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Road vehicles — Transient open-loop response test method with pseudo-random steering input

Véhicules routiers — Méthode d'essai en régime transitoire et sur boucle ouverte avec signal d'entrée pseudo-aléatoire

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ISO/TR 8726 was prepared by Technical Committee ISO/TC 22, *Road vehicles.*

The reasons which led to the decision to publish this document in the form of a technical report type 2 are explained in the Introduction.

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Descriptors: road vehicles, private cars, tests, dynamic tests, determination, transient response.

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Contents

0 Introduction

0.1 Reasons for a Technical Report

This test method is one of several open-loop transient response test methods adopted by ISO/TC 22. Originally the intention was to publish each of these as separate International Standards. It was then decided to combine them in a single International Standard, ISO 7401, and restrict each procedure to its most basic content. It was, however, also agreed that some of the procedures in their original form contained technical information and additional interesting forms of data presentation that it was desirable to have available. Thus it was decided to have some of the test methods published also as Technical Reports to be used as supplements to ISO 7401.

This document is one of these Technical Reports and it presents an extension of, and gives further explanation to, the transient response test method with pseudo-random steering input. The main additions made in this Technical Report, by comparison with ISO 7401, are amplification of the sections describing data analysis and interpretation. The test conditions are identical to those described in ISO 7401.

The transient open-loop response test methods described in ISO 7401 are based on five different steering-wheel inputs, i.e. step/ramp, one period sinusoidal, pseudo-random, pulse and continuous sinusoidal. The pseudo-random input method applies where vehicle behaviour is assumed to be linear. It enables a vehicle's response to be calculated to any defined input within the range of lateral accelerations used in the tests, including those of the procedures mentioned above. Therefore, it is recommended that this method be selected when the maximum amount of information is required over a limited range of lateral accelerations, as for example during normal public road driving. Other procedures may be more suitable where specific inputs are of interest or where the range of lateral accelerations of interest is large.

0.2 General

See ISO 7401.

0.3 Object of test

The primary object of the test is to determine the frequency response characteristics of a vehicle subjected to a pseudo-random steering input over a frequency range from the lowest possible (limited by vehicle speed and test track width) to the highest achievable. The range normally achievable in practice lies between approximately 0,1 and 4,5 Hz.

Important criteria are

— the variation with frequency of the gain with respect to steering-wheel input of the lateral acceleration and yaw rate responses;

— the variation with frequency of the phase angle with respect to steering-wheel input of the lateral acceleration and yaw rate responses.

These criteria are determined during nominally straight line travel at a constant forward speed and using a steering-wheel amplitude which generates a lateral acceleration within the linear range of operation of the vehicle.

Steering-wheel torque and roll angle are examples of other responses which are believed to be of importance but until now have not been widely used.

It is necessary to measure

— steering-wheel angle;

— lateral acceleration;

— yaw velocity;

— forward velocity.

It is desirable to measure

— steering-wheel torque;

— vehicle roll angle or roll angle velocity.

The variables listed in this clause are not exhaustive.

1 Scope and field of application

This Technical Report specifies a method for determining transient response behaviour at approximately constant speed and applies to passenger cars as defined in ISO 3833. In a simplified form, this test method is also specified in ISO 7401 together with alternative and complementary procedures.

The quasi-open-loop manoeuvre used in this method is not representative of real driving conditions but is useful in obtaining measures of vehicle transient behaviour in terms that will enable the response to any deterministic input to be calculated. Thus, it is not necessary to repeat the test if the response to a different input is required. As long as the input can be quantified, a reprocessing of the test results is all that is necessary. Repeatability is good so long as the same test surface is used and provided the limits put on the statistical tests of the data are observed (see clauses 6 and 8).

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

There is however a limit to how small an input range can be used because if the input amplitudes are too small, the level of spurious input (which is constant at a given test speed on a given surface) will become unacceptably significant. In practice therefore, a compromise must be made depending on the extent of non-linearity of response in the range of behaviour under investigation, and the test track smoothness. An indication of the former can be obtained by carrying out the steady-state circular test in ISO 4138. Obviously the test track used must be as smooth as possible.

It can be stated that from modern vehicles, which if acceptable to the customer have generally good linearity, and with well maintained test surfaces, no problems of this sort are likely to arise.

2 References

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

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

ISO 7401, *Road vehicles — Lateral transient response test methods.*

3 Instrumentation

See ISO 7401.

NOTE — Vehicle roll angle data may be obtained by integration of a roll velocity signal. If roll velocity is measured, a transducer having a range of ± 20 °/s and a maximum error, when combined with the recorder system, of ± 0,2 °/s is recommended.

4 Test conditions

See ISO 7401.

5 Test method

5.1 Tyre warm-up

See ISO 7401.

5.2 Test speed

See ISO 7401.

5.3 Steering-wheel angle amplitude

The steering-wheel angle amplitude may be determined either

a) by driving in steady-state on a circle the radius of which gives the preselected lateral acceleration at the required test speed; or

b) from a continuous read-out of instantaneous lateral acceleration during a run made at the required test speed and with an oscillatory steering-wheel input at the lowest frequency possible.

The recommended value of lateral acceleration is ± 2 m/s^2 but the value used shall not normally exceed ± 4 m/s^2 because the analysis technique is based on an assumption of linear vehicle behaviour (see clause 1).

The value used and the corresponding steering-wheel angle shall be recorded in the summary form as shown in annex A.

The steering-wheel angle amplitude shall be indicated to the driver by suitable marking of the steering-wheel. It is important that mechanical limit stops are not used because their action will affect the harmonic content of the input (see 6.2).

Maintenance of an exact steering-wheel angle amplitude over the complete frequency range of input is not necessary, providing that the amplitude is adequate (see 6.2) but does not exceed that which causes the vehicle to be operated outside its range of linear operation.

5.4 Random input

Test runs shall be made by driving the vehicle in a nominally straight line at the required test speed (see 5.2) and making continuous oscillatory inputs up to predetermined limits of steering-wheel amplitude (see 5.3) over the frequency range of interest. The frequency of input should cover the range from the lowest possible, usually determined by the limits imposed by the test speed and available track width, to the highest attainable. To ensure adequate high-frequency content, the input must be energetic and of several minutes duration.

It is important the the input is continuous because periods of relative inactivity will seriously reduce the signal-to-noise ratio. Ideally, the test should be performed in one continuous run, but this may be prevented for two practical reasons. Firstly the test track may not be long enough to permit a continuous run of such a length at the required mean lateral acceleration and, secondly, the computer used to analyse the data may not have the capacity to handle all the data at one go. In either case, it is permissible to use a number of shorter runs, and having calculated the power spectral densities for each run, they can then be averaged (see annex B, clause B.1). The averaging function used shall be noted (see clause 7).

6 Data analysis

6.1 General

The data-processing requirements which follow can be carried out most rapidly using a multi-channel real time analyser, but if this is not available, the data should be digitized and processed on a computer with the appropriate software (see annex B).

6.2 Preliminary analysis

The recorded time history of forward velocity shall be displayed and examined visually to ensure that it is within 5 % of the nominal value. If it is not, the results shall be discarded.

Good data shall be filtered to remove all information above 15 Hz and each time history digitized at a rate of not less than 40 samples per second.

A Fourier analysis shall be made of the steering-wheel angle history, and the result shall be displayed as a graph of the steering-wheel angle input level relative to that at the lowest frequency versus frequency as shown in annex C, figure 2.

This graph shall be examined visually to ensure adequate frequency content. The recommended difference between maximum and minimum shall not be greater than 12 dB. If the difference is greater, the results may be discarded or, if used, the extent of the difference shall be noted in the general data (annex A).

6.3 Further processing

Digitized data which has passed the above tests shall be further processed as follows:

— If measured, the roll angular velocity data sequences shall be converted to roll angle sequences by integration.

— If necessary, the lateral acceleration data shall be corrected for vehicle roll angle (see ISO 7401). Normally this step will be necessary unless the lateral accelerometer has been mounted on a stabilized platform.

The data shall then be processed using appropriate equipment (see 6.1 and annex B) to produce the transfer function amplitude and phase information together with the coherence function for the chosen combinations of input and output variables.

Combinations which have been found useful are

— lateral acceleration per unit of steering-wheel angle;

— yaw rate per unit of steering-wheel angle;

— roll angle or angular velocity per unit of steering-wheel angle;

— steering-wheel torque per unit of steering-wheel angle;

— lateral acceleration per unit of steering-wheel angle;

— roll angle or angular velocity per unit of lateral acceleration.

7 Data presentation

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

For each chosen pair of input and output variables, the frequency response functions (gain), phase angle function and coherence function shall be presented on a graph as shown in annex C, figure 3 together with the number and length of the data sequences and the averaging function, the digitizing rate and the windowing function used. The units of the frequency response function are metres per second squared per degree for lateral acceleration, degree per second per degree for yaw velocity, degree per degree for roll angle and newton metres per degree for steering-wheel torque.

If roll angle or roll angular velocity has been measured, the roll response to lateral acceleration may be presented on a graph as shown in annex C, figure 4. The units for the frequency response function are degrees per metre per second squared for roll angle and degrees per second per metre per second squared for roll angular velocity.

8 Data interpretation

The significance of the test results in terms of vehicle dynamic behaviour is explained in annex D but some remarks on the statistical significance of the results need to be made here.

The most important parameter in this Technical Report is the coherence function which quantifies the amount of uncorrelated information or noise present in the data. Where coherence is high, i.e. near unity, the output may be taken to be a response entirely due to steering-wheel input. Lower values of coherence indicate that other factors, in addition to wheel input, are influencing the output response. Low values of coherence are associated normally with inadequate wheel input or low vehicle response.

Tables 1 and 2 in annex E show the 90 % confidence limits on amplitude and phase angle, in terms of the measured values and the number of averages. Also shown are the 90 % confidence limits on the coherence function itself.

It can be seen that in order to obtain close limits it is necessary to have high coherence levels and/or a large number of averages.

It is recommended that the 90 % confidence limits for gain lie between + 1 and − 1,5 dB and that those for phase angle lie between ± 10°.

The number of averages needed to achieve this will depend on the coherence which in turn is related to the amount of uncorrelated data and hence to the quality of the test condition.

9 Bibliography

[1] HOFFMAN, E.R. Human control of road vehicles. *Vehicle system dynamics,* Vol. 5, Nos. 1-2, August 1975, pp. 105-106.

[2] GOOD, M.C. Sensitivity of driver vehicle performance characteristics revealed in open loop tests. *Vehicle system dynamics,* Vol. 6, No. 4, October 1977, pp. 245-277.

Annex A

General data presentation

Test number: .....

Vehicle identification

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

Vehicle number: ....

Steering type: ....

Suspension type: Front: ....

Rear: ....

Engine size: ....

Optional equipment: ....

Tyres and condition: ....

....

Tyre pressures

— cold: Front: .... bar[1]

Rear: .... bar

— hot (if measured): Front: .... bar

Rear: .... bar

Rims: ....

Wheelbase: .... m

Track: Front: .... m

Rear: .... m

Overall steering ratio: ....

Other (in particular, relevant suspension settings): ....

....

Vehicle loading

Loading condition and location: ....

Vehicle mass as tested: Left front: .... kg Right front: .... kg

Left rear: .... kg Right rear: .... kg

TOTAL: .... kg

Vehicle mass distribution: .... front/ .... rear

Vehicle centre of gravity height: .... m [measured/estimated[2]]

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

2) Delete as applicable.

Test conditions

Test surface description : ....

Weather conditions :

- temperature : .... °C
- wind speed : .... m/s

Test speed : .... m/s

Mean lateral acceleration and range .... ± .... °

Corresponding steering-wheel angle and range .... ± .... °

Difference between maximum and minimum steering-wheel angle gain .... °

Steering ratio ....

Test personnel

Driver : ....

Observer : ....

Data analyst : ....

General comments

....

....

....

Annex B

Data processing

B.1 Symbols

The following symbols are used:

$C_{xy}(f)$	coincident spectral density function
f	cyclical frequency
$G_x(f)$, $G_y(f)$	power spectral density functions
$G_{xy}(f)$	cross spectral density function
$\lvert H(f) \rvert$	frequency response function
$H(f)$	frequency response gain factor
$N(f)$	extraneous input due to noise
$Q_{xy}(f)$	quadrature spectral density function
$x(t)$	time dependent input variable
$y(t)$	time dependent output variable
$X(f)$, $Y(f)$	Fourier transforms of $x(t)$, $y(t)$
$\gamma_{xy}(f)$	coherence function
$\theta_{xy}(f)$	argument of $G_{xy}(f)$
$\phi(f)$	system phase

B.2 Procedure

The random steering input test is used to extract the frequency response function $H(f)$ relating lateral acceleration, yaw velocity, and roll displacement to steering input for the vehicle operating within its linear range.

To obtain the frequency response function of a constant parameter linear system excited by a stationary random function, the following steps are necessary:

1 Digitize data.

2 Truncate data sequence or add zeros to fit Fourier transform routine used.

3 Taper the resulting data sequence using an appropriate window function, e.g. cosine or Hanning.

4 Using a Fourier transform routine, extract the complex Fourier coefficients.

5 Multiply by the window correction factor.

6 Calculate $G_{nx}(f)$, $G_{ny}(f)$, $G_{nxy}(f)$.

7 Calculate the averaged function $G_x(f)$, $G_y(f)$, $G_{xy}(f)$.

8 From the averaged functions calculate $H(f)$, $\phi(f)$, $\gamma_{xy}(f)$.

This process is summarized in the flow chart (see figure 1). Details of the theory underlying the process are given in clause B.4.

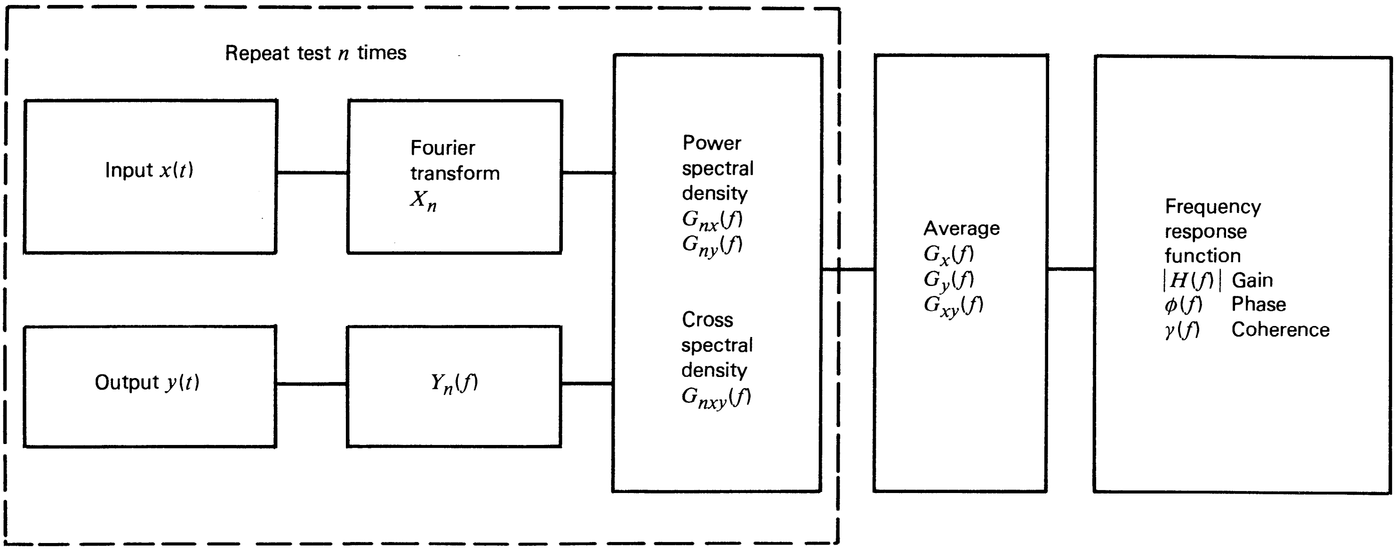

Figure 1 — Flow chart

Frequency response function:

$$H(f) = \frac{G_{xy}(f)}{G_x(f)}$$

System gain:

$$|H(f)| = \frac{|G_{xy}(f)|}{G_x(f)}$$

In both cases, $G_{xy}(f)$ is a complex function:

$$G_{xy}(f) = C_{xy}(f) - \mathrm{j}\, Q_{xy}(f)$$

and is based on the correlation between output and input.

Either by averaging as above or by use of a long sample length, any part of the output such as extraneous noise, which cannot be related linearly to the input is eliminated (see clause B.3).

Because $G_x(f)$ is a real function, system phase $\phi(f)$ is the same as the argument of $G_{xy}(f)$:

$$\phi(f) = \theta_{xy}(f) = \tan^{-1}\left[\frac{Q_{xy}(f)}{C_{xy}(f)}\right]$$

The scalar gain $|H_s(f)|$ is given by

$$|H_s(f)|^2 = \frac{G_y(f)}{G_x(f)}$$

The coherence function $\gamma_{xy}(f)$ is given by

$$\gamma_{xy}^2(f) = \frac{|H(f)|^2}{|H_s(f)|^2}$$

$$= \frac{|G_{xy}(f)|^2}{G_x^2(f)} \times \frac{G_x(f)}{G_y(f)}$$

$$= \frac{|G_{xy}(f)|^2}{G_x(f) \times G_y(f)}$$

Two cases of coherence function are possible:

- if $\gamma_{xy}(f) = 1$, then $x(t)$ and $y(t)$ are correlated at a particular frequency;
- if $\gamma_{xy}(f) < 1$, then $x(t)$ and $y(t)$ are not correlated or there is noise in the output signal or there are multiple inputs.

B.3 Effect of extraneous input due to noise

Let

$X = X(f)$ $\qquad G_x = G_x(f)$

$Y = Y(f)$ $\qquad G_y = G_y(f)$

$\gamma = \gamma_{xy}(f)$ $\qquad G_{xy} = G_{xy}(f)$

$N = N(f)$ $\qquad H = H(f)$

Input power spectral density $G_x = XX^*$

Output power spectral density $G_y = YY^*$

Generally $Y = H(X + N)$

where

X, Y are the real components;

X^*, Y^* are the imaginary components of complex functions X, Y.

Therefore

$$G_y = HH^* (X + N)(X + N)^*$$

$$= HH^* (XX^* + XN^* + NX^* + NN^*)$$

Since XN and NX disappear in averaging:

$$G_y = HH^* (XX^* + NN^*)$$

$$= HH^* (G_x + NN^*) \qquad \ldots (1)$$

Cross spectral density:

$$G_{xy} = YX^*$$

$$= H(X + N)X^*$$

$$= HXX^* \text{ since } NX^* \text{ disappears in averaging}$$

$$= HG_x \qquad \ldots (2)$$

Coherence function:

$$\gamma_{xy}^2 = \frac{|G_{xy}|^2}{G_x G_y}$$

$$= \frac{|H|^2 G_x^2}{G_x |H|^2 (G_x + NN^*)}$$

$$= \frac{G_x}{(G_x + NN^*)}$$