a continuous run, but practical considerations can prevent this for two reasons. Firstly, the test track could be insufficiently long to permit a continuous run of such a length at the required test speed. Secondly, the computer used to analyse the data might not be large enough to handle all the data at once. In either case, data may be captured using a number of shorter runs of at least 30 s duration.

For each test run, maintain the longitudinal velocity within a tolerance of ± 3 km/h of the desired test speed.

Determine the steering-wheel angle limits by steady-state driving on a circle, the radius of which gives the preselected steady-state lateral acceleration at the required test speed. The standard steady-state lateral acceleration level is 3 m/s^2 or less, as necessary to remain within the range in which the vehicle exhibits linear properties (see “IMPORTANT” in Clause 3, and ISO/TR 8726). Optionally, higher lateral acceleration levels may also be used, provided the vehicle remains in the linear range.

10.2 Data analysis

10.2.1 General

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

10.2.2 Preliminary analysis

A Fourier analysis shall be made of the steering-wheel angle time history. 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 B.3.

This graph shall be examined to ensure adequate frequency content. The recommended ratio between maximum and minimum steering-wheel angle should be not greater than 4:1 (12 dB). If this ratio is greater, the results may be discarded or, if used, the extent of the ratio shall be recorded in the test report (see Figure B.3).

10.2.3 Further data processing

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

— lateral acceleration related to steering-wheel angle;

— yaw velocity related to steering-wheel angle.

If data has not been captured in a continuous run, calculate the auto and cross-spectral densities for each run. The results of individual runs shall then be averaged. The averaging function used shall be recorded in the test report (see Annex A).

10.3 Data presentation

10.3.1 General

General data shall be presented in accordance with Annex A.

If a curve is fitted to any set of data, the method of curve fitting shall be described in accordance with Annex B.

10.3.2 Frequency response functions

For each pair of input and the output variables, the frequency response (i.e. gain and phase-angle functions) shall be presented on a graph as shown in Figure B.4. The figure shall be completed with the number and length of the data sequences, the averaging function, the digitizing rate and the windowing function used.

The coherence function shall also be presented on the graph (see Figure B.4). This coherence function quantifies the amount of correlated information in relation to noise present in the data. To obtain close confidence limits, it is necessary to have high coherence levels and a large number of averages.

10.3.3 Frequency response data summary

This is to be specified based on further test experience.

11 Pulse input

11.1 Test procedure

Drive the vehicle at the test speed (see 7.6) in a straight line. The initial speed shall not deviate by more than 2 km/h from the test speed. Starting from a 0°/s ± 0,5°/s yaw velocity equilibrium condition, apply a triangular waveform steering-wheel input, followed by 3 s to 5 s neutral steering-wheel position. No change in throttle position shall be made, although speed may decrease.

Use a pulse width of 0,3 s to 0,5 s. Make efforts to minimize the overshoot of the steering-wheel angle and the differences between zero references before and after the steering-wheel input to values $\leqslant$ 5 % of the peak input level. The zero reference is the steady-state value before and after the steering-wheel input.

Determine the amplitude of the steering-wheel input by steady-state driving on a circle, the radius of which gives the preselected steady-state lateral acceleration at the required test speed. The standard steady-state lateral acceleration level is 4 m/s^2 or less as necessary to remain within the range in which the vehicle exhibits linear properties (see “IMPORTANT” in Clause 3). Optionally, higher lateral acceleration levels may also be used, provided the vehicle remains in the linear range.

Perform all test runs at least three times.

11.2 Data analysis

11.2.1 General

The data processing can be carried out using a multi-channel real time analyser or a computer with the appropriate software.

11.2.2 Preliminary analysis

A Fourier analysis shall be made of the steering-wheel angle time history. 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 B.3.

11.2.3 Further data 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 related to steering-wheel angle;

— yaw velocity related to steering-wheel angle.

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

11.3 Data presentation

11.3.1 General

General data shall be presented in accordance with Annex A.

Time histories of variables used for data evaluation shall be plotted. If a curve is fitted to any set of data, the method of curve fitting shall be described in the test report in accordance with Annex B.

11.3.2 Frequency response functions

For each pair of input and output variables, the frequency response (i.e. gain and phase-angle functions) shall be presented on a graph, as shown in Figure B.4. The graph shall be completed with the number and length of the data sequences, the averaging function, the digitizing rate and the windowing function used.

The coherence function shall also be presented on the graph (see Figure B.4). This function quantifies the amount of correlated information in relation to noise present in the data. To obtain close confidence limits, it is necessary to have high coherence levels and a large number of averages.

11.3.3 Frequency response data summary

This is to be specified based on further test experience.

12 Continuous sinusoidal input

12.1 Test procedure

Drive the vehicle at the test speed (see 7.6) in a straight line. The initial speed shall not deviate more than 2 km/h from the test speed. Starting from a 0°/s ± 0,5°/s yaw velocity equilibrium condition, apply at least three periods of sinusoidal steering-wheel input with the predetermined steering-wheel angle amplitude and frequency. No change in throttle position shall be made, although speed may decrease.

Increase the steering frequency in steps. The test shall cover a minimum frequency range of 0,2 Hz to 2 Hz. Optionally, the frequency range may also be extended above and below these limits.

Determine the steering-wheel angle amplitude by steady-state driving on a circle the radius of which gives the preselected steady-state lateral acceleration at the required test speed. The standard steady-state lateral acceleration level is 4 m/s^2. Additional levels of 2 m/s^2 and 6 m/s^2 may be used.

12.2 Data analysis

12.2.1 Amplitude

The amplitude of the steering-wheel angle, lateral acceleration and yaw velocity 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.

12.2.2 Lateral acceleration gain

Lateral-acceleration gain shall be calculated as the ratio of the lateral acceleration amplitude to the steering-wheel angle amplitude, both amplitudes being in accordance with 12.2.1.

12.2.3 Yaw velocity gain

Yaw velocity gain shall be calculated as the ratio of the yaw velocity amplitude to the steering-wheel angle amplitude, both amplitudes being in accordance with 12.2.1.

12.2.4 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.

12.3 Data presentation

12.3.1 General

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

Time histories of variables used for data evaluation shall be plotted. If a curve is fitted to any set of data, the method of curve fitting shall be described in the presentation of results as in Annex B.

12.3.2 Frequency response functions

For each pair of the input and output variables lateral acceleration and yaw velocity, the frequency response (i.e. gain and phase-angle functions) shall be presented on a graph as shown in Figure B.4.

12.3.3 Frequency response data summary

This is to be specified based on further test experience.

Annex A
(normative)

Test report — General data

Vehicle identification	Make, year, model, type:	....	
	Vehicle identification number:	....	
	Steering type:	....	
	Suspension type:	**Front**	**Rear**
		....	....
	Engine size, optical equipment:	.... cm³	
	Tyres: make, size, date, condition:	....	
	Tyre pressure:	**Front**	**Rear**
	— Cold:	.... kPa	.... kPa
	— Hot, after test (if measured):	.... kPa	.... kPa
	Tyre tread depth:	**Front**	**Rear**
	— Before test:	.... mm	.... mm
	— After test:	.... mm	.... mm
	Rims:	....	
	Wheelbase:	.... m	
	Track:	**Front**	**Rear**
		.... m	.... m
	Overall steering ratio:	....	
	Other data (in particular, relevant suspension settings):	....	

Vehicle loading		**Left**	**Right**	**Sum**
	Vehicle kerb mass:	Front: .... kg	Front: .... kg	.... kg
		Rear: .... kg	Rear: .... kg	.... kg
	Loading condition and location:	**Left**	**Right**	**Sum**
		Front: .... kg	Front: .... kg	.... kg
		Rear: .... kg	Rear: .... kg	.... kg
			Total	.... kg

Test conditions	Test surface description:	....
	Weather conditions:	
	— Temperature	.... °C
	— Wind speed	.... m/s
	Test method chosen for evaluation (see "IMPORTANT", Clause 3)	
	— Time domain	....
	— Frequency domain	....

Test personnel	Driver:	....
	Observer:	....
	Data analyst:	....

General comments ....

....

....

....

....

....

Annex B
(normative)

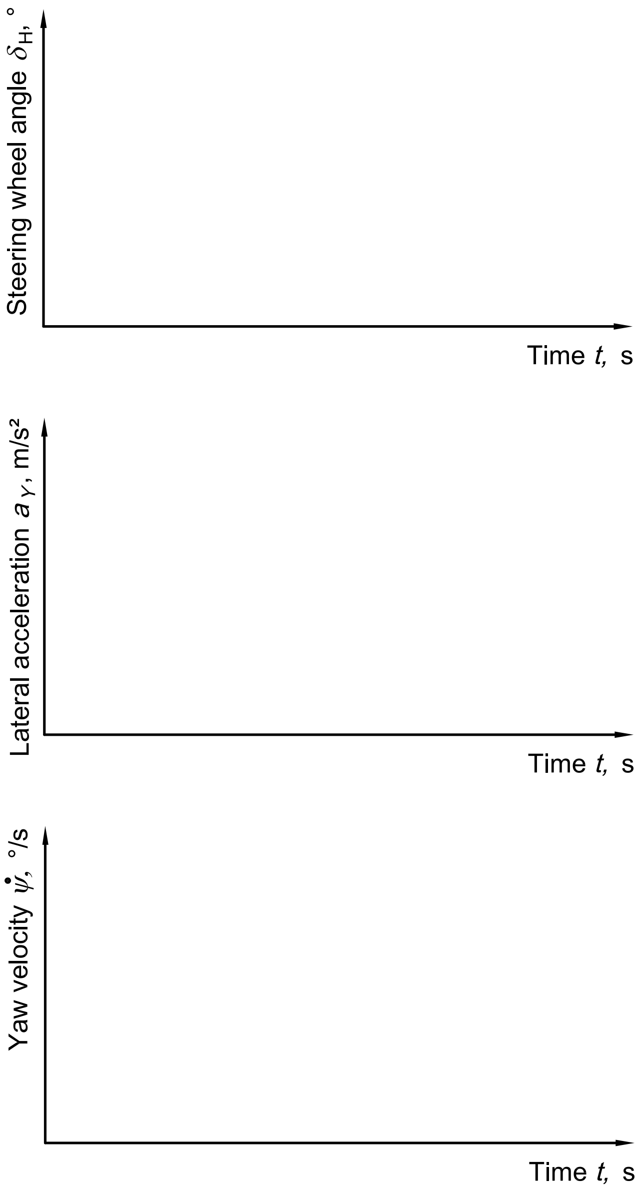
Test report — Presentation of results

B.1 Step input

Test number: ....

v_X = 100 km/h | .... km/h

a_Y = 4 m/s² | .... m/s²



$\delta_{H,SS}$ = ...

50 % $\delta_{H,ss}$ = ...

t_0 = ...

$a_{Y,SS}$ = ...

90 % $a_{Y,ss}$ = ...

$a_{Y,max}$ = ...

T_{aY} = ...

$T_{aY,max}$ = ...

$\dot{\psi}_{SS}$ = ...

90% $\dot{\psi}_{ss}$ = ...

$\dot{\psi}_{max}$ = ...

$T_{\dot{\psi}}$ = ...

$T_{\dot{\psi},max}$ = ...

Figure B.1 — Step input — Time histories

Table B.1 — Step input — Response data summary

Parameter	Symbol	Unit	Left turn	Right turn	Average
Steady-state yaw velocity response gain	$\left(\frac{\dot{\psi}}{\delta_H}\right)_{ss}$	s^{-1}			
Lateral acceleration response time	T_{aY}	s			
Yaw velocity response time	$T_{\dot{\psi}}$	s			
Lateral acceleration peak response time	$T_{aY,max}$	s			
Yaw velocity peak response time	$T_{\dot{\psi},max}$	s			
Overshoot value of lateral acceleration	U_{aY}	—			
Overshoot value of yaw velocity	$U_{\dot{\psi}}$	—			

B.2 Sinusoidal input

Test number: ....

v_X = 100 km/h | .... km/h

a_Y = 4 m/s^2 | .... m/s^2

f = 0,5 Hz | .... Hz

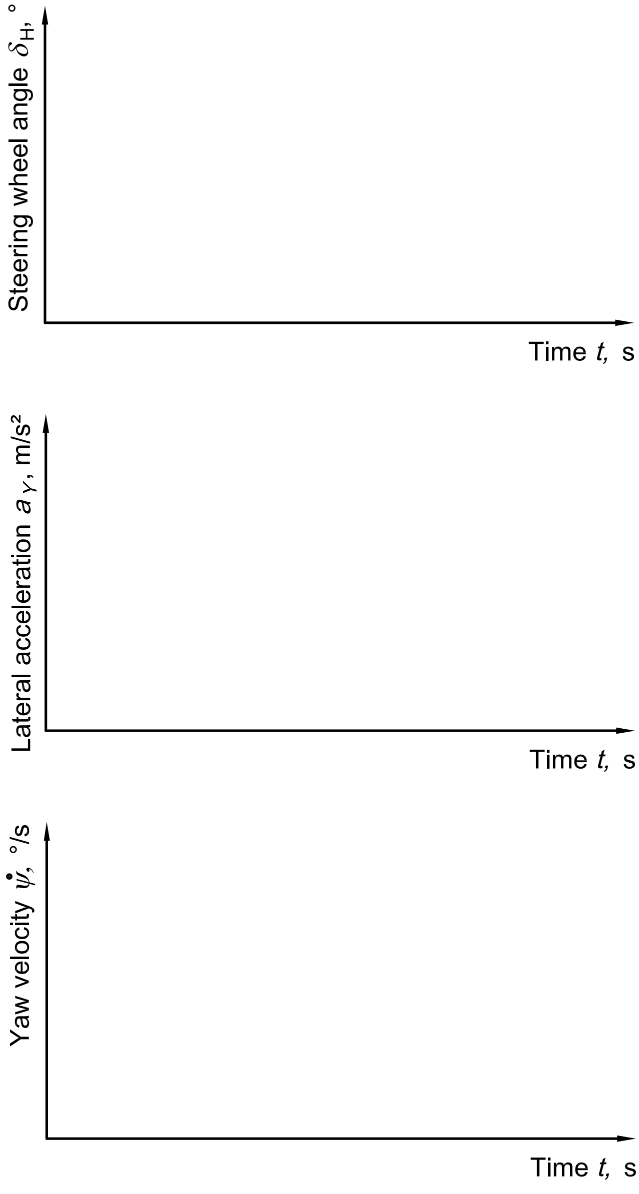


Figure B.2 — Sinusoidal input (one period) — Time histories

Table B.2 — Sinusoidal input (one period) — Response data summary

Parameter	Symbol	Unit	Left turn		Right turn	
			Mean value	Standard deviation	Mean value	Standard deviation
Time lag between steering wheel angle and lateral acceleration	$T(\delta_{\mathrm{H}} - a_Y)$					
Peak 1	$T(\delta_{\mathrm{H}} - a_Y)_1$	ms				
Peak 2	$T(\delta_{\mathrm{H}} - a_Y)_2$	ms				
Time lag between steering wheel angle and yaw velocity	$T(\delta_{\mathrm{H}} - \dot{\psi})$					
Peak 1	$T(\delta_{\mathrm{H}} - \dot{\psi})_1$	ms				
Peak 2	$T(\delta_{\mathrm{H}} - \dot{\psi})_2$	ms				
Lateral acceleration gain	$\frac{a_Y}{\delta_{\mathrm{H}}}$	$(\mathrm{m/s^2})/°$				
Yaw velocity gain	$\frac{\dot{\psi}}{\delta_{\mathrm{H}}}$	s^{-1}				

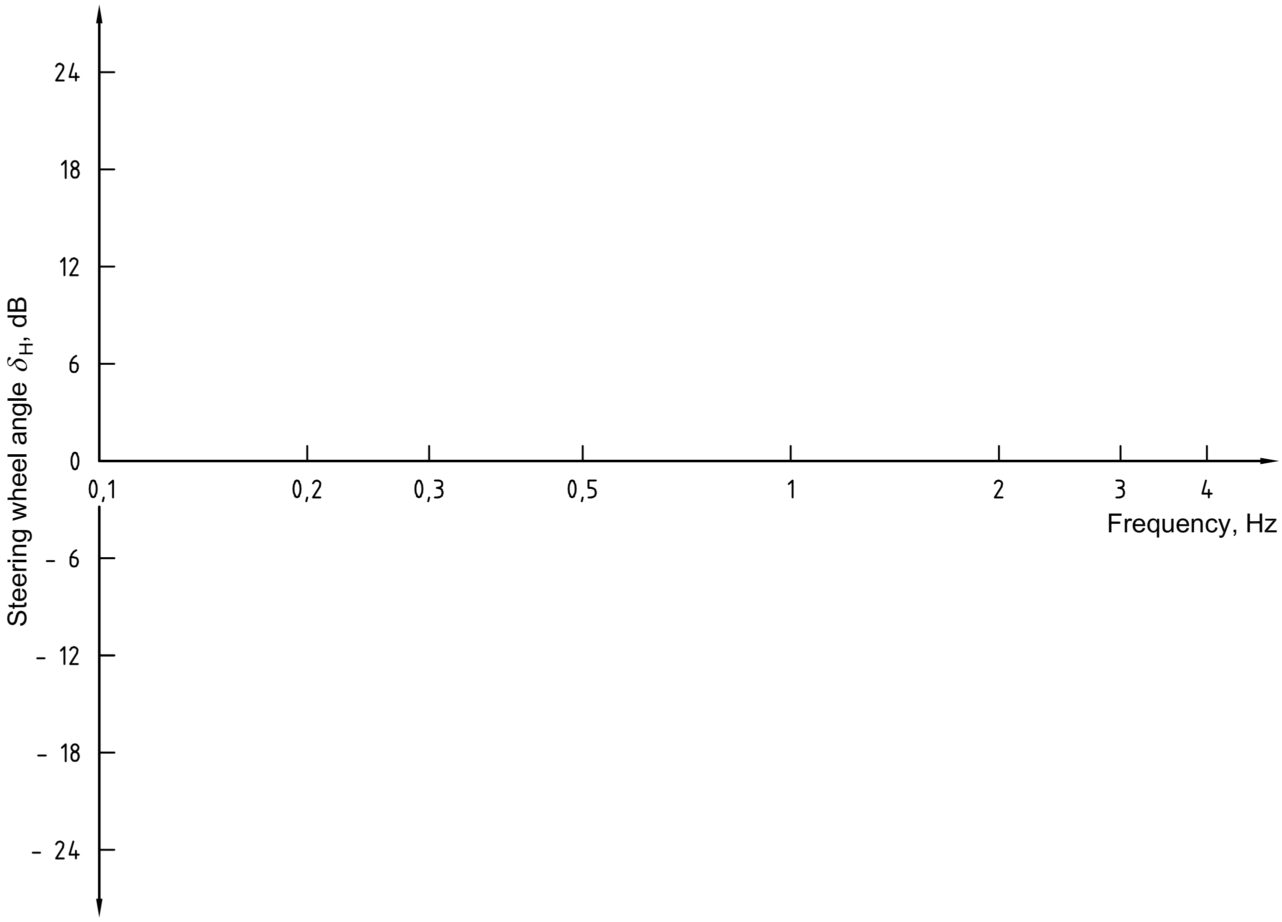
B.3 Random/pulse[2)] input

Test number: ....

v_X = 100 km/h | .... km/h

a_Y = 4 m/s^2 | .... m/s^2

f = 0,5 Hz | .... Hz



Optional is a linear scale for the frequency (X-axis).

Figure B.3 — Random/pulse input — Harmonic content of steering-wheel angle

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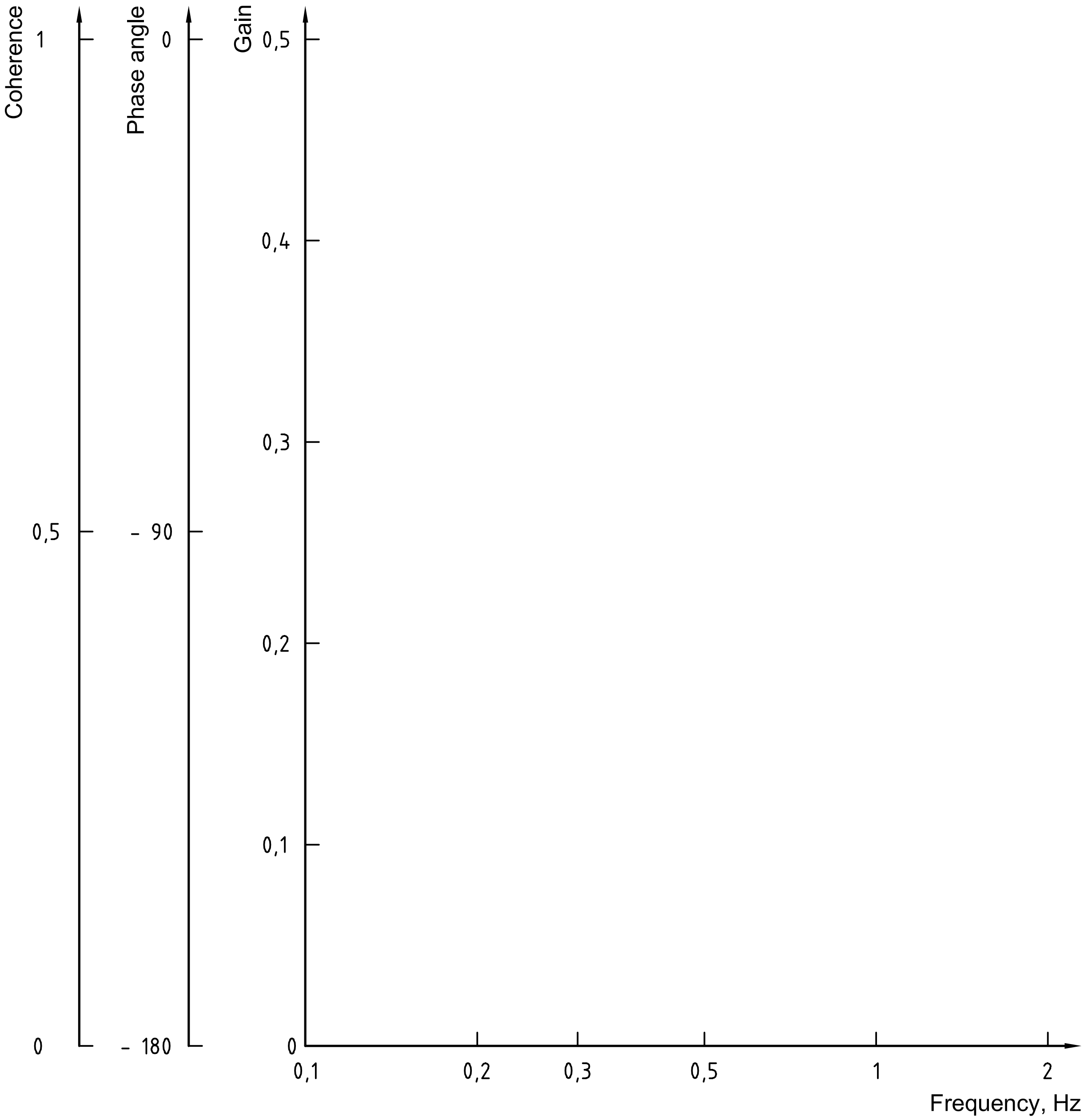
2) Delete as applicable.

B.4 Random/pulse/continuous[3] sinusoidal input

Test number: ....

v_X = 100 km/h | .... km/h

a_Y = 4 m/s^2 | .... m/s^2



Optional is a linear scale for the frequency (X-axis).

Figure B.4 — Random/pulse/continuous sinusoidal input — Transient response to steering-wheel angle

3) Delete as applicable.

Bibliography

[1] ISO 4138, *Passenger cars — Steady-state circular driving behaviour — Open-loop test procedure*

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