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Road vehicles — Vehicle dynamics test methods —

Part 1: **General conditions for passenger cars**

Véhicules routiers — Méthodes d'essai de la dynamique des véhicules —

Partie 1: Conditions générales pour voitures particulières

ICS: 43.100

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The committee responsible for this document is ISO/TC22/SC33/WG2.

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Introduction

The dynamic behaviour of a road vehicle is a most important part of active vehicle safety. Any given vehicle, together with its driver and the prevailing environment, constitutes a unique closed-loop system. The task of evaluating the dynamic behaviour of the vehicle is therefore very difficult since there is significant interaction between these driver-vehicle-environment elements, and each of these elements is individually complex in itself.

The test conditions exert large influence on the test results. Only test results obtained at identical test conditions are comparable

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Road vehicles — Vehicle dynamics test methods —

Part 1:
General conditions for passenger cars

1 Scope

This part of ISO 15037 specifies the general conditions that apply when vehicle dynamics properties are determined according to ISO test methods.

In particular, it specifies general conditions for

— variables,

— measuring equipment and data processing,

— environment (test track and wind velocity),

— test vehicle preparation (tuning and loading),

— initial driving, and

— test reports (general data and test conditions).

These items are of general significance, independent of the specific vehicle dynamics test method. They apply when vehicle dynamics properties are determined, unless other conditions are required by the standard which is actually used for the test method.

This part of ISO 15037 is applicable to passenger cars as defined in ISO 3833 and light trucks.

NOTE The general conditions defined in existing vehicle dynamics standards are valid until a reference to this part of ISO 15037 is included.

NOTE Please take into account that this standard is referred in many other standards without a dated reference. By revising this standard the numbering of clauses, tables and figures should not changed.

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, *Road vehicles — Masses — Vocabulary and codes*

ISO 2416, *Passenger cars — Mass distribution*

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

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

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3 Variables

3.1 Reference system

The variables of motion used to describe 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 this position shall be reported (see Annex A).

NOTE Useful positions for the reference point include (1) the centre of gravity of the vehicle and (2) a fixed point of geometry such as the point in the longitudinal plane of symmetry at the height of the centre of gravity and at mid-wheelbase. Locating the reference point at the centre of gravity is very useful for analytical evaluation of the test results of individual vehicles, but may cause difficulty in comparing results for different vehicles. Locating the reference point at the geometrical position is more convenient for comparing results from different tests, but may complicate theoretical analysis.

3.2 Variables to be determined

To describe the vehicle dynamics in terms of driver input and vehicle response, the principal relevant variables are the following:

— steering-wheel angle (δ_H)

— steering-wheel torque (M_H)

— longitudinal velocity (v_X)

— sideslip angle (β) or lateral velocity (v_Y)

— longitudinal acceleration (a_X)

— lateral acceleration (a_Y)

— yaw velocity ($\mathrm{d}\psi/\mathrm{d}t$)

— roll velocity ($\mathrm{d}\varphi/\mathrm{d}t$)

— pitch velocity ($\mathrm{d}\theta/\mathrm{d}t$)

— roll angle (φ)

— pitch angle (θ)

These variables are defined in ISO 8855.

All standards that make reference to this part of ISO 15037 shall specify which variables apply. Depending on the specific standard, additional variables can be required or recommended.

NOTE These variables can be determined directly by measuring or by calculation from measured values.

4 Measuring equipment

4.1 Description

Time histories of the measured variables shall be recorded by a time-based multi-channel recording system by means of appropriate transducers (see Annex C). Typical operating ranges and recommended maximum errors of the transducer and recording system are shown in Table 1. The specified accuracies shall be achieved whether the variables are measured or are calculated.

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

Variable	Typical operating range	Recommended maximum “overall” error
Steering-wheel angle	−360° to 360°	± 1° for δ_H < 50° ± 2° for δ_H > 50° and < 180° ± 4° for δ_H > 180°
Steering-wheel torque	−30 Nm to 30 Nm	± 0,1 Nm for M_H < 10 Nm ± 0,3 Nm for M_H > 10 Nm
Longitudinal velocity	0 km/h to 180 km/h	± 1 km/h for v_X < 100 km/h ± 2 km/h for v_X > 100 km/h
Lateral velocity	−10 m/s to 10 m/s	± 0,2 m/s
Sideslip angle	−20° to 20°	± 0,3°
Longitudinal acceleration	−15 m/s2 to 15 m/s2	± 0,15 m/s^2
Lateral acceleration	−15 m/s2 to 15 m/s2	± 0,15 m/s^2
Yaw velocity	−50 °/s to 50 °/s	± 0,3 °/s for dψ/dt < 20 °/s ± 1 °/s for dψ/dt > 20 °/s
Pitch velocity	−50 °/s to 50 °/s	± 0,3 °/s for dθ/dt < 20 °/s ± 1 °/s for dθ/dt > 20 °/s
Roll velocity	−50 °/s to 50 °/s	± 0,3 °/s for dφ/dt < 20 °/s ± 1 °/s for dφ/dt > 20 °/s
Roll angle	−15° to 15°	± 0,15°
Pitch angle	−15° to 15°	± 0,15°
Increased measurement accuracy may be desirable for computation of some of the characteristic values. If any system error exceeds the recommended maximum value, this and the actual maximum error shall be stated in the test report (see Annex A).		

4.2 Transducer installations

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

If a transducer does not measure a variable in the defined position, appropriate transformation shall be carried out.

4.3 Data processing

4.3.1 General

The frequency range relevant for tests on horizontal dynamics of passenger cars is between 0 Hz and the maximum utilized frequency f_{max} = 5 Hz. Based on whether analogue or digital data processing methods are used, the requirements given in 4.3.2 or in 4.3.3 apply.

4.3.2 Analogue 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 shall be employed. The width of the passband (from 0 Hz to frequency f_0 at −3 dB) shall not be less than 9 Hz. Amplitude errors shall be less than ± 0,5 % in the relevant frequency range of 0 Hz to 5 Hz. All analogue signals shall be processed

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with filters having sufficiently similar phase characteristics to ensure that time delay differences due to filtering lie within the required accuracy for time measurement.

NOTE During analogue filtering of signals with different frequency contents, phase shifts can occur. Therefore, a digital data processing method, as described in 4.3.3, is preferable.

4.3.3 Digital data processing

4.3.3.1 General considerations

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

Attenuation and phase shift information for a Butterworth filter is provided in Annex D.

4.3.3.2 Aliasing errors and anti-aliasing filters

In order to avoid uncorrectable aliasing errors, the analogue 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:

a) within the relevant frequency range of 0 Hz to f_{max} = 5 Hz, the maximum attenuation of the analogue signal is less than the resolution of the digitized signal; and

b) 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 digital resolution.

For 0,05 % resolution, 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.

It is recommended that anti-aliasing filters be of order four or higher (see Annex D).

Although filtering for anti-aliasing is required, excessive analogue filtering shall be avoided. Moreover, all filters shall have sufficiently similar phase characteristics to ensure that differences in time delays between signals are compatible with the required accuracy for the time measurement.

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

4.3.3.3 Data sampling and digitizing

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

The digitizing system shall have a resolution of 12 bits (± 0,05 %) or more and an accuracy of 2 LSB (± 0,1 %). Amplification of the analogue signal before digitizing shall be such that, in the digitizing process, the combined error due to the finite resolution and inaccuracy of digitizing is less than 0,2 %.

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4.3.3.4 Digital filtering

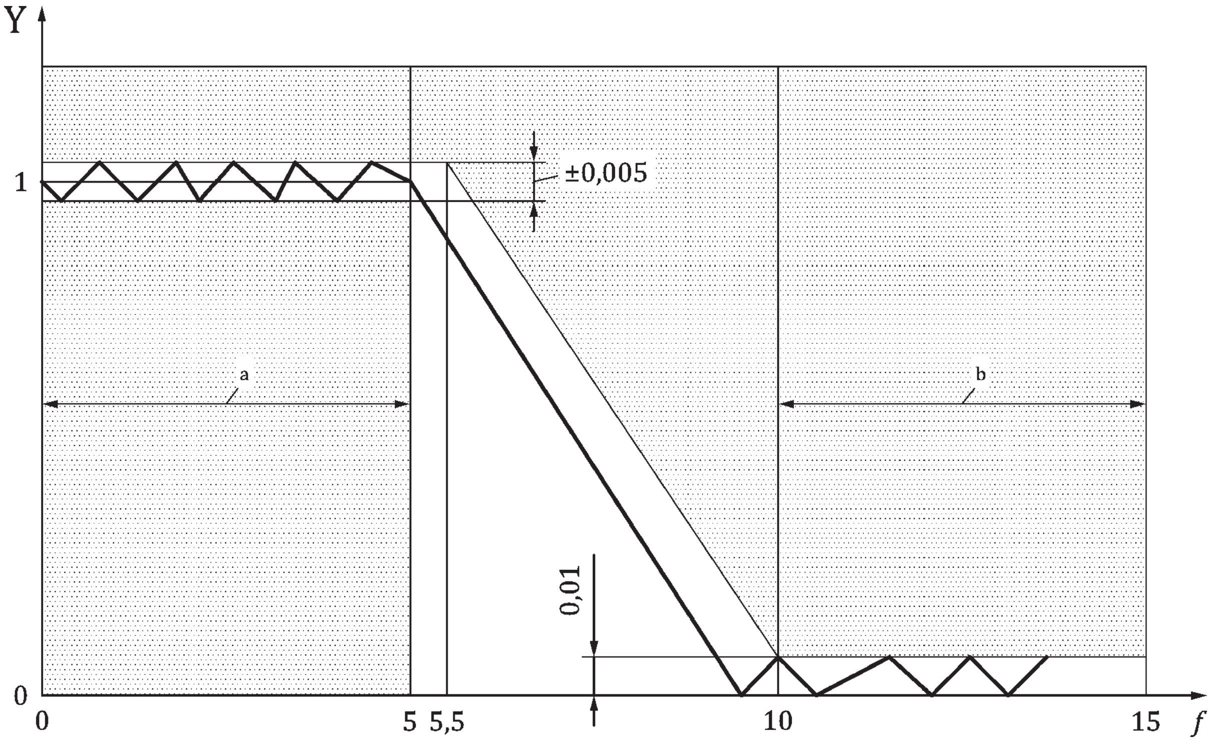
For filtering of sampled data in data evaluation, phaseless (zero phase shift) digital filters shall be used incorporating the following characteristics (see Figure 1):

— passband shall range from 0 Hz to 5 Hz;

— stopband shall begin between 10 Hz and 15 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%).



Key

f frequency (Hz)

Y filter gain

a Passband.

b Stopband.

Figure 1 — Required characteristics of phaseless digital filters

5 Test conditions

5.1 General

Limits and specifications for the ambient conditions and vehicle test conditions are established below. These shall be maintained during the specific test. Any deviations shall be shown in the test report (see Annexes A and B), including the individual diagrams of the presentation of results. For each test method, the test-specific conditions and those which may not be kept constant (e.g. tread depths) shall be recorded in a separate test report in accordance with Annex B.

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5.2 Test track

All tests shall be carried out on a smooth, clean, dry and uniform paved road surface. The gradient of the paved test surface to be used shall not exceed 2 % (recommended 1,5 %) 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 B).

5.3 Wind velocity

The ambient wind velocity shall not exceed 5 m/s during a test. For each test method, the climatic conditions shall be recorded in the test report (see Annex B).

5.4 Test vehicle

5.4.1 General data

General data of the test vehicle shall be presented in the test report shown in Annex A. For any change of vehicle specification (e.g. load), the general data shall be documented again.

If a new vehicle is used, it is recommended to make an adequate run-in before starting the tests.

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

5.4.2 Tyres

For a general tyre condition, new tyres shall be fitted on the test vehicle according to the vehicle manufacturer's specifications. If not specified otherwise by the tyre manufacturer, they shall be run in for at least 150 km on the test vehicle or an equivalent vehicle without excessively harsh use, for example braking, acceleration, cornering, hitting the kerb, etc. After run in, the tyres shall be maintained at the same vehicle positions for the tests.

Tyres shall have a tread depth of at least 90 % of the original value across the whole breadth of the tread and around the whole circumference of the tyre.

Tyres shall not be manufactured more than one year before the test. The date of manufacturing shall be noted in the presentation of test conditions (see Annex B).

Tyres shall be inflated to the pressure as 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 pressure above 250 kPa.

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

Tests may also be performed under conditions other than general tyre conditions. The details shall be noted in the test report (see Annex B).

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

As the tread depth or uneven tread wear may have a significant influence on test results, it is recommended that they be taken into account when making comparisons between vehicles or between tyres.

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

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5.4.3 Operating components

For the standard test condition, the type (e.g. part number or model number) and condition (e.g. shock-absorber settings and suspension-geometry adjustments) of all components likely to influence the test results shall be as specified by the manufacturer. Any deviations from manufacturer's specifications shall be noted in the presentation of general data (see Annex A).

5.4.4 Loading conditions of the vehicle

The test mass shall be between the complete vehicle kerb mass (ISO 1176, code ISO-M06) plus driver and test equipment (combined mass should not exceed 150 kg) and the maximum authorized total mass (ISO 1176, code ISO-M08).

The maximum authorized axle loads (ISO 1176, code ISO-M13) shall not be exceeded.

Care shall be taken to generate a minimum deviation in the location of the centre of gravity and in the moments of inertia as compared to the loading conditions of the vehicle in normal use (refer to ISO 2416). The resulting wheel loads shall be determined and recorded in the test report (see Annex A).

5.4.5 Drivetrain conditions of the vehicle

For vehicles with regenerative braking capabilities the specific vehicle configuration may alter the dynamic vehicle behavior while releasing the accelerator pedal and/or while pressing the brake pedal. For vehicles with regenerative braking capabilities the different dynamic vehicle behaviour with or without active regenerative braking must be considered while performing the tests. The selected level of regenerative braking capability and the transmission lever position shall be documented in the test report.

5.4.6 Active systems

For vehicles with active systems influencing the test results, such as active steering, electronic stability control, or active suspensions, the different dynamic vehicle behaviour with possible different settings of the systems must be considered while performing the tests. If the driver can choose between different settings of the system, e.g. by a "sport/comfort" switch, the settings chosen for the test shall be documented in the test report.

6 Test method

6.1 Warm-up

All relevant vehicle components shall be warmed up prior to the tests in order to achieve component temperatures 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.

A procedure equivalent to driving at the test speed for a distance of 10 km or driving 500 m at a lateral acceleration of 3 m/s^2 (both left and right turns) may be appropriate for warming up the tyres.

6.2 Initial driving condition

6.2.1 General

The initial driving condition is specified in most of the vehicle dynamics test methods. It can either be a steady-state straight-ahead run or a steady-state circular run.

If there is no specific requirement defined in a test method standard, the tests shall be performed in the highest suitable gear for vehicles with manual transmission and for vehicles with automatic transmission in drive D. The position of the transmission lever and the selected driving programme shall be recorded in the test report (see Annex B).

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The position of the steering wheel and the accelerator pedal shall be kept as constant as possible during the initial driving condition. The moment of observation t_{SS} to evaluate steady-state conditions is defined as the point in time which usually is between 0,5 s and 0,8 s before the reference point in time t_0 of the specific test method (see note below). The initial condition is considered to be sufficiently constant if for the moment of observation t_{SS} the requirements of 6.2.2 and 6.2.3 are fulfilled (see Figure 2, which also introduces the definition of t_1 and t_2).

NOTE For test methods which are used to determine only steady-state values (e.g. ISO 4138) the moment of observation t_{SS} and the reference time t_0 will be identical.

6.2.2 Steady-state straight-ahead run

The longitudinal velocity in the initial driving condition shall not deviate by more than ± 1 km/h (± 2 km/h for velocities above 100 km/h) from the nominal value during the time interval from t_1 to t_2 and the mean value of lateral acceleration shall be within a range from −0,3 m/s^2 to +0,3 m/s^2. As an alternative to the limits of lateral acceleration, the mean value of the yaw velocity shall be within a range from −0,5 °/s to +0,5 °/s.

For the time interval from t_1 to t_2, the standard deviation of the lateral acceleration shall not exceed 0,3 m/s^2. As an alternative to the limits on lateral acceleration, the standard deviation of the yaw velocity shall not exceed 0,5 °/s.

The difference between the mean values of the longitudinal velocity during the time intervals t_1 to t_{SS} and t_{SS} to t_2 shall not exceed ± 1 km/h (± 2 km/h for velocities above 100 km/h).

6.2.3 Steady-state circular run

The initial radius R_0 shall be calculated as follows:

— $R_0 = v_{X,0}/(\mathrm{d}\psi_0/\mathrm{d}t)$

— $R_0 = {v_{X,0}}^2/a_{Y,0}$

The radius in the initial driving condition shall not deviate by more than 2 % or ± 2 m from the nominal value during the time interval from t_1 to t_2.

For the time interval from t_1 to t_2, the standard deviation of the lateral acceleration shall not exceed 5 % of its mean value and the standard deviation of the longitudinal velocity shall not exceed 3 % of its mean value.

The difference between the mean values of lateral acceleration during the time intervals t_1 to t_{SS} and t_{SS} to t_2 shall not exceed the nominal value of lateral acceleration by more than 5 %. The difference between the mean values of longitudinal velocity during the time intervals t_1 to t_{SS} and t_{SS} to t_2 shall not exceed the nominal value of longitudinal velocity by more than 3 %.

For the time interval from t_1 to t_2, the mean value of the lateral acceleration shall not deviate from the nominal value by more than ± 3 %.

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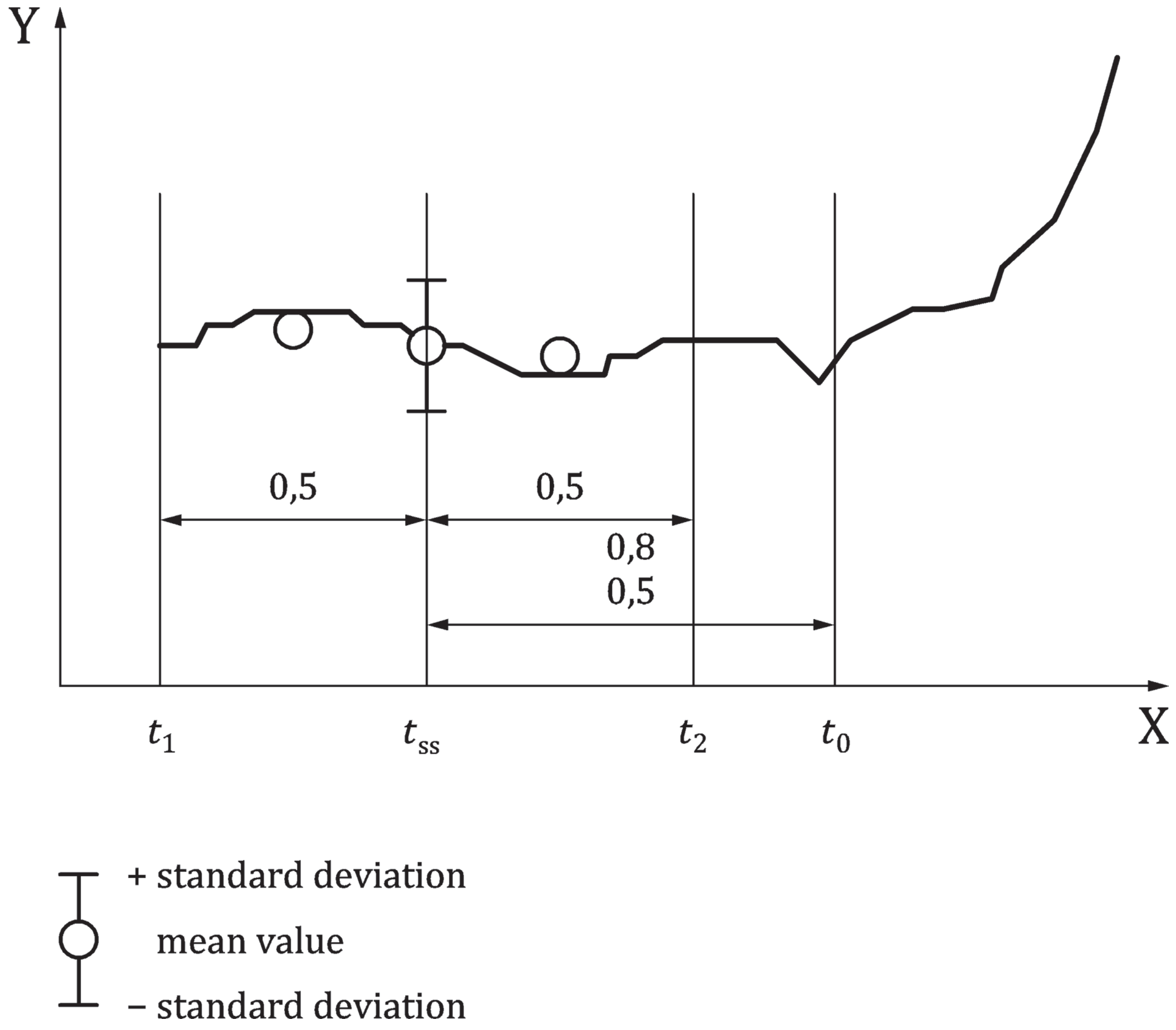

Key

X time, s

Y measured variable

t_0 reference point in time of the specific test method

t_1 time measurement 1

t_2 time measurement 2

t_{ss} moment of observation to evaluate steady state conditions

Figure 2 — Definition of times

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Annex A
(normative)

Test report — General data

Vehicle identification	Vehicle identification number:	....	
	Type of vehicle:	....	
	Manufacturer:	....	
	Model:	....	
	Model year/first registration date:	....	
Drive train	Type:	☐ combustion	☐ electric ☐ hybrid
	Driven axle:	☐ front axle	☐ rear axle
	Type of 4WD:	....	
	Special features:	....	
Electric engine	Identification code:	....	
	Maximum power:	.... kW	
	Maximum torque:	.... Nm	
Combustion engine	Identification code:	....	
	Type of engine:	☐ spark ignition	☐ diesel
	Air/fuel mixture control:	☐ carburettor	☐ injection
	Charging system:	☐ turbo charger	☐ super-charger
	Ignition point control:	☐ mechanical	☐ electronic
	Fuel cut-off:	☐ yes	☐ no
	Displacement/number of cylinders:	.... cm^3	.... cylinders
	Maximum power/engine speed:	.... kW	.... 1/min
	Maximum torque/engine speed:	.... Nm	.... 1/min

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Transmission	Identification code:		
	Type/number of forward gears:	☐ manual	.... gears
		☐ automatic	.... gears
		☐ continuously variable (e.g. CVT)	
	Gear ratios:	1st gear: .... : 1	2nd gear: .... : 1
		3rd gear: .... : 1	4th gear: .... : 1
		5th gear: .... : 1	6th gear: .... : 1
	Final drive ratio:	.... : 1	
Rear axle	Type of rear axle:	....	
	Suspension/damping:	....	
	Stabilizer/Anti-roll bar:	☐ yes	☐ no
	Active systems:	....	
Front axle	Type of front axle:	....	
	Suspension/damping:	....	
	Stabilizer/Anti-roll bar:	☐ yes	☐ no
	Active systems:	....	
Steering	Steered axle:	☐ front axle	☐ rear axle
	Active front axle steering:	☐ yes	☐ no
	Active rear axle steering:	☐ yes	☐ no
	Power assisted:	☐ yes	☐ no
	Type of steering assist:	☐ electric	☐ hydraulic
		☐ electro-hydraulic	
	Overall steering ratio on front axle:	....	
	Steering wheel diameter:	.... mm	
Braking system	Power assisted:	☐ yes	☐ no

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	Electronic stability control system:	☐ yes ☐ no
	Type:	....
	Wheel brakes on front axle:	☐ drums ☐ discs
	Wheel brakes on rear axle:	☐ drums ☐ discs
Wheels	Rim size:	front: .... rear: ....
Tyres	Size:	front: .... rear: ....
	Tread depth (new):	front: .... mm rear: .... mm
	Inflation pressure, according to the vehicle manufacturer's specifications:	
	— at complete vehicle kerb mass (ISO-M06):	front: .... kPa rear: ....kPa
	— at maximum authorized total mass (ISO-M08):	front: .... kPa rear .... kPa
Masses	Complete vehicle kerb mass (ISO-M06):	.... kg
	Maximum authorized total mass (ISO-M08):	.... kg
	Maximum authorized axle load (ISO-M13):	front: .... kg rear: .... kg
	Type of loads used for mass reproduction:	
	Measured wheel loads of test vehicle, including driver and instrumentation:	FL: .... kg FR: .... kg
		RL: .... kg RR: .... kg
Vehicle dimensions	Overall length:	.... mm
	Overall width:	.... mm
	Overall height at test mass:	.... mm
	Wheelbase:	.... mm

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	Track:	front: .... rear: .... mm mm
	Height of centre of gravity at complete vehicle kerb mass (ISO-M06):	.... mm

Reference point coordinates for measured variables	X_V (from half wheel base): .... mm	Y_V (from half track): .... mm	Z_V (from ground): .... mm

General comments and/or other relevant details

....

....

....

Sensor positions (referred to the reference point)

Variable	*X* (mm)	*Y* (mm)	*Z* (mm)
Longitudinal velocity			
Lateral velocity			
Sideslip angle			
Longitudinal acceleration			
Lateral acceleration			
Yaw velocity			
Pitch velocity			
Roll velocity			
Roll angle			
Pitch angle			

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Annex B
(normative)

Test report — Test conditions

Test method	ISO	....	
Proving ground	Location:	....	
	Path radius:	....	
Ambient conditions	Road surface:	Type:	
		Condition:	
		Track temperature: .... °C	
		Tyre-road peak friction coefficient:	
		....	
		Friction measuring method:	
		....	
	Climate:	Air temperature: .... °C	
		Relative humidity: .... %	
		Wind speed: .... m/s	
		Wind direction:	
Tyres	Date of manufacture:	front:	rear:
	Tread depth:		
	— before warm-up:	FL: .... mm	FR: .... mm
		RL: .... mm	RR: .... mm
	Tyre pressure:		
	— before warm-up:	FL: .... kPa	FR: .... kPa

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		RL: .... kPa RR: .... kPa
Driving conditions	Manual transmission:	Engaged gear: .... gear
	Automatic transmission:	Transmission program:
		Gear selector position:
	Electric/Hybrid mode:	....
	State of charge at start of test:	...................%
	Active safety systems:	....
Staff	Driver:	....
	Observer:	....
	Data analyst:	....
Test method specific data	....	

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Annex C
(informative)

Transducers and their installations

C.1 General

Transducers of various types, some commercially available and some specially fabricated, are used in measuring the required and optional variables. If a transducer does not directly measure the required variable, appropriate adjustments shall be made to its signal to obtain the required variable with a sufficient level of accuracy.

Because of the variety of instrumentation possibilities, the type of each instrument used shall be recorded; and where applicable, its location on the vehicle shall be entered on the test data sheets (see Annex A).

Typical errors for various direct measurement transducers are given in following clauses. Net percentage error for a variable computed from the output signals of several transducers is found by taking the differential of the computed variable and dividing it by the computed variable.

As sensor performance is rapidly changing, the information contained in the following clauses should be considered as general requirements referred to in the last revision of this part of ISO 15037.

C.2 Steering-wheel angle

Steering-wheel angle is measured relative to the sprung mass. Typical transducers are multi-turn potentiometers or digital shaft encoders, geared to the back of the steering wheel or attached to a “second steering wheel”.

C.3 Longitudinal velocity

A longitudinal velocity transducer should be installed as close as possible to the reference point position on the vehicle. The location of the velocity transducer shall be recorded and its signal corrected as necessary during data processing to provide longitudinal velocity at the reference point. Typical transducers are fifth wheels with accuracies to 0,2 km/h, and “contactless” velocity transducers based upon optical or Doppler principles, with optical accuracies to 0,1 km/h and Doppler accuracies to 0,5 km/h. The steady-state fifth-wheel signal is very close to horizontal velocity, while optical transducers measure longitudinal velocity (the component of horizontal velocity in the X direction, equal to horizontal velocity multiplied by the cosine of the sideslip angle). An additional way to measure the longitudinal velocity is by Global Positioning System (GPS) sensor (see C.11).

C.4 Lateral velocity and sideslip angle

Lateral velocity at a given point can be measured directly by means of a bipolar velocity transducer based upon optical principles, installed according to the manufacturer’s specifications. The location of the transducer must be recorded. Lateral velocity at any other point can be obtained by interpolation between two lateral velocity transducers or by extrapolation from the lateral velocity at the point of measurement, by adding the product of yaw velocity times the distance to the desired point. Sideslip angle is computed as the angle whose tangent is lateral velocity divided by longitudinal velocity. Commercially available bipolar velocity transducers have full-scale range of ± 10 m/s and ± 1 % full-scale steady-state accuracy.

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Sideslip angle can be measured directly by a castered trolley, attached to the vehicle through gimbals and loading springs to keep the caster axis vertical. The sideslip angle measured is that which exists at the caster axis. The sideslip angle at any other point on the longitudinal axis of the vehicle can be computed from the sideslip angle at the point of measurement and the yaw velocity. The vehicle sideslip angle is defined as that obtained for the location of the origin of the vehicle axis system. At steady state, accuracies of 0,25 degrees are possible using sideslip trolleys.

Lateral velocity can also be computed by integration of lateral acceleration (corrected for position, roll angle, and surface inclination errors) minus the product of longitudinal velocity and yaw velocity. Sideslip angle is then computed. This method is suitable only for short tests because the net acceleration error, including zero offsets, is integrated.

C.5 Angular velocity

Yaw, roll and pitch velocity are measured directly by angular-rate transducers, installed as specified by the manufacturer. The traditional angular-rate sensors are rate gyroscopes. Typically, good performance for rate gyroscopes includes: linearity of ± 0,2 to ± 0,5 % full scale to 1/2 full scale and ± 1 to ± 2 % to full scale; cross-axis sensitivity of 0,04 %; thresholds of 0,05% full scale; and hysteresis 0,15 % full scale. “Solid-state” sensors based on the Coriolis acceleration of vibrating elements, fiber optics, lasers or other principles are also commercially available. These typically have performance properties such as: linearity of ± 0,1 to 1 % full scale; sensitivity threshold of 0,01 %; and zero hysteresis.

Angular-rate transducers are typically fixed in the vehicle: therefore, in steady-state turning they measure earth-plane yaw velocity multiplied by the cosine of the vehicle roll angle. The signal must be corrected for vehicle roll and pitch angles in order to obtain yaw velocity in the earth plane.

When sideslip transducers are installed at both front and rear, yaw velocity in the earth plane can be computed from the difference between front and rear lateral velocities, divided by the longitudinal distance between the transducers.

C.6 Lateral acceleration

In most manoeuvres, particularly in steady state, the quantity of interest is centripetal acceleration. In practice, lateral acceleration is the quantity that is typically measured. Centripetal acceleration can be determined from lateral acceleration if other vehicle motion variables are also known.

Lateral acceleration (a_Y) can be measured by an accelerometer having sufficient accuracy over a sufficient bandwidth, which includes steady state, and installed in one of the following ways.

a) Mounted on the sprung mass and aligned with its sensitive axis aligned with the vehicle Y_V axis. If it is not located at the origin of the vehicle axis system, its output will have an error due to yaw, roll and pitch accelerations. Although this error should not exist under steady-state conditions, the accelerometer location should be recorded. The position-corrected signal will measure “side acceleration”, which in turn must be corrected for the component of gravitational acceleration due both to the sine of the vehicle roll angle plus that of track surface inclination.

b) Mounted on a platform stabilized by a gyroscope system: Position correction considerations are as in a), above. Consideration must be given to gyro erection and drift errors, as described below.

An accelerometer mounted to the vehicle sprung mass, as in a) and b) above, will measure the lateral acceleration of the sprung mass. In steady state, this will be equivalent to the lateral acceleration of the total vehicle.

High quality “servo” accelerometers have linearities of ± 0,05 to ± 0,1 % full scale, with 0,02 % hysteresis and 0,001 % resolution. Accelerometers based upon measurement of beam or spring deflection typically have linearities of ± 1 % of full scale. Measurement errors can be dominated by installation conditions: for example, a 0,6 degree error in roll angle compensation will cause a 0,01 g acceleration measurement error.

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Steady-state centripetal acceleration may be obtained as the product of horizontal velocity and yaw velocity. Steady-state centripetal acceleration differs from lateral acceleration by the cosine of the vehicle sideslip angle. This correction factor may be applied in data processing, or for sufficiently small sideslip angles (e.g. cosine 8 degrees is 0,99), the difference may be ignored.

When travelling in steady state on a known radius, centripetal acceleration may be obtained from horizontal velocity squared divided by the circle radius or from yaw velocity squared multiplied by the radius. For these methods of determining acceleration, “radius” should ideally be the radius of the circular path of the reference point, including corrections for body roll, etc. Practically, such errors may have to be tolerated.

NOTE The side acceleration is the component of the vector acceleration of a point in the *Y*-direction.

C.7 Body angles

Vehicle roll and pitch angles with respect to the gravity vertical can be measured by a two-axis gyroscope, either a case-referenced free gyro or a gravity-referenced vertical gyro. The free-gyro element is caged, or locked to its case when not measuring. When uncaged, it remains fixed in inertial space, enabling measurement of angular vehicle motion. A free gyro may be used to measure roll and yaw, or roll and pitch motion. A vertical gyro is “erected” to a gravity vertical by pendulous switches, which when activated control slow-acting torquer motors. Neither type can maintain the required measurement accuracy for long periods of steady turning. Free gyros and vertical gyros with deactivated erection systems tend to “drift” at a rate usually specified by the manufacturer at 0,5 to 1 degree per minute maximum; and vertical gyros with activated erection systems seek an “apparent vertical”, which is the sum of the gravity and lateral acceleration vectors, at a rate of 2 to 5 degrees per minute. In the absence of lateral acceleration, the accuracy of vertical-gyro erection is typically specified at ± 0,15 to ± 1 degree.

Vehicle roll and pitch angles with respect to the road surface can be measured by:

c) an angular measurement transducer installed in the roll and pitch gimbals of a sideslip trolley;

d) measurement of changes in the vertical distance to the ground from reference points on either side and/or the front and rear of the vehicle, by ultrasonic or optical transducers. The accuracy of the ultrasonic or optical transducers of ± 0,5 mm is sufficient, taking into account that the pavement reference surface is far from being flat and its roughness is quite noticeable. Fitment of three transducers to the vehicle will define a plane that can be used to compute both pitch and roll angles relative to the road surface. It is recommended to fit the ultrasonic or optical transducers as far apart as possible in order to improve measurement accuracy;

e) measurement of wheel jounce and rebound motion with respect to the sprung mass, taking into account suspension linkage factors. (This method will not account for tyre deflections.)

In each of these methods, it is practical to attain the specified accuracy, with no restriction on test run duration. To obtain vehicle roll and pitch angles relative to the earth plane, the signal must be corrected for the angle of the road surface relative to horizontal.

The change in vehicle roll and pitch angles from an initial test condition can be measured by integration of the signals from an angular-rate gyros. This method is suitable only for short tests since the entire signals, including any zero offsets, will be integrated.

NOTE 1 In vehicles with suspended cab or separated cab to the chassis there could be two body angles. One of the cab relative to the road surface and the other of the chassis relative to the road surface.

NOTE 2 The measurements of changes in the vertical distance to the road surface from reference points on either side of the vehicle by ultrasonic or optical transducers to measure roll angle may give different results than other methods, depending on vehicle chassis roll stiffness. This effect could be noticeable in vehicles with separated chassis or very long vehicles.

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Use of roll angle data obtained with respect to the test surface or to gravity should be corrected for road surface inclination, according to the end usage.

C.8 Steering-wheel torque

Steering-wheel torque is measured by a torque load cell, installed as specified by the manufacturer to measure the torque applied to the steering wheel about its axis of rotation. In some tests, the results are not valid if the steering-wheel inertia is not the original one.

C.9 Steer angles

Steer angles of the wheels with respect to the sprung mass can be obtained by angle measurement transducers, attached between the sprung mass and spindle assemblies; mounted in bearings to the wheel hubs and attached to the sprung mass through restraints which permit unrestricted fore/aft, vertical, and camber motions; or by linear or angular displacement transducers mounted in the steering linkage.

The resultant front-wheel steer angle resulting from force and moment compliance plus suspension kinematics is computed by subtracting steering-wheel angle divided by overall steering ratio from total front road-wheel steer angle.

Resultant rear-wheel steer angle resulting from force and moment compliance plus suspension kinematics is the same as rear road-wheel steer angle, except for vehicles having four-wheel steering.

C.10 Slip angles

Tyre slip angles can be measured directly by available optical transducers. Alternatively, they can be computed as the difference between sideslip angle referred to the front and rear wheel locations and the respective total road-wheel angles.

C.11 Vehicle trajectory

The vehicle trajectory can be measured by a Global Positioning System (GPS). The GPS provides a simple non-contact measurement of speed and both X and Y position in the earth-fixed coordinate system. Sampling update rate is usually 20 Hz. Resolution of X and Y coordinate changes into course angle can be performed in post-processing or within some commercially available units. Some commercial units provide both analogue and digital outputs. Typical speed accuracy is 0,1 km/h, with resolution to 0,01 km/h. Typical distance resolution is 1 cm. Typical course angle accuracy is 0,1 degree, with resolution of 0,01 degree. Trajectory can be determined by integration of X and Y velocity components or directly from X and Y displacements. Sideslip angle can be computed from the X and Y velocities, or from the difference between course angle and the integrated signal from a vehicle-fixed yaw rate gyro. The defined accuracy of GPS is valid only for steady-state conditions.

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Annex D
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Analogue filtering: Butterworth filter

For a Butterworth filter, the attenuation is given by

$$A^2 = \frac{1}{1+(f_{\mathrm{max}} / f_0)^{2n}} \text{ and } A^2 = \frac{1}{1+(f_{\mathrm{N}} / f_0)^{2n}}$$

where

n is the order to 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.

For a fourth order filter

— for A = 0,999 5: f_0 = 2,37 ´ f_{max} = 11,86 Hz;

— for A = 0,000 5: f_{s} = 2 ´ (6,69 ´ f_0) = 158 Hz, where f_{s} is the sampling frequency = 2 ´ f_{N}.

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

— Φ = 81 ´ (f/f_0) degrees for second order;

— Φ = 150 ´ (f/f_0) degrees for fourth order;

— Φ = 294 ´ (f/f_0) degrees for eighth order.

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

For fourth-order filters, the passband frequency f_0 (from 0 Hz to frequency f_0) should be greater than 2,37 × f_{max} if phase errors are subsequently adjusted in digital data processing, and greater than 5 × f_{max} otherwise. For fourth-order filters, the data sampling frequency f_{s} should be greater than 13,4 × f_0. For filters having orders different from fourth, f_0 and f_{s} should be selected for adequate flatness and alias error prevention.

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