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Road vehicles — Transient open-loop response test method with one period of sinusoidal input

Vehicules routiers — Méthode d'essai en régime transitoire et boucle ouverte avec impulsion d'entrée sinusoïdale d'une période

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The main task of ISO technical committees is to prepare International Standards. In exceptional circumstances a technical committee may propose the publication of a technical report of one of the following types :

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- type 2, when the subject is still under technical development requiring wider exposure;
- type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example).

Technical reports are accepted for publication directly by ISO Council. Technical reports types 1 and 2 are subject to review within three years of publication, to decide if they can be transformed into International Standards. Technical reports type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

ISO/TR 8725 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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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 method to its most basic content. It was, however, also agreed that some of the methods 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 a supplement 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 one period of sinusoidal input. The main additions made in this Technical Report, by comparison with ISO 7401, are the study of the transient characteristics as functions of lateral acceleration up to the limit of adhesion and the introduction of some new parameters in order to express the characteristics in a comprehensive and understandable form. A detailed description on how to perform the data analysis is also included. The test conditions are identical to those described in ISO 7401 except for some details concerning the test track and loading conditions.

The transient open-loop response test methods described in ISO 7401 are based on three different steering-wheel inputs, i.e. step/ramp, one period sinusoidal and random/sinesweep. The one period sinusoidal input is preferable when the range of lateral accelerations of interest is wide, or when the linearity of the behaviour of the vehicle is to be determined.

0.2 General

See ISO 7401.

0.3 Object of test

The primary object of the test is to determine the transient response behaviour of a vehicle subjected to one period of sinusoidal input which is similar to what is used in real traffic during lane change manoeuvres.

Important criteria are

- time lags between steering-wheel angle, lateral acceleration and yaw velocity;
- response of lateral acceleration to steering-wheel angle;
- response of yaw velocity to steering-wheel angle.

These criteria are determined at different levels of acceleration, primarily at 0,5 Hz steering-wheel input frequency. Higher and lower frequencies may, however, also be of interest.

Steering-wheel torque, sideslip angle 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;
- sideslip angle;
- lateral velocity;
- vehicle roll angle.

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.

A method for measuring transient response behaviour due to braking in a turn is specified in ISO 7975: the measurement of steady-state properties is given in ISO 4138.

The open-loop manœuvre specified in this test method is useful to determine vehicle transient response to one period of sinusoidal steering input under closely controlled test conditions. It is not fully representative of real driving conditions but similar to lane change manœuvres in real traffic.

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 method.*

ISO 7975, *Road vehicles — Braking in a turn — Open loop test procedure.*

3 Instrumentation

See ISO 7401.

4 Test conditions

Generally the test conditions are identical to ISO 7401, with the additions given in 4.1 and 4.2.

4.1 Test track

If tests are made up to the limit of adhesion, a wet test track with a maximum coefficient of adhesion of not more than 0,8 is recommended in order to reduce the risk of overturning.

4.2 Minimum loading conditions

It is desirable that not only the load distribution but also the actual load is as close as possible to the mass of two occupants in the front seats (i.e. 136 kg).

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 shall be increased in approximately constant steps. The step size shall be such that the first step results in a lateral acceleration of 2 ± 0,5 m/s^2. The number of steps shall be such that the limit of adhesion is reached (i.e. the same lateral acceleration is obtained for two successive amplitudes, or that the vehicle becomes unstable).

5.4 Sinusoidal input

The vehicle shall be driven at the test speed (see 5.2), in a straight line. Starting from 0 ± 0,5 °/s yaw velocity equilibrium condition, one full period of sinusoidal steering-wheel input shall be applied with a steering frequency of 0,5 Hz. Optional steering frequencies of 0,3, 0,7 and 1 Hz are recommended. The allowable amplitude error compared to the true sine wave is ± 5 % of the first peak value.

No change in throttle position shall be made, even though speed may decrease.

Data shall be taken for both initial left and right turns. All the data may be taken in one direction followed by all the data in the other direction. Alternatively, data may be taken successively in one direction and then the other for each lateral acceleration level going from the lowest to the highest. The method chosen shall be noted in the general data (see annex A).

All test runs shall be performed at least three times in order to obtain mean values and standard deviations.

6 Data analysis

6.1 General

By comparison with ISO 7401, data analysis in this Technical Report is somewhat more extended. In addition to the evaluation of values for left and right initial turn directions, mean values of left and right initial turn and asymmetry factors are deduced. If data are digitized, a minimum sampling frequency of 200 Hz shall be used to get the desired time resolution. Peak values shall be taken from data filtered according to annex C.

6.2 Lateral acceleration

Unless otherwise specified lateral acceleration is measured as the first peak value of the lateral acceleration at the vehicle centre of gravity corrected for roll angle.

6.3 Yaw velocity

Unless otherwise specified yaw velocity is measured as the first peak value of the yaw velocity.

6.4 Time lag and sine time lag

The time lags between the variables steering-wheel angle, yaw velocity, lateral acceleration, etc. are calculated for the first and second peak by cross-correlation of the first and second halfwaves respectively (of the positive and negative parts of the time history) (see annex C).

The mean value of the time lag for initial left and initial right turns for the second peak is used as a reference value named "sine time lag".

6.5 Lateral acceleration gain

See ISO 7401.

6.6 Yaw velocity gain

See ISO 7401.

6.7 Time lag ratio, R_T

This is the ratio between the time lag at the second peak and the time lag at the first peak.

6.8 Yaw velocity ratio, $R_{\dot{\psi}}$

This is the ratio between the second peak value and the first peak value of the yaw velocity.

6.9 Lateral acceleration ratio, R_{a_y}

This is the ratio between the second peak value and the first peak value of the lateral acceleration.

6.10 Asymmetry factor

The asymmetry factor for a variable is calculated as ten times the logarithm (to the base 10) of the ratio between results obtained in tests with initial right turn and initial left turn. Equal results then give the asymmetry factor zero. Positive values indicate that larger values are obtained in tests with initial right turns.

6.11 Test data analysis

The following data shall be calculated:

a) time lag between steering-wheel angle and yaw velocity;

b) time lag between steering-wheel angle and lateral acceleration;

c) lateral acceleration gain per unit of steering-wheel angle;

d) yaw velocity gain per unit of steering-wheel angle;

e) time lag ratio for the variables listed;

f) lateral acceleration ratio;

g) yaw velocity ratio;

h) asymmetry factors for the variables and ratios listed.

7 Data presentation

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

Time histories of measured variables shall be plotted (see ISO 7401).

If a curve is fitted to any set of data, the method of curve fitting shall be described in the results.

Test data shall be presented on the summary form shown in annex B, as mean values and standard deviations of initial left and initial right turns, respectively. One column for the mean of the values for initial left and initial right turns is also given. Values shall be presented for a lateral acceleration level of 4 m/s^2 and additional levels of 2 and 6 m/s^2 are recommended.

Sine time lag data as a function of lateral acceleration shall be plotted according to figure 1 (see annex B).

Lateral acceleration ratio, lateral acceleration gain and time lag ratio for steering-wheel angle to lateral acceleration as functions of lateral acceleration shall be plotted according to figure 2.

The asymmetry factors of lateral acceleration ratio, lateral acceleration gain and time lag for steering-wheel angle to lateral acceleration as functions of lateral acceleration shall be plotted according to figure 3.

Yaw velocity ratio, yaw velocity gain and time lag ratio for steering-wheel angle to yaw velocity as functions of lateral acceleration shall be plotted according to figure 4.

The asymmetry factors of yaw velocity ratio, yaw velocity gain and time lag for steering-wheel angle to yaw velocity as functions of lateral acceleration shall be plotted according to figure 5.

8 Optional data analysis and presentation

If measured,

a) steering-wheel torque,

b) roll angle,

c) sideslip angle,

d) lateral velocity

shall be plotted as functions of time. Similarly,

e) time lags,

f) time gains,

g) ratios,

h) asymmetry factors

shall be calculated and plotted in the same way as for lateral acceleration and yaw velocity.

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*

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 centre of gravity height: .... m

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

Test conditions

Test surface description: ....

Weather conditions:

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

Reference point for sideslip angle and lateral velocity (see ISO 7401): ....

Test method chosen for evaluation: Sinusoidal input (one period)

Test personnel

Driver: ....

Observer: ....

Data analyst: ....

General comments

....

....

....

Annex B

Presentation of test results

Response data summary

Test number: .....

Vehicle type: .... Test speed: ...... km/h

Loading condition: .... Lateral acceleration: ...... m/s^2

Test vehicle data: (see annex A) Frequency: ...... Hz

Parameter	Symbol	Unit	Left turn		Right turn		Mean value
			Mean value	Standard deviation	Mean value	Standard deviation	
Time lag steering-wheel angle to lateral acceleration							
Peak 1	$T(\delta\text{-}a_y)_1$	ms					
Peak 2	$T(\delta\text{-}a_y)_2$	ms					
Sine time lag	$T(\delta\text{-}a_y)$	ms	–	–	–	–	
Asymmetry factor			–	–	–	–	
Time lag ratio							
Time lag steering-wheel angle to yaw velocity							
Peak 1	$T(\delta\text{-}\dot{\Psi})_1$	ms					
Peak 2	$T(\delta\text{-}\dot{\Psi})_2$	ms					
Sine time lag	$T(\delta\text{-}\dot{\Psi})$	ms	–	–	–	–	
Asymmetry factor			–	–	–	–	
Time lag ratio							
Lateral acceleration gain	a_y/δ	$(m/s^2)/°$					
Asymmetry factor			–	–	–	–	
Yaw velocity gain	$\dot{\Psi}/\delta$	s^{-1}					
Asymmetry factor			–	–	–	–	
Lateral acceleration ratio	R_{a_y}						
Asymmetry factor			–	–	–	–	
Yaw velocity ratio	$R_{\dot{\Psi}}$						
Asymmetry factor			–	–	–	–	

Test No.: .....

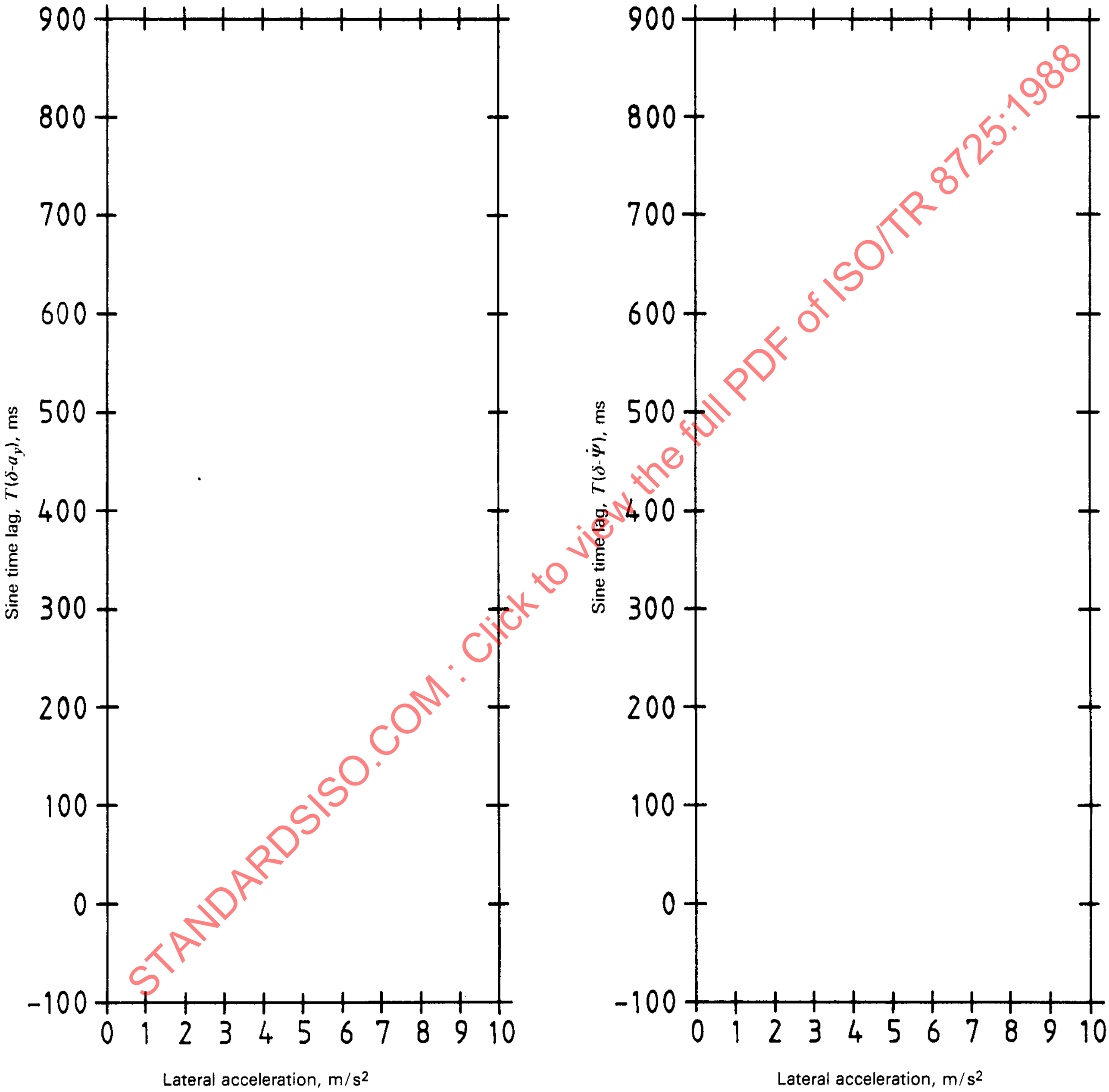
Vehicle type: ....

Vehicle data: (see annex A)

Load condition: ....

Test speed: ...... km/h

Frequency: ...... Hz



a) Sine time lag between steering-wheel angle and lateral acceleration

b) Sine time lag between steering-wheel angle and yaw velocity

Figure 1 — Sine time lag as function of lateral acceleration

Test No.: .....

Vehicle type: ....

Vehicle data: (see annex A)

Load condition: ....

Test speed: ...... km/h

Frequency: ...... Hz

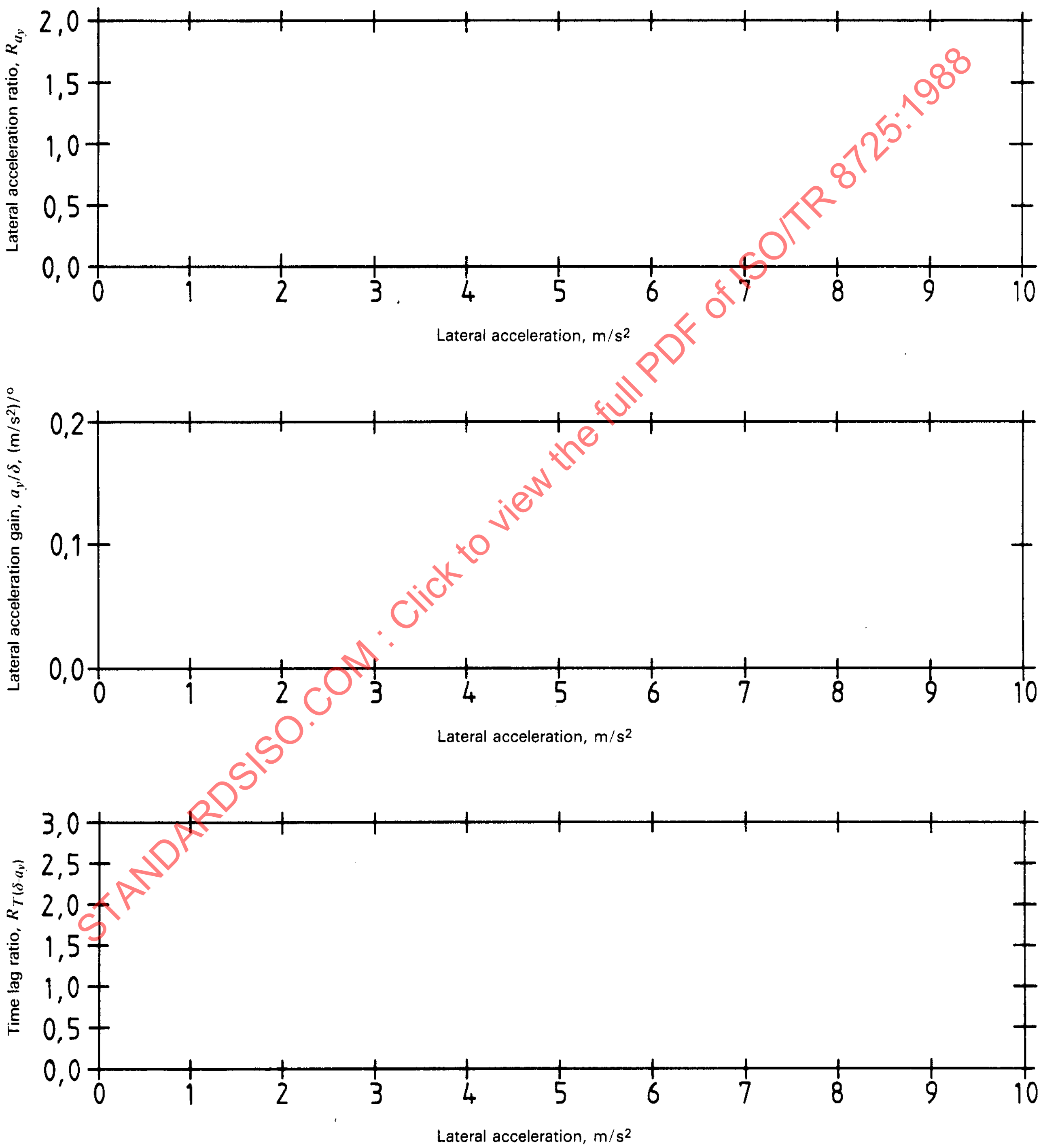


Figure 2 — Lateral acceleration ratio, R_{a_y}, lateral acceleration gain, a_y/δ, and time lag ratio, $R_{T(\delta-a_y)}$, as functions of lateral acceleration

Test No. : .....

Load condition : ....

Vehicle type : ....

Test speed : ...... km/h

Vehicle data : (see annex A)

Frequency : ...... Hz

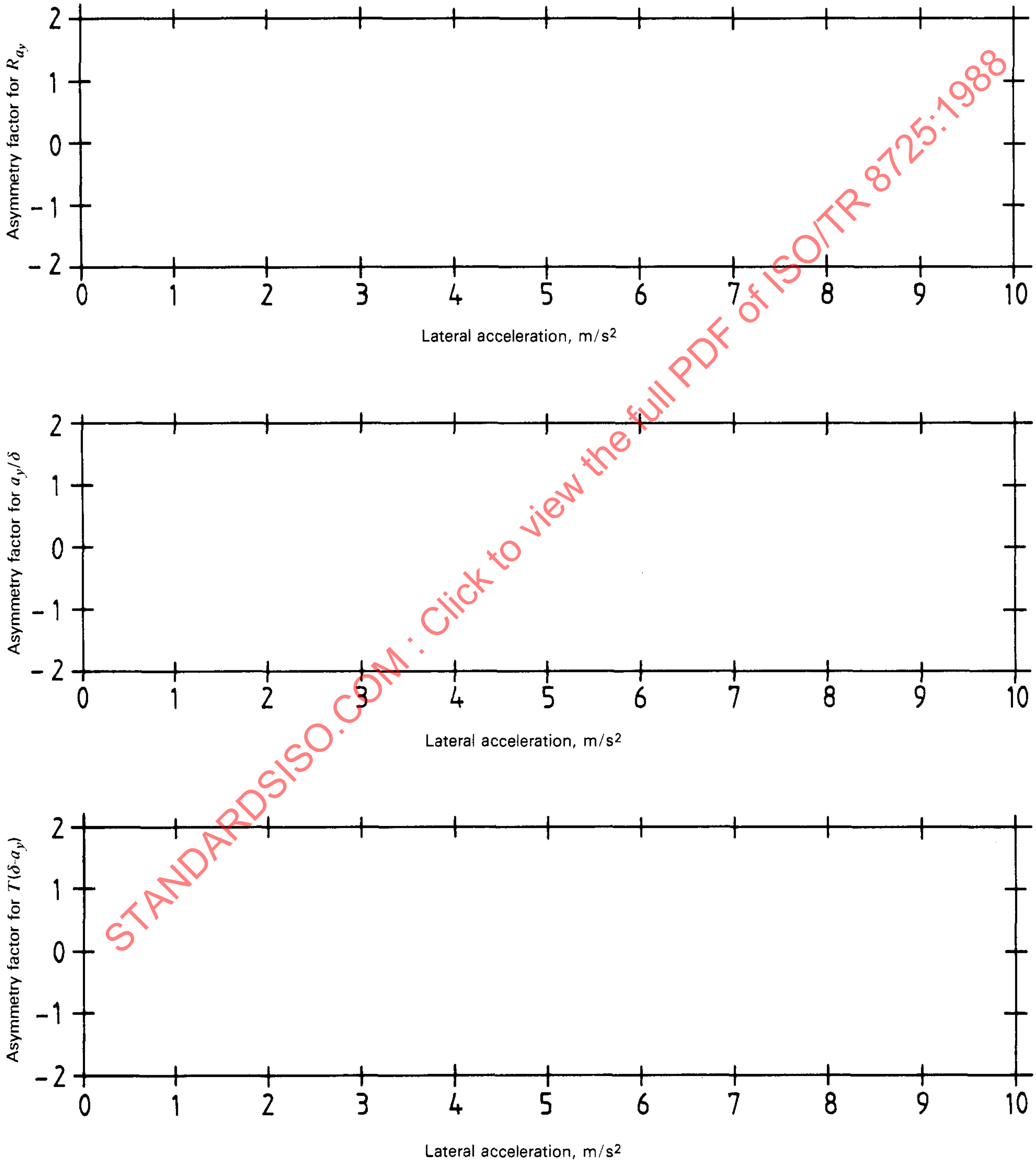


Figure 3 — Asymmetry factors for R_{a_y}, a_y/δ and $T(\delta\text{-}a_y)$ as functions of lateral acceleration

Test No. : .....

Load condition : ....

Vehicle type : ....

Test speed : ...... km/h

Vehicle data : (see annex A)

Frequency : ...... Hz

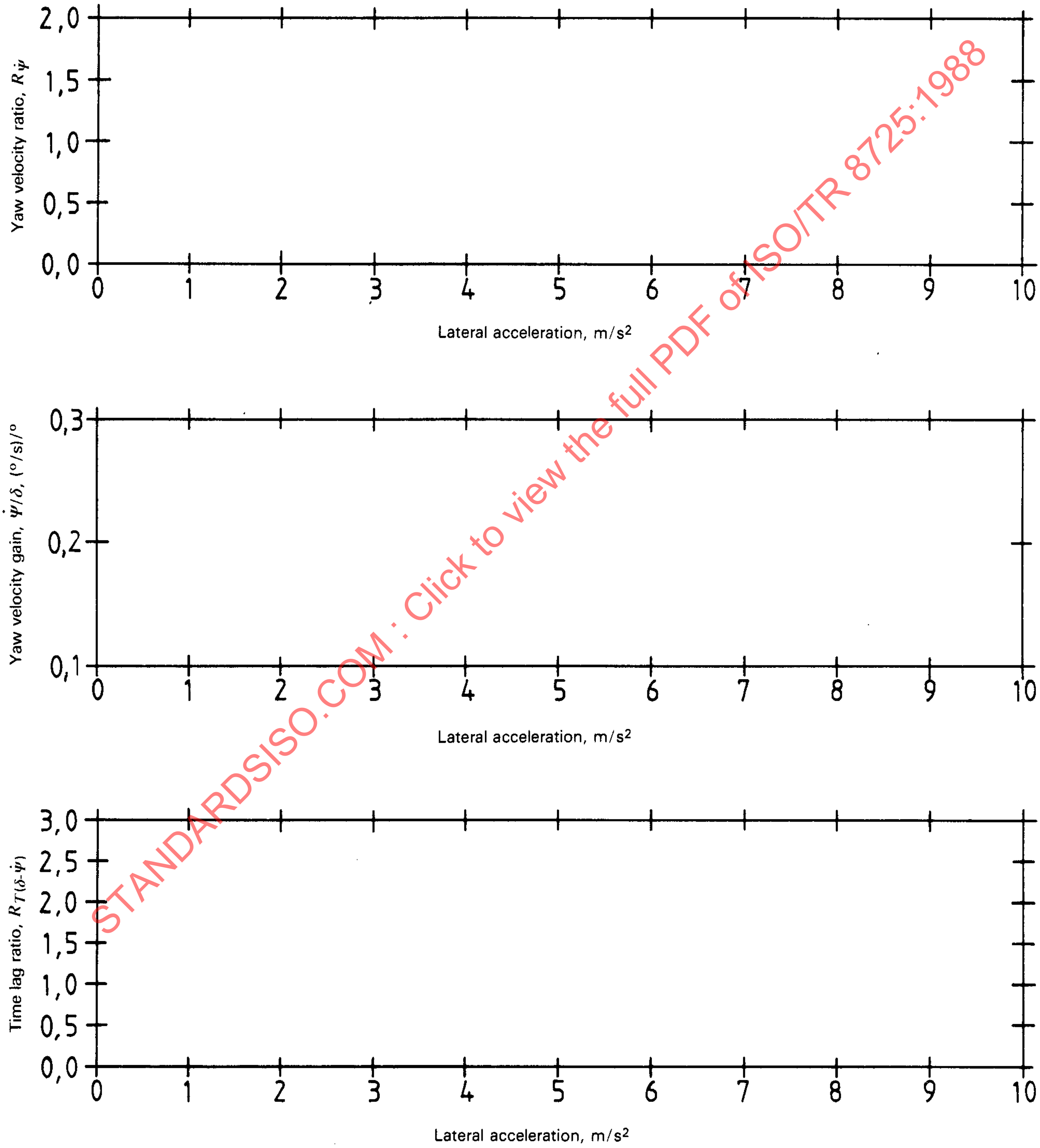


Figure 4 — Yaw velocity ratio, $R_{\dot{\psi}}$, yaw velocity gain, $\dot{\Psi}/\delta$, and time lag ratio, $R_{T(\delta\text{-}\dot{\psi})}$, as functions of lateral acceleration

Test No. : .....

Vehicle type : ....

Vehicle data : (see annex A)

Load condition : ....

Test speed : ...... km/h

Frequency : ...... Hz

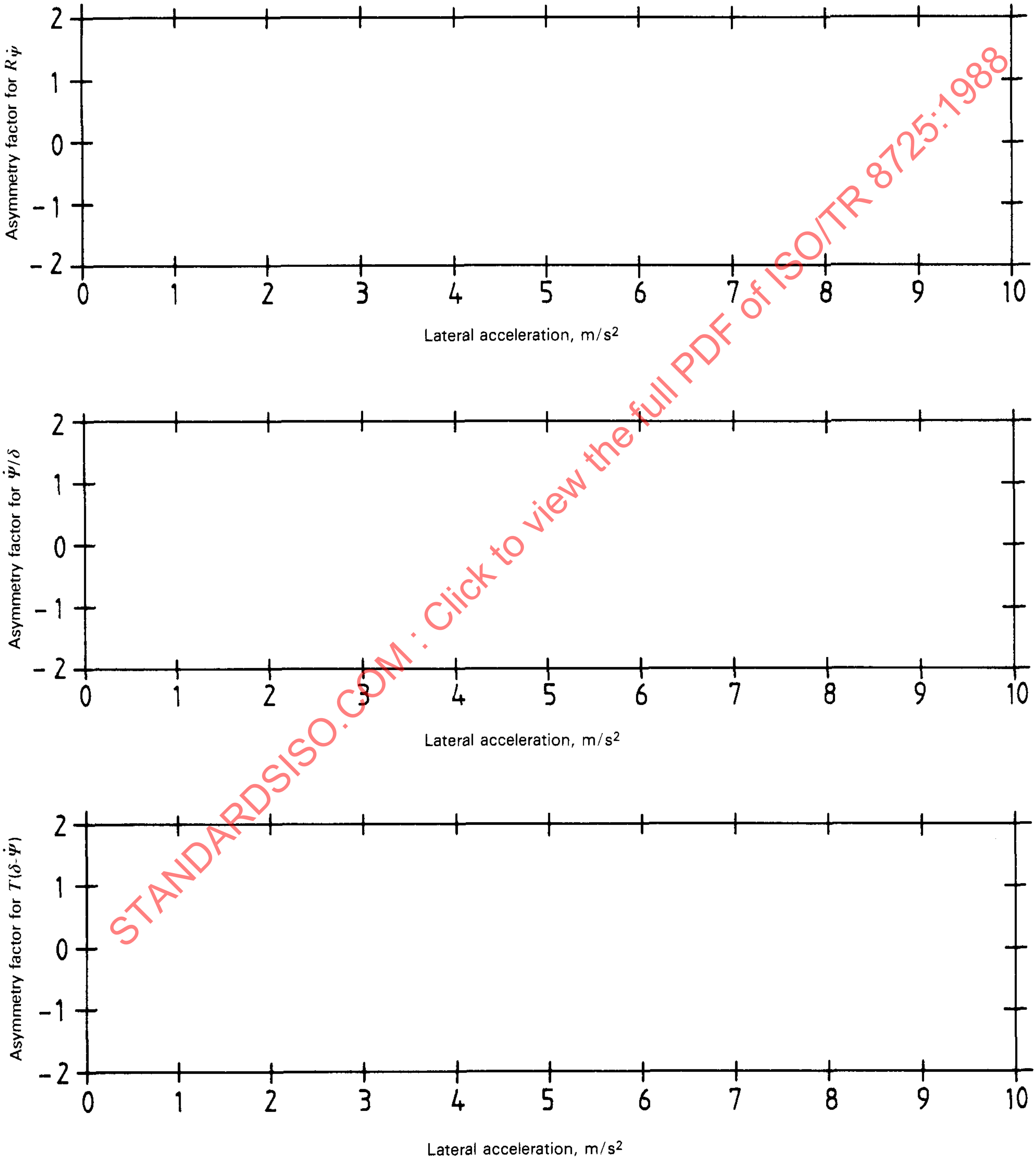


Figure 5 — Asymmetry factors for $R_{\dot{\psi}}$, $\dot{\Psi}/\delta$ and $T(\delta\text{-}\dot{\Psi})$ as functions of lateral acceleration

Annex C

Processing of test data

C.1 General

The primary purpose of further processing of the acquired data is to derive parameters which can be used when comparing different vehicles.

C.2 Filtering of data

The data shall be filtered in an analogue or digital manner according to a 5 Hz low-pass second-order Butterworth filter. It is important that the same type of filter is used for all signals.

C.3 Mathematical method for calculation of time lags by cross-correlation between two signals

C.3.1 To find the time displacement (time lag), τ_R, between the two signals $x(t)$ and $y(t)$, the maximum of the cross-correlation function R_{xy} has to be found. This function shall be calculated as follows:

$$R_{xy}(\tau) = \frac{1}{T} \int_{t=0}^{t=T} x(t) \cdot y(t+\tau) \, dt$$

The maximum of $R_{xy}(\tau)$ is found by moving the delayed signal $y(t)$ stepwise towards the signal $x(t)$ by increasing τ (see figure 6).

The length of the output signal, $y(t)$, varies with two cases:

a) there is a second zero crossing (see figure 6) and the signal length, T_L, is equal to the difference between the time for second zero crossing and the time of start;

b) there is no second zero crossing (see figure 7) and the signal length is then set to $T_L = 1{,}5/f_x$ where f_x is the input signal frequency.

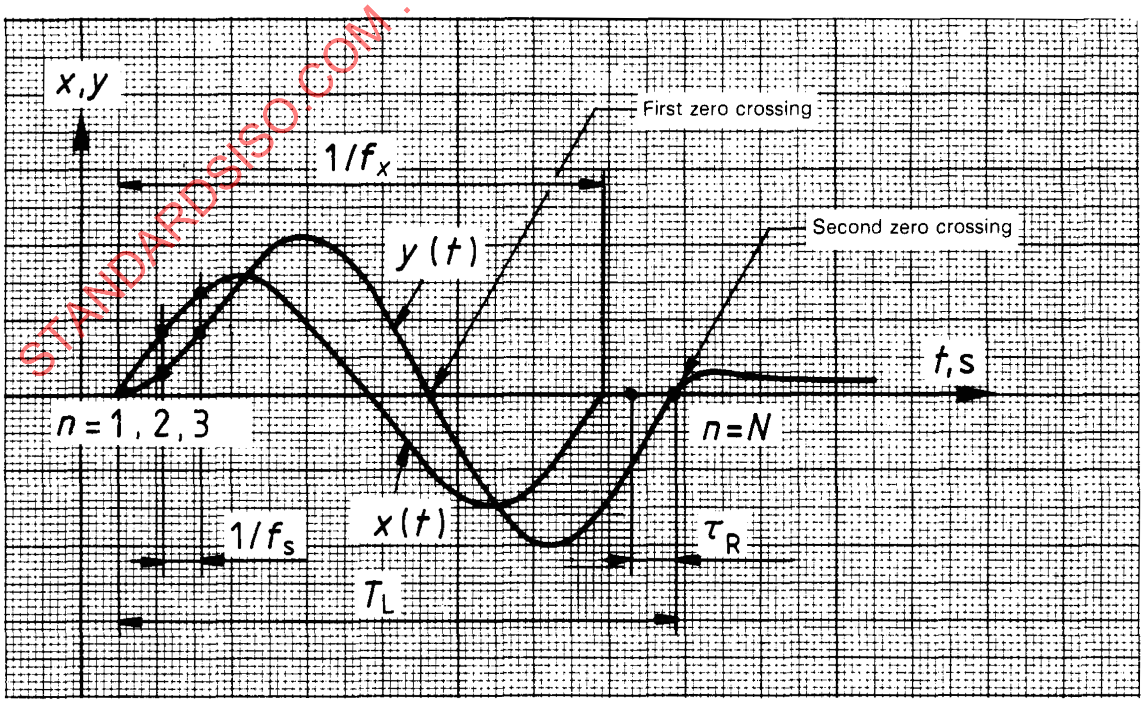


Figure 6 — Two signals $x(t)$ and $y(t)$ with time displacement τ_R and two zero crossings

The time displacement (time lag), τ_R, is equal to the time τ at which $R_{xy}(\tau)$ reaches its first maximum.

$$R_{xy}(\tau) = R_{xy_{1,\max}} \rightarrow \tau_R$$

Furthermore, the cross-correlation function $R_{xy}(\tau)$ can be normalized using the root mean square values $R_{xx} = R_x(0)$ and $R_{yy} = R_y(0)$ of the signals $x(t)$ and $y(t)$:

$$r_{xy}(\tau) = \frac{R_{xy}(\tau)}{\sqrt{R_{xx} \cdot R_{yy}}}$$

where

$$R_{xx} = R_x(0) = \frac{1}{T} \int_{t=0}^{t=T} x^2(t)\,dt$$

$$R_{yy} = R_y(0) = \frac{1}{T} \int_{t=0}^{t=T} y^2(t)\,dt$$

Also here the time displacement (time lag), τ_R, is equal to the time at which $r_{xy}(\tau)$ reaches its first maximum.

$$r_{xy}(\tau) = r_{xy_{1,\max}} \rightarrow \tau_R$$

C.3.2 For computer treatment of digitized data, a numerical method is necessary for the calculation of the time displacement (time lag), τ_R.

The cross-correlation function R_{xy} shall be calculated as follows:

$$R_{xy}(p) = \frac{1}{N} \sum_{n=1}^{n=N-p} x_n \cdot y_{n+p}$$

where

N is the number of samples;

p is the number of displacement steps.

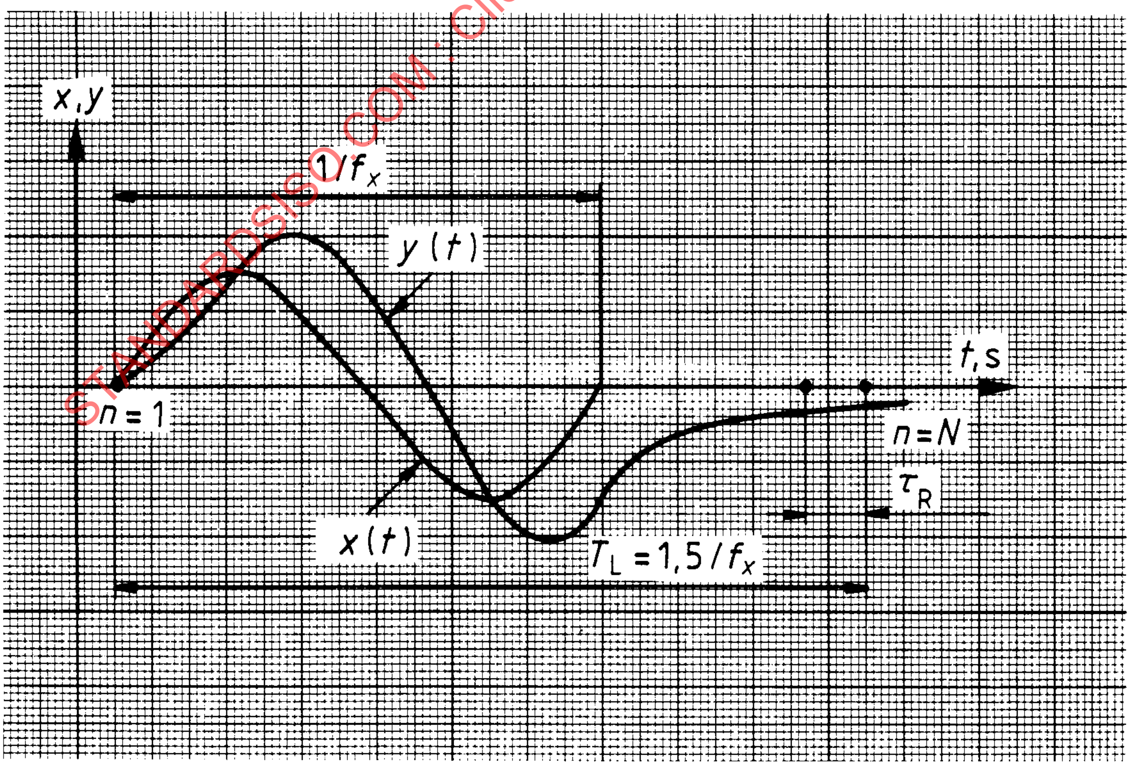


Figure 7 — Two signals $x(t)$ and $y(t)$ with time displacement τ_R and no second zero crossing