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ISO 14793

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Road vehicles — Heavy commercial vehicles and buses — Lateral transient response test methods

Véhicules routiers — Véhicules utilitaires lourds et autobus — Méthodes d'essai de réponse transitoire latérale

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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 14793 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 14793:2003), which has been technically revised.

Introduction

The main purpose of this International Standard is to provide repeatable and discriminatory test results.

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

Since this test method quantifies only one small part of the complete vehicle handling characteristics, 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 overall vehicle dynamic properties and accident avoidance. A substantial amount of work 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. Consequently, any application of this test method for regulation purposes will require proven correlation between test results and accident statistics.

Road vehicles — Heavy commercial vehicles and buses — Lateral transient response test methods

1 Scope

This International Standard specifies test methods for determining the transient response behaviour of heavy commercial vehicles, heavy commercial vehicle combinations, buses and articulated buses, as defined in ISO 3833 for trucks and trailers above 3,5 t and buses above 5 t maximum weight, and in UNECE (United Nations Economic Commission for Europe) and EC vehicle classification, categories M3, N2, N3, O3 and O4.

NOTE The open-loop manoeuvres specified in this International Standard are not representative of real driving conditions, but are nevertheless useful for obtaining measures of vehicle transient behaviour — particularly with respect to that which the driver experiences — in response to several specific types of steering input under closely controlled test conditions. For combinations where the response of the last vehicle unit is of importance, see ISO 14791.

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 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 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 8855 and the following apply.

3.1
vehicle unit
unit of a vehicle combination which is connected with a yaw-articulation joint

EXAMPLE Tractor, semitrailer, dolly.

NOTE The number of vehicle units is one more than the number of articulation joints.

4 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 which, together, cover the total range of interest.

The objective of these tests is to determine the transient response of a vehicle. Characteristic values and functions of both linear and nonlinear behaviour are considered necessary for fully characterizing vehicle transient response. Linear characteristic values and functions are determined with tests in the frequency domain and nonlinear characteristic values and functions with tests in the time domain. In the case of vehicle combinations, it is primarily the response of the first vehicle unit that is evaluated.

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 9.2.1),

— lateral acceleration gain (lateral acceleration divided by steering-wheel angle),

— yaw velocity gain (yaw velocity divided by steering-wheel angle), and

— overshoot values (see 9.2.3).

Important characteristics in the frequency domain are the transfer functions of

— lateral acceleration related to steering-wheel angle, and

— yaw velocity related to steering-wheel angle,

expressed as gain and phase functions between input and output variables.

There are several test methods for obtaining these characteristics in the time and frequency domains, 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.

5 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 shall be thus defined.

6 Variables

The following variables shall be determined:

— yaw velocity, $\dot{\psi}$;

— lateral acceleration, a_Y;

— steering-wheel angle, δ_H;

— longitudinal velocity, v_X.

The following variables may be determined:

— lateral deviation, y;

— roll angle at relevant points, φ;

— steering-wheel torque, M_H;

— sideslip angle, β.

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

7 Measuring equipment

7.1 Description

The variables to be determined in accordance with Clause 6 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.

7.2 Transducer installation

The transducers shall be installed 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.

7.3 Data processing

7.3.1 General

The frequency range relevant for this test is between 0 Hz and the maximum utilized frequency of $f_{max} = 2$ Hz. Depending on the data processing method chosen (analog or digital data processing) the provisions of 7.3.2 or 7.3.3 shall be observed.

For lighter trucks it may be necessary to increase f_{max} to 3 Hz. In this case, the following requirements concerning the frequency f_{max} may be modified correspondingly.

7.3.2 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 2 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 7.3.3, is preferable.

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

Variable	Range	Recommended maximum error of combined transducer and recorder system
Yaw velocity	− 50°/s to + 50°/s	± 0,5°/s
Lateral acceleration	− 15 m/s² to + 15 m/s²	± 0,15 m/s²
Steering-wheel angle	− 360° to + 360°	± 2° for angles < 180° ± 4° for angles > 180°
Longitudinal velocity	0 m/s to 35 m/s	± 0,35 m/s
Roll angle	− 15° to + 15°	± 0,15°
Side slip angle	− 10° to + 10°	± 0,3°
Lateral velocity	− 10 m/s to + 10 m/s	± 0,1 m/s
Steering-wheel torque		
without power steering	− 50 N·m to + 50 N·m	± 0,5 N·m
with power steering	− 20 N·m to + 20 N·m	± 0,2 N·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).		

7.3.3 Digital data processing

7.3.3.1 General considerations

Preparation of analog signals includes consideration of filter amplitude attenuation and sampling rate in order to avoid aliasing errors, and filter phase lags and time delays. Sampling and digitizing considerations include presampling 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.

7.3.3.2 Aliasing errors

In order to avoid uncorrectable aliasing, the analog signals shall be appropriately filtered before sampling and digitizing. The order of the 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} = 2 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 2 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

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

and

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

where

n is the order of the filter;

f_{max} is the relevant frequency range (2 Hz);

f_0 is the filter cut-off frequency;

f_{N} is the Nyquist or “folding” frequency;

f_{s} is the sampling frequency $= 2 \times f_{\text{N}}$

For example, for a fourth-order filter:

— for $A = 0{,}999\,5$, $f_0 = 2{,}37 \times f_{\text{max}} = 4{,}74$ Hz;

— for $A = 0{,}000\,5$, $f_{\text{s}} = 2 \times (6{,}69 \times f_0) = 63{,}4$ Hz.

7.3.3.3 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.

Phase shifts are especially significant when measured variables are multiplied together to form new variables. This is because, while amplitudes multiply, phase shifts and associated time delays add. Phase shifts and time delays are reduced by increasing f_0. Whenever equations describing the presampling filters are known, it is practical to remove their phase shifts and time delays by simple algorithms performed in the frequency domain.

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

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

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

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

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

7.3.3.4 Data sampling and digitizing

At 2 Hz the signal amplitude changes by up to 1,25 %/ms. To limit dynamic errors caused by changing analog inputs to 0,1 %, sampling or digitizing time shall be less than 80×10^{-6} s. All pairs or sets of data samples to be compared shall be taken simultaneously or over a sufficiently short time period.

In order not to exceed an amplitude error of 0,5 % in the relevant frequency range from zero to f_{max}, the sampling rate, f_s, shall be at least 30 f_{max}.

7.3.3.5 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; 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 80×10^{-6} s.

7.3.3.6 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):

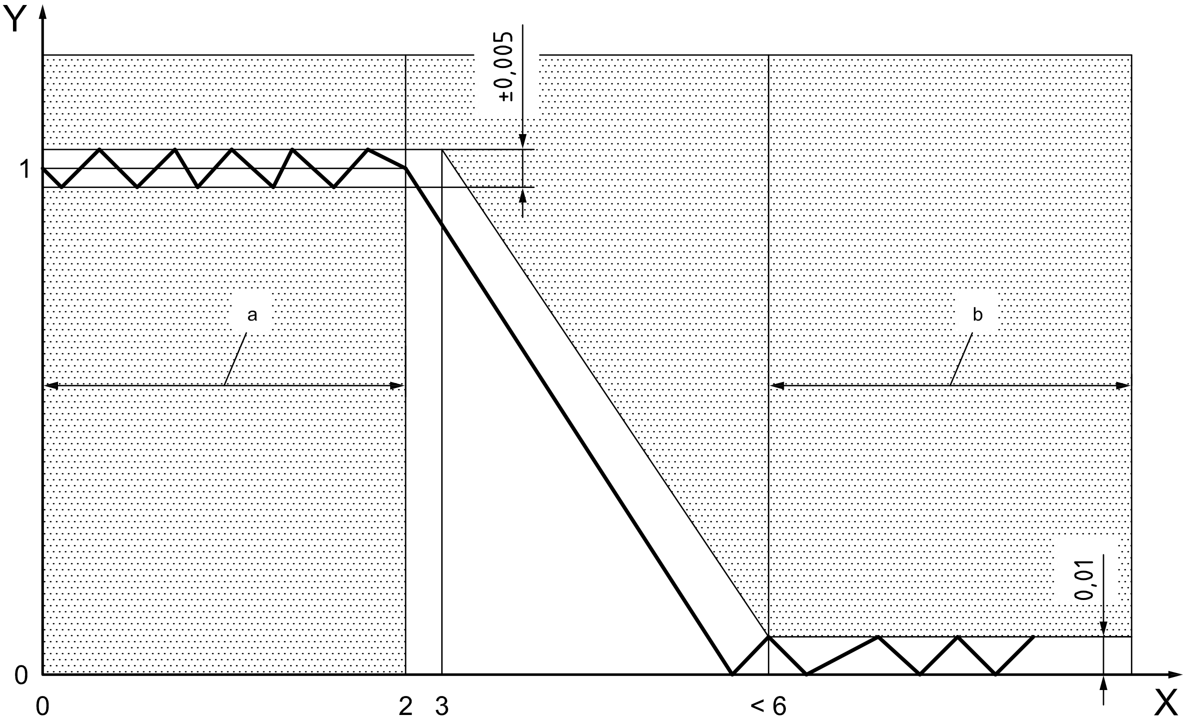
— the passband shall range from 0 Hz to 2 Hz;

— the stopband shall begin at < 6 Hz;

— the filter gain in the passband shall be 1 ± 0,005 (100 ± 0,5) %;

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

— the filter gain shall fall within the unshaded area of Figure 1.



X frequency, in Hz

Y filter gain

[a] Passband.

[b] Stopband.

Figure 1 — Required characteristics of phaseless digital filters

8 Test conditions

8.1 General

Limits and specifications for the ambient wind and vehicle test conditions in accordance with 8.3 and 8.4 shall be maintained throughout the 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).

8.2 Test track

All standard 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 greater than or equal to the vehicle track. In addition, for tests concerned with damping of combination vehicles, the gradient of the test surface shall not exceed 1 % along the path of the vehicle as measured over any distance of 25 m or more. For each test the road surface conditions and paving material shall be recorded in the test report (see Annex A).

8.3 Weather conditions

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

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

Since, in certain cases, ambient temperature can have a significant influence on test results, it should be taken into account when making comparisons between vehicles.

8.4 Test vehicle

8.4.1 General data

Appropriate general data on the test vehicle or vehicle unit shall be presented in the test report in accordance with Annex A.

8.4.2 Tyres

For the standard test conditions, new tyres shall be fitted on the test vehicle according to the vehicle 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), shall have been stored in accordance with the manufacturer's recommendation and shall not have been manufactured more than two years 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. The tolerance for setting the cold inflation pressure is ± 2 %.

Inflation pressure and tread depth before 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 with tyres in any state of wear as well as with retreaded or regrooved tyres. The details shall be recorded in the test report (see Annex A). 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.

8.4.3 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 specification shall be recorded in the test report (see Annex A).

Levelling systems of the chassis and cabin suspension which affect the response behaviour inappropriately should be disabled during steady-state and step-input tests.

8.4.4 Vehicle loading conditions

8.4.4.1 General

The maximum design total mass (Code: ISO-M07) and the maximum design axle load (Code: ISO-M12), in accordance with ISO 1176:1990, 4.7 and 4.12, shall not be exceeded.

The total weight and the centre-of-gravity position (longitudinal, lateral and vertical) can be expected to influence all test results. Moments of inertia can be expected to influence transient test results. For all tests, the total mass and the centre-of-gravity position in three dimensions should be reported for each vehicle unit, and for transient tests, the moment of inertia in yaw should also be reported. Moments of inertia in pitch and roll should be reported if available.

Alternatively, the loading condition of the vehicle shall be described adequately such that these parameters can be reproduced.

Care shall be taken to ensure that the masses, centre-of-gravity positions and moments of inertia of the test vehicle compare closely to those parameters of the vehicle in normal use. The resulting static wheel loads shall be determined and recorded in the test report (see Annex A).

8.4.4.2 Minimum loading condition

For the minimum loading condition, the total mass of the vehicle or combination shall consist of the complete vehicle kerb mass (Code: ISO-M06) in accordance with ISO 1176:1990, 4.6, plus the mass of the instrumentation. In the case of the first vehicle unit, the mass of the driver and, if applicable, the mass of an instrument operator or observer shall be added. The minimum loading condition is optional.

8.4.4.3 Maximum loading condition

For the maximum loading condition, the total mass of a fully laden vehicle or combination shall consist of the complete vehicle kerb mass plus the maximum load of interest (e.g. the legal limit) distributed such that none of the maximum axle loads is exceeded (see ISO 1176). The height of the centre of gravity and the mass distribution of the payload should be established to reflect the application of interest. The maximum loading condition is the standard test condition.

8.4.4.4 Other loading conditions

Other loading conditions, representing special transport conditions, are encouraged.

8.5 Warm-up

All relevant vehicle components shall be warmed up prior to the tests in order to achieve a temperature representative of normal driving conditions. Tyres shall be warmed up prior to the tests to achieve an equilibrium temperature and pressure representative of normal driving conditions.

To warm up the tyres, a procedure by driving at the test speed for a distance of at least 50 km or equivalent to driving 5 km at a lateral acceleration of 1 m/s^2 (left and right turn each) could be appropriate.

The tyre pressures after warm-up may be recorded.

8.6 Test speed

All tests shall be conducted at either 80 km/h, 90 km/h or 100 km/h, depending on the intended use of the vehicle, or at the maximum speed of the vehicle if it is less than 80 km/h. Other test speeds of interest may be used (preferably in 10 km/h steps).

For each test run, the average speed shall be maintained within a tolerance of ± 2 km/h of the selected speed. A deviation of the vehicle speed of ± 3 km/h from the selected speed is permissible.

8.7 Lateral acceleration

IMPORTANT — Stepwise increase of the lateral acceleration and the use of outriggers are strongly recommended in order to prevent rollover.

The lateral acceleration of the vehicle, or first vehicle unit in the case of combinations, shall be appropriate to the particular type of test. For linear tests, the lateral acceleration of all vehicle units shall be small enough to generate only linear vehicle behaviour. For nonlinear tests, the lateral acceleration shall be large enough to have the vehicle show nonlinear behaviour.

The recommended value of the lateral acceleration level should be 3 m/s^2, except for the random input test where the lateral acceleration level should be 2 m/s^2. For safety reasons, the maximum lateral acceleration should be smaller than 75 % of the estimated rollover limit or 75 % of the road adhesion limit.

The applied lateral acceleration level shall be recorded in the test report (see Annex B).

NOTE Lateral acceleration measured from different vehicles cannot be compared.

8.8 Average longitudinal acceleration

For tests concerned with damping of combination vehicles, the average longitudinal acceleration over the time period during which measurements are actually made shall be within ± 0,1 m/s^2.

9 Step input

9.1 Test procedure

Drive the vehicle at the test speed (see 8.6) in a straight line. Starting from a steady-state condition with yaw velocity in the range of ± 0,5 °/s, apply a steering input as rapidly as possible to a preselected value and maintain it at that value until the measured vehicle motion variables reach a steady state.

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. 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.

Increase the steering-wheel amplitude stepwise up to a magnitude sufficient to produce the desired lateral acceleration level (see 8.7).

Perform at least three test runs at each steering-wheel angle amplitude.

9.2 Data analysis

9.2.1 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 attain the designated percentage of its new steady-state value. The 90 % response times should be determined (see Figure 2), and in some cases it may be desirable to determine other response times, for example, the 63 % response time.

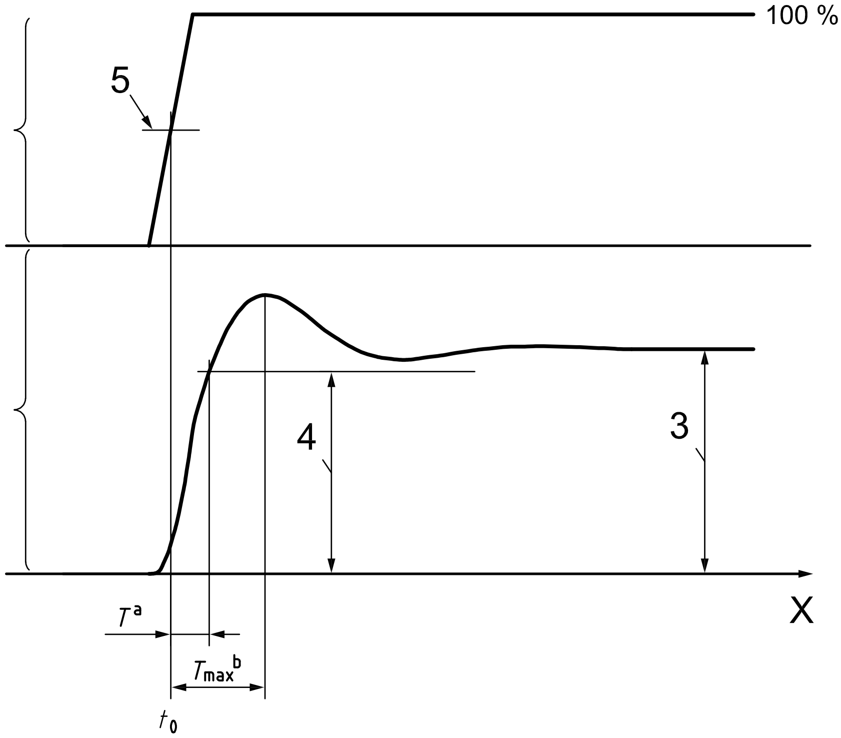
9.2.2 Peak response time

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.

9.2.3 Overshoot values

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



Key

X time

1 steering-wheel input

2 vehicle motion response

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

9.3 Data presentation

9.3.1 General

General data shall be presented in accordance with Annex A.

9.3.2 Time histories

The 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 presentation of results in accordance with Annex B.

Plot the time histories of steering-wheel angle, lateral accelerations and yaw velocities for the selected lateral acceleration level, as shown in Figure B.1.

9.3.3 Time-response data summary

Record in accordance with Table B.1, as applicable, the means and standard deviation of the following variables for the selected test speed and the lateral acceleration level:

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

b) steady-state lateral acceleration response gain, $\left(\frac{a_Y}{\delta_{\mathrm{H}}}\right)_{\mathrm{ss}}$;

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

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

e) lateral acceleration peak response time, $T_{aY,\mathrm{max}}$;

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

g) overshoot value (see 9.2.3) of lateral acceleration, U_{aY};

h) overshoot value (see 9.2.3) of yaw velocity, $U_{\dot{\psi}}$.

The confidence intervals for these variables should also be determined.

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

10.1 Test procedure

Drive the vehicle at the test speed (see 8.6) in a straight line. Starting from a steady-state condition with yaw velocity in the range of ± 0,5 °/s, apply one full period sinusoidal steering-wheel input with a frequency of 0,2 Hz. An additional frequency of 0,5 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.

Take data while the steering wheel is rotated initially both to the left and to the right. All data may 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 amplitude stepwise up to a magnitude sufficient to produce the desired lateral acceleration level (see 8.7 and 10.2.2).

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

10.2 Data analysis

10.2.1 General

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

10.2.2 Lateral acceleration

Lateral acceleration in this test is defined as the first peak value of the lateral-acceleration time history.

10.2.3 Yaw velocity

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

10.2.4 Time lags

The time lags between the variables steering-wheel angle and 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).

10.2.5 Lateral acceleration gain

Lateral acceleration gain shall be calculated as the ratio of the lateral acceleration (in accordance with 10.2.2) to the corresponding peak value of the steering-wheel angle.

10.2.6 Yaw velocity gain

Yaw velocity gain shall be calculated as the ratio of the yaw velocity (according to 10.2.3) to the corresponding peak value of the steering-wheel angle.

10.3 Data presentation

10.3.1 General

General data shall be presented in accordance with Annex A.

10.3.2 Time histories

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 presentation of results (see Annex B).

Plot the time histories of steering-wheel angle, lateral accelerations and yaw velocities for the selected lateral acceleration level as shown in Figure B.2.

10.3.3 Time-response data summary

Test data shall be presented in summary form as presented in Table B.2, as mean values ± standard deviation (see 10.1).

The confidence intervals for the appropriate variables should also be determined.

10.3.4 Data as functions of lateral acceleration

If optional measurements are made at other lateral accelerations, it is useful to present data as functions of lateral acceleration. The justification for making two initial turn directions is that an asymmetry can exist. This asymmetry can be presented in terms of asymmetry factors. These further types of presentation are described in detail in ISO/TR 8725.

11 Random input (see ISO/TR 8726)

11.1 Test procedure

Make the test runs by driving the vehicle at the selected test speed (see 8.6) 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 0,1 Hz to 2 Hz. Optionally, the frequency range may also be extended above and below these limits.

Do not use mechanical limiters of steering-wheel angle, owing to 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 11.2.2 and 11.2.3).

To ensure enough total data, capture at least 12 min of data, unless confidence limits indicate that a shorter time is sufficient. Ideally, this 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 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.

Determine the steering-wheel angle limits by steady-state driving on a circle, the radius of which gives the desired steady-state lateral acceleration (see 8.7) at the selected test speed (see 8.6). The recommended steady-state lateral acceleration is 2 m/s^2 or less, as necessary to remain within the range in which the vehicle exhibits linear properties (see “IMPORTANT” in Clause 4, and ISO/TR 8726). Optionally, higher lateral accelerations may also be used, provided the vehicle remains in the linear range.

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 (see ISO/TR 8726).

11.2.2 Preliminary analysis

A spectral analysis shall be made of the steering-wheel angle time history. The result shall be displayed as a graph of the input level 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 not be greater than 4:1. 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).

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.

If data have 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).

11.3 Data presentation

11.3.1 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.

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 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.

12 Pulse input

12.1 Test procedure

Drive the vehicle at the test speed (see 8.6) in a straight line. Starting from a steady-state condition with yaw velocity in the range of ± 0,5 °/s, apply a triangular waveform steering-wheel input, followed by 3 s to 5 s of neutral steering-wheel position.

Use a pulse width of 0,3 s to 2,0 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 ⩽ 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 recommended 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 4, and ISO/TR 8726). Optionally, higher lateral acceleration levels may also be used, provided the vehicle remains in the linear range.

Perform at least seven test runs.

12.2 Data analysis

12.2.1 General

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

12.2.2 Preliminary analysis

A spectral analysis shall be made of the steering-wheel angle time history. The result shall be displayed as a graph of the input level versus frequency, as shown in Figure B.3.

12.2.3 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 the test runs shall be averaged.

12.3 Data presentation

12.3.1 General

General data shall be presented in accordance with 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 test report in accordance with Annex B.

12.3.2 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.

13 Continuous sinusoidal input

13.1 Test procedure

Drive the vehicle at the test speed (see 8.6) in a straight line. Starting from a steady-state condition with yaw velocity in the range of ± 0,5 °/s, apply sinusoidal steering with a predetermined amplitude and frequency. Continue steering input for enough cycles to produce at least three consecutive cycles of steady-state response. The amplitude error of the actual waveform compared to the true sine wave shall be less than 5 % of the amplitude as defined in 13.2.1.

Increase the steering frequency in steps. The test shall cover a minimum frequency range of 0,1 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 desired steady-state lateral acceleration at the selected test speed.

Perform at least three tests at each frequency.

13.2 Data analysis

13.2.1 Amplitude

The amplitudes of the steering-wheel angle, the lateral acceleration or the yaw velocity are defined as the mean value of the peak amplitudes taken during the manoeuvre when the vehicle is in a periodic steady-state condition. In no case shall the first period be used.

13.2.2 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 13.2.1.

13.2.3 Yaw velocity gain

Yaw velocity gain shall be calculated as the ratio of yaw velocity amplitude to the amplitude of the steering-wheel angle, both amplitudes being in accordance with 13.2.1.

13.2.4 Phase angle

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

13.3 Data presentation

13.3.1 General

General data shall be presented in accordance with 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 accordance with Annex B.

13.3.2 Frequency response functions

For each pair of input and output variables, mean values and standard deviations of the gain and phase angle shall be presented on a graph as a function of excitation frequency, as shown in Figure B.4. Similar graphs showing mean values and confidence intervals should also be made.

Annex A
(normative)

Test report — General data

A.1 Towing vehicle

A.1.1 Vehicle identification

Make, year, model, type: ....

Vehicle identification number: ....

Steering type: ....

Engine size: .... cm^3

Optional equipment: ....

Axle 1 (front)

Suspension type: ....

Tyres

make: ....

size: ....

condition: ....

Number of wheels: ....

Track width: .... m

Rim: ....

Axle 2

Suspension type: ....

Tyres

make: ....

size: ....

condition: ....

Number of wheels: ....

Track width: .... m

Rim: ....

Axle 3

Suspension type: ....

Tyres

make: ....

size: ....

condition: ....

Number of wheels: ....

Track width: .... m

Rim: ....

Axle 4

Suspension type: ....

Tyres

make: ....
size: ....
condition: ....

Number of wheels: ....

Track width: .... m

Rim: ....

Tyre pressure

Cold: Axle 1: .... Axle 2: .... Axle 3: .... Axle 4: .... kPa

Hot

after warm-up: Axle 1: .... Axle 2: .... Axle 3: .... Axle 4: .... kPa

after test: Axle 1: .... Axle 2: .... Axle 3: .... Axle 4: .... kPa

Steering ratio (wheel angle/steering angle):

Axle 1: ....

Axle 2: ....

Axle 3: ....

Axle 4: ....

Distance between axles:

Axle 1–Axle 2: .... m

Axle 2–Axle 3: .... m

Axle 3–Axle 4: .... m

Distance between Axle 1 and front coupling: .... m

Distance between Axle 1 and rear coupling: .... m

Height of coupling (with trailer attached to the towing vehicle or the trailer in front): .... m

Other data (in particular relevant suspension settings):

....

....

....

....

A.1.2 Vehicle loading

Vehicle curb mass:

Axle 1 left wheel	kg	+	Right wheel	kg	=	.... kg
Axle 2 left wheel(s)	kg	+	Right wheel(s)	kg	=	.... kg
Axle 3 left wheel(s)	kg	+	Right wheel(s)	kg	=	.... kg
Axle 4 left wheel(s)	kg	+	Right wheel(s)	kg	=	.... kg
						Total .... kg

Loading condition and location: ....

Vehicle mass as tested:

Axle 1 left wheel	kg	+	Right wheel	kg	=	.... kg
Axle 2 left wheel(s)	kg	+	Right wheel(s)	kg	=	.... kg
Axle 3 left wheel(s)	kg	+	Right wheel(s)	kg	=	.... kg
Axle 4 left wheel(s)	kg	+	Right wheel(s)	kg	=	.... kg
						Total .... kg

Maximum permitted static load on the coupling of the towing vehicle: .... kg

Centre of gravity height: .... m

A.1.3 Test conditions

Test surface description: ....

Weather conditions

Temperature: .... °C

Wind velocity: .... m/s

Reference point for side slip angle and lateral velocity:

Test method chosen for evaluation

In the time domain: ....

In the frequency domain: ....

A.1.4 Test personnel

Driver: ....

Observer: ....

Data analyst: ....

A.1.5 General comments

....
....
....
....
....

A.2 Semi- or full trailer

A.2.1 Vehicle identification

Make, year, model, type: ....

Vehicle number: ....

Axle 1 (front) ....

Suspension type: ....

Tyres

make: ....
size: ....
condition: ....

Number of wheels: ....

Track width: .... m

Rim: ....

Axle 2

Suspension type: ....

Tyres

make: ....
size: ....
condition: ....

Number of wheels: ....

Track width: .... m

Rim: ....

Axle 3

Suspension type: ....

Tyres

make: ....
size: ....
condition: ....

Number of wheels: ....

Track width: .... m

Rim: ....

Axle 4

Suspension type: ....

Tyres

make: ....

size: ....

condition: ....

Number of wheels: ....

Track width: .... m

Rim: ....

Tyre pressure

Cold: Axle 1: .... Axle 2: .... Axle 3: .... Axle 4: .... kPa

Hot

after warm-up: Axle 1: .... Axle 2: .... Axle 3: .... Axle 4: .... kPa

after test: Axle 1: .... Axle 2: .... Axle 3: .... Axle 4: .... kPa

Steering ratio (wheel angle/steering angle):

Axle 1: ....

Axle 2: ....

Axle 3: ....

Axle 4: ....

Distance between axles:

Axle 1–Axle 2 .... m

Axle 2–Axle 3 .... m

Axle 3–Axle 4 .... m

Distance between Axle 1 and front coupling: .... m

Distance between Axle 1 and rear coupling: .... m

Height of coupling (with trailer attached to the towing vehicle or the trailer in front): .... m

Other data (in particular relevant suspension settings):

....

....

....

....

A.2.2 Vehicle loading

Vehicle curb mass:

Axle 1 left wheel .... kg	+	Right wheel .... kg	=	.... kg
Axle 2 left wheel(s) .... kg	+	Right wheel(s) .... kg	=	.... kg
Axle 3 left wheel(s) .... kg	+	Right wheel(s) .... kg	=	.... kg
Axle 4 left wheel(s) .... kg	+	Right wheel(s) .... kg	=	.... kg
			Total	.... kg

Loading condition and location: ....

Vehicle mass as tested:

Axle 1 left wheel .... kg	+	Right wheel .... kg	=	.... kg
Axle 2 left wheel(s) .... kg	+	Right wheel(s) .... kg	=	.... kg
Axle 3 left wheel(s) .... kg	+	Right wheel(s) .... kg	=	.... kg
Axle 4 left wheel(s) .... kg	+	Right wheel(s) .... kg	=	.... kg
			Total	.... kg

Maximum permitted static load on the front coupling of the trailer (dolly): .... kg

Static load on the rear coupling of the trailer: .... kg

Maximum permitted static load on the rear coupling of the trailer (dolly): .... kg

Centre of gravity height: .... m

Annex B
(normative)

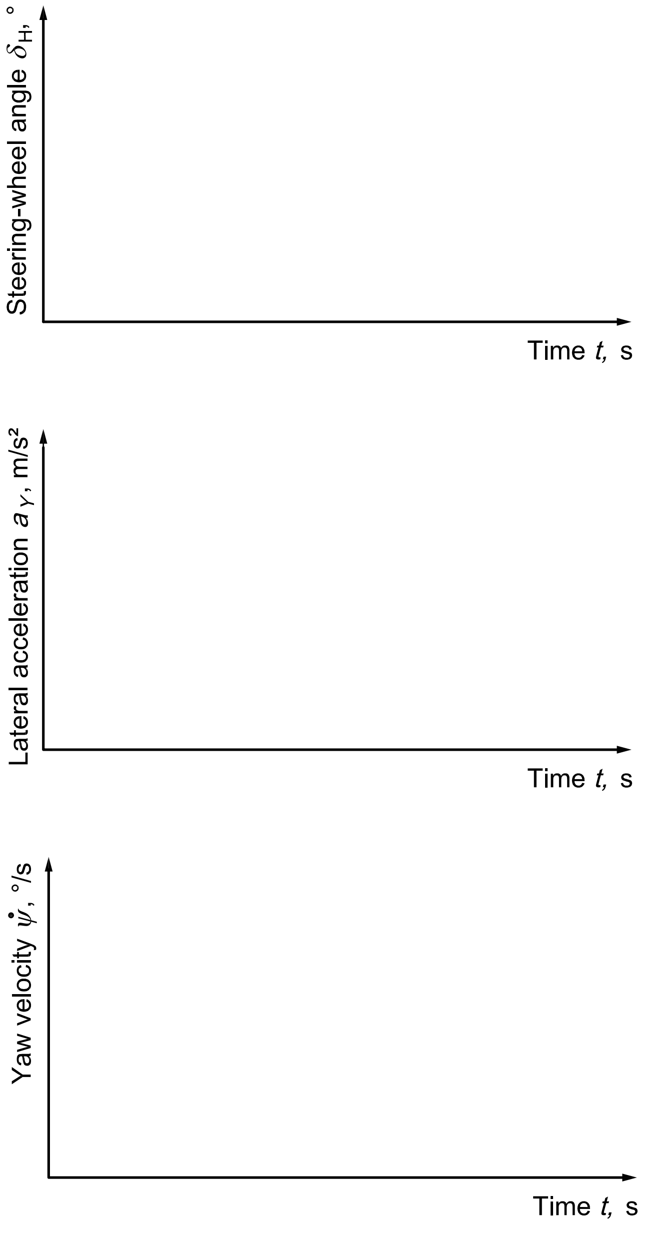
Test report — Presentation of results

B.1 Step input

Test number: ....

v_X = 80 km, 90 km or 100 km/h |......... km/h

a_Y = 3 m/s^2 |......... m/s^2



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

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

t_o = ...

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

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	
			Mean value	Standard deviation	Mean value	Standard deviation
Steady-state yaw velocity response gain	$\left(\frac{\dot{\psi}}{\delta_{\mathrm{H}}}\right)_{\mathrm{ss}}$	s^{-1}				
Lateral acceleration response time	T_{aY}	s				
Yaw velocity response time	$T_{\dot{\psi}}$	s				
Lateral acceleration peak response time	$T_{aY,\mathrm{max}}$	s				
Yaw velocity peak response time	$T_{\dot{\psi},\mathrm{max}}$	s				
Overshoot value of lateral acceleration	U_{aY}	—				
Overshoot value of yaw velocity	$U_{\dot{\psi}}$	—				

B.2 Sinusoidal input

Test number: ....

v_X = 80 km, 90 km or 100 km/h | .... km/h

a_Y = 3 m/s^2 | .... m/s^2

f = 0,2 Hz | .... Hz

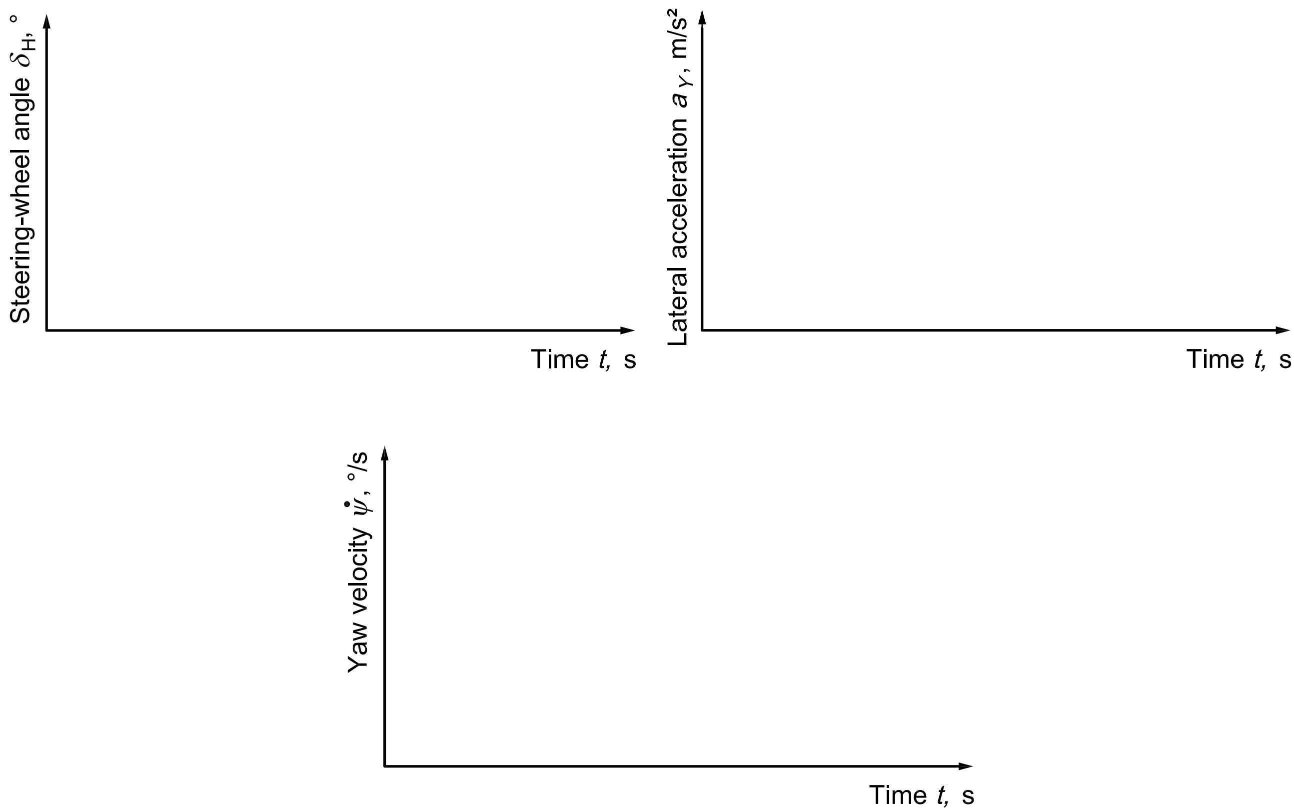


Figure B.2 — Sinusoidal input (one period) — Time histories

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	$T\left(\delta_{\mathrm{H}} - a_Y\right)$					
Peak 1	$T\left(\delta_{\mathrm{H}} - a_Y\right)_1$	ms				
Peak 2	$T\left(\delta_{\mathrm{H}} - a_Y\right)_2$	ms				
Time lag between steering-wheel angle and yaw velocity	$T\left(\delta_{\mathrm{H}} - \dot{\psi}\right)$					
Peak 1	$T\left(\delta_{\mathrm{H}} - \dot{\psi}\right)_1$	ms				
Peak 2	$T\left(\delta_{\mathrm{H}} - \dot{\psi}\right)_2$	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[1] input

Test number: ....

v_X = 80 km, 90 km or 100 km/h | .... km/h

a_Y = 2 m/s^2 or 3 m/s^2 | .... m/s^2

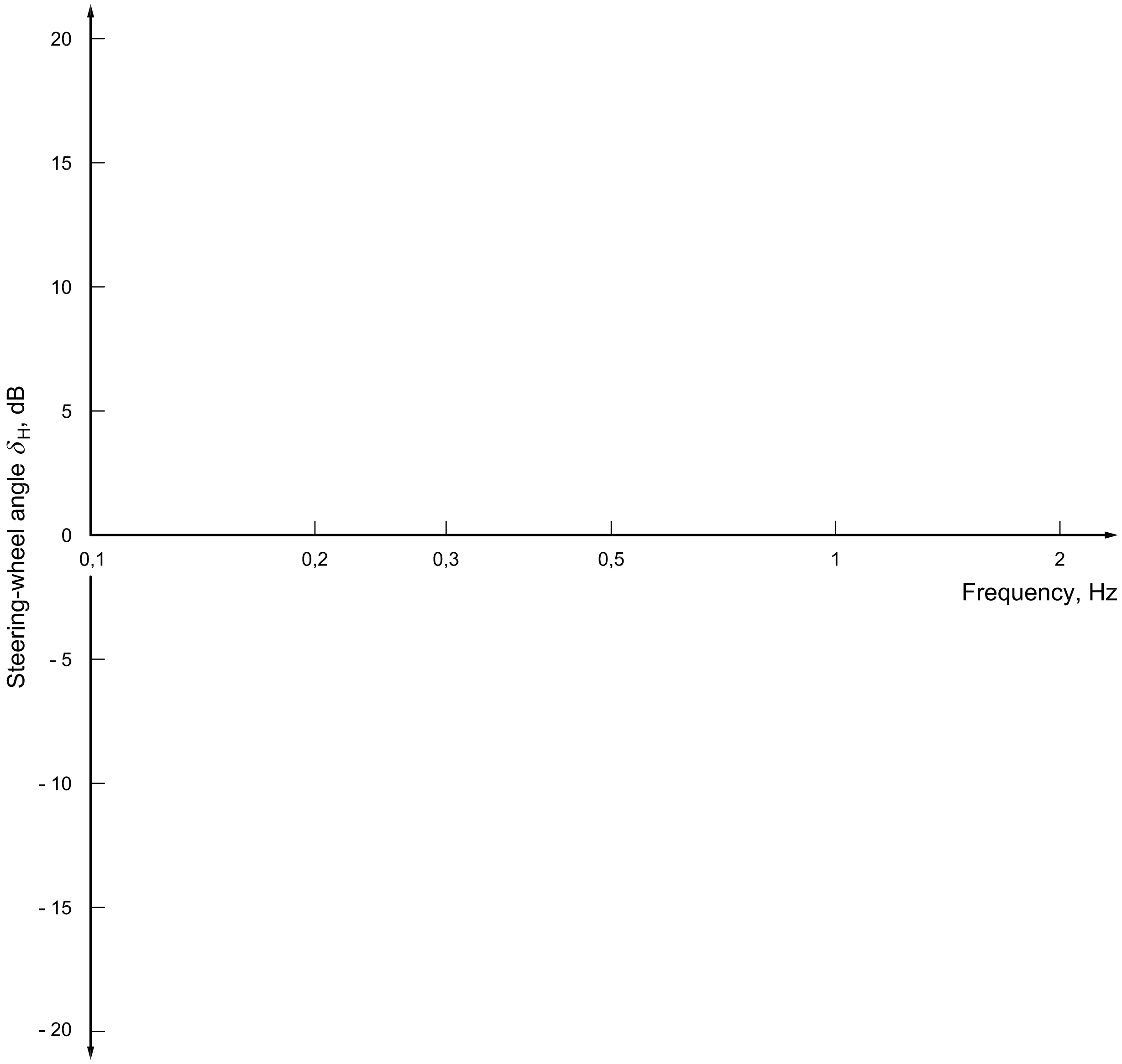


Figure B.3 — Random/pulse input — Harmonic content of steering-wheel angle

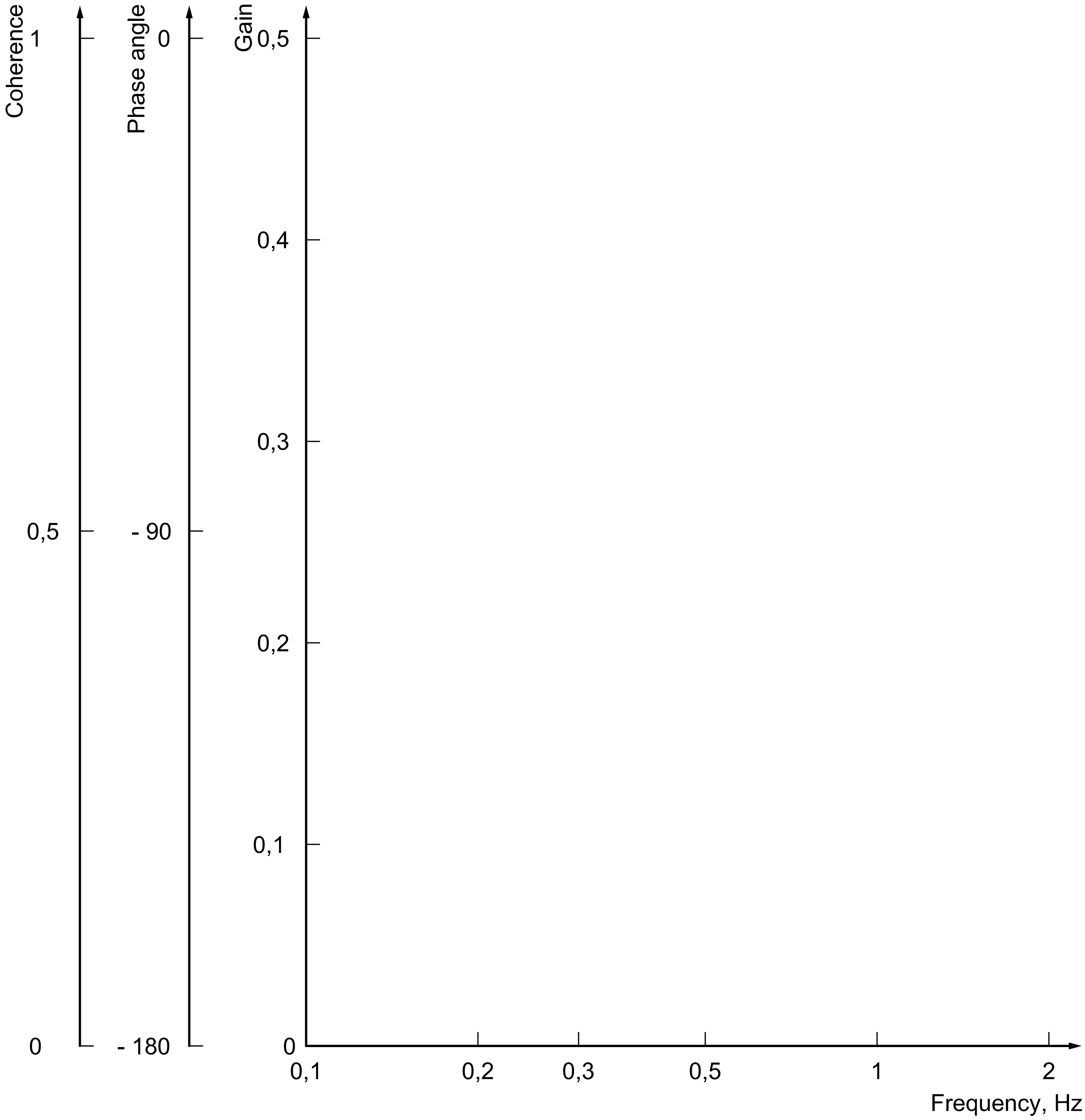
1) Delete as applicable.

B.4 Random/pulse/continuous[2)] sinusoidal input

Test number: ....

v_X = 80 km, 90 km or 100 km/h |......... km/h

a_Y = 2 m/s^2 or 3 m/s^2 |......... m/s^2



Variable $\dot{\psi}$, a_Y: .... Averaging function: ....

Number of data sequences: .... Windowing function: ....

Length of data sequences: .... Digitization rate: ....

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

2) Delete as applicable.

Bibliography

[1] ISO 7401, *Road vehicles — Lateral transient response test methods — Open-loop test methods*

[2] ISO 14791, *Road vehicles — Heavy commercial vehicle combinations and articulated buses — Lateral stability test methods*

[3] EC Council Directive No. 92/53/EEC Annex II, *Definition of vehicle categories and vehicle types*

[4] UNECE Regulation No. 13, *Uniform provisions concerning the approval of vehicles of categories M, N and O with regard to braking*

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