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

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

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

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

Introduction

The dynamic behaviour of road vehicles is a most important part of active vehicle safety. Any given vehicle, together with its driver and the prevailing environment, forms a unique closed-loop system. The task of evaluating the dynamic behaviour is therefore very difficult since there is a significant interaction between these driver–vehicle–environment elements, each of which is complex in itself. A complete and accurate description of the behaviour of the road vehicle must necessarily involve information obtained from a number of tests of different types. Since they quantify only a small part of the whole handling field, the results of these tests can only be considered significant for a correspondingly small part of the overall dynamic behaviour.

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

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

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

1 Scope

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

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

2 Normative references

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

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

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

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

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

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

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

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

3 Principle

IMPORTANT — The method of data analysis in the frequency domain is based on the assumption that the vehicle has a linear response. Over the whole range of lateral acceleration this is unlikely to be the case, the standard method of dealing with such a situation being to restrict the range of the input so that linear behaviour can be assumed and, if necessary, to perform more than one test at different ranges of inputs that together cover the total range of interest.

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

Important characteristics in the time domain are

— time lags between steering-wheel angle, lateral acceleration and yaw velocity,

— response times of lateral acceleration and yaw velocity (see 8.2.1),

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

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

— overshoot values (see 8.2.3).

These characteristics show correlation with subjective evaluation during road driving.

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

— lateral acceleration related to steering-wheel angle, and

— yaw velocity related to steering-wheel angle.

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

a) Time domain:

1) step input;

2) sinusoidal input (one period).

b) Frequency domain:

1) random input;

2) pulse input;

3) continuous sinusoidal input.

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

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

— linear versus non-linear vehicle behaviour;

— periodic versus non-periodic steady state condition;

— steady state versus dynamic vehicle behaviour.

4 Reference system

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

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

5 Variables

The following variables shall be determined:

— steering-wheel angle, δ_H;

— lateral acceleration, a_Y;

— yaw velocity, $\dot{\psi}$;

— longitudinal velocity, v_X.

The following variables may be determined:

— roll angle, ϕ;

— sideslip angle, β;

— lateral velocity, v_Y;

— steering-wheel torque, M_H.

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

6 Measuring equipment

6.1 Description

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

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

6.2 Transducer installation

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

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

6.3 Data processing

6.3.1 General

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

6.3.2 Analog data processing

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

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

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

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

Variable	Range	Recommended maximum error of combined transducer and recorder system
Steering-wheel angle	– 180° to + 180 [a]	± 1°
Lateral acceleration	– 15 m/s^2 to + 15 m/s^2	± 0,15 m/s^2
Yaw velocity	– 50 °/s to + 50 °/s	± 0,5°/s
Sideslip angle	– 15° to + 15°	± 0,3°
Longitudinal velocity	0 m/s to 50 m/s	± 0,5 m/s
Lateral velocity	– 10 m/s to + 10 m/s	± 0,1 m/s
Roll angle	– 15° to + 15°	± 0,15°
Steering-wheel torque	– 30 N·m to + 30 N·m	± 0,3 ·m
Transducers for some of the listed variables are not widely available and are not in general use. Many such instruments are developed by users. If any system error exceeds the recommended maximum value, this and the actual maximum error shall be stated under general data in the test report (see Annex A).		
[a] Assuming a conventional steering system.		

6.3.3 Digital data processing

6.3.3.1 General considerations

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

6.3.3.2 Aliasing errors

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

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

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

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

NOTE For a Butterworth filter the attenuation is given by

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

and

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

where

n is the order of the filter;

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

f_0 is the filter cut-off frequency;

f_N is the Nyquist or "folding" frequency;

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

For example, for a fourth-order filter:

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

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

6.3.3.3 Phase shifts and time delays for anti-aliasing filtering

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

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

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

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

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

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

6.3.3.4 Data sampling and digitizing

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

6.3.3.5 Data acquisition system requirements

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

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

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

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

6.3.3.6 Digital filtering

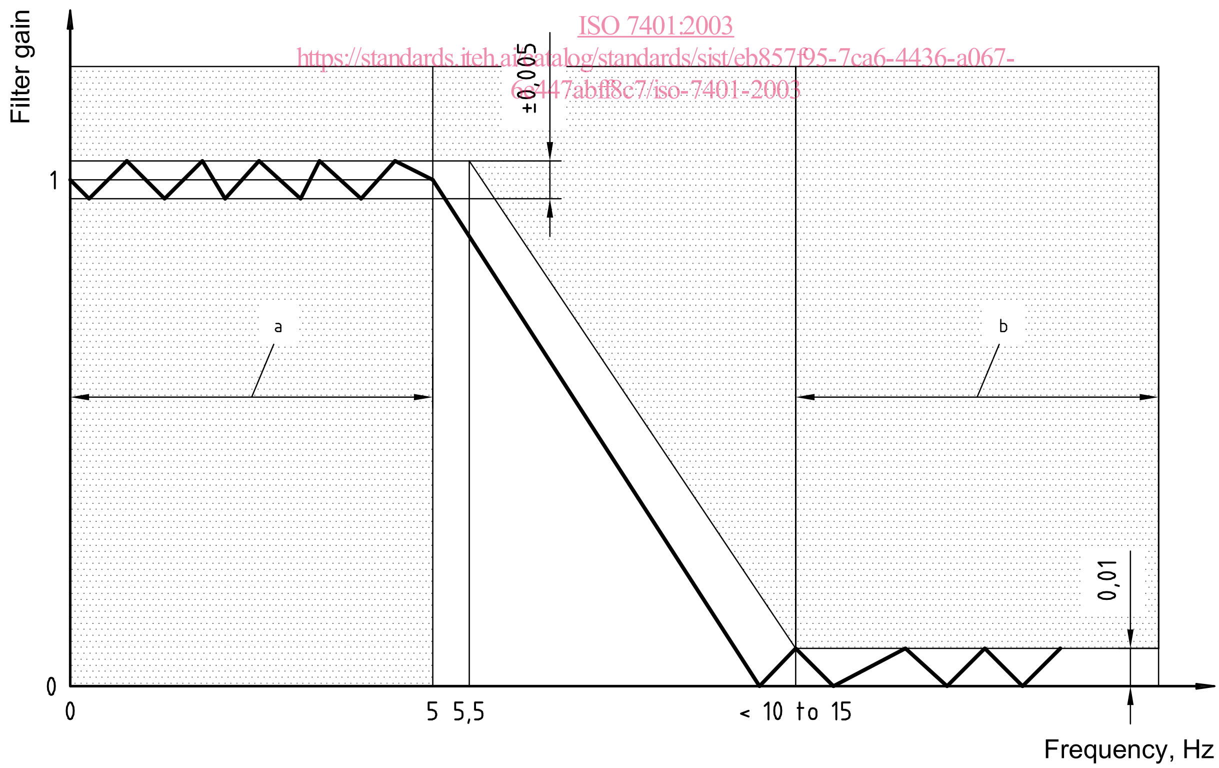
For filtering of sampled data in data evaluation, phaseless (zero-phase-shift) digital filters shall be used, in accordance with the following (see Figure 1):

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

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

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

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



a Passband

b Stopband

Figure 1 — Required characteristics of phaseless digital filters