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Road vehicles — Brake lining assemblies — Inertia dynamometer test method

Véhicules routiers — Ensembles de garnitures de frein — Méthode d'essai sur banc dynamométrique à inertie

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Contents

Page

Foreword

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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 11157 was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 2, *Braking systems and equipment*.

This second edition cancels and replaces the first edition (ISO 11157:1999), which has been technically revised.

Road vehicles — Brake lining assemblies — Inertia dynamometer test method

1 Scope

This International Standard specifies a dynamometer test method to homologate alternative types of brake linings (including pads) mounted on original equipment, in accordance with UN-ECE Regulation No. 13-09, Annex 15.

This International Standard is applicable to road vehicles of categories M, N and O (see 3.1) as defined in UN ECE *Consolidated resolution of the construction of vehicles,* R.E.3, Annex 7.

Application for approval corresponding to this test method is to be made by the vehicle manufacturer (in the case of vehicles of category O the application is to be made by the axle or brake manufacturer) or by his duly accredited representative.

The values in square brackets, i.e. [ ], are taken from UN-ECE Regulation No. 13-09.

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 611:2003, *Road vehicles — Braking of automotive vehicles and their trailers — Vocabulary*

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

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

UN-ECE Regulation No. 13, Uniform provisions concerning the approval of vehicles of categories M, N and O with regard to braking, incorporating the 09 series of amendments.

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms, definitions and symbols given in ISO 611, ISO 1176, ISO 3833 and the following apply.

3.1.1
category M
power-driven vehicles having at least four wheels and used for the carriage of passengers

3.1.2
category N
power-driven vehicles having at least four wheels and used for the carriage of goods

3.1.3
category O
trailers (including semi-trailers)

3.2 Symbols

Symbol	Unit	Description
d_i, d_j	m/s^2	mean deceleration within the time window i resp. j
d_m	m/s^2	mean fully developed deceleration (MFDD)
$d(t)$, $d(T)$	m/s^2	deceleration in dependence of time t resp. T
f_d	—	required accuracy of the MFDD
f_S	—	required accuracy for the measurement of the stopping distance
f_v	—	required accuracy for the measurement of the prescribed speed
I	kg/m^2	rotational inertia
i, j	—	index characterizing all events which can be consecutively allocated to a time window with a given duration t_d
m	kg	mass acting on the ground for the wheel(s) under consideration
n_i	—	number of pulses within the time window i
r	m	dynamic tyre rolling radius
S_d	m	stopping distance travelled between v_b and v_e
S_i	m	distance travelled within the time window i
S_pb	m	stopping distance travelled between v_p and v_b
S_pe	m	stopping distance travelled between v_p and v_e
t, T	s	time used as a variable in different functions
t_b	s	time at the beginning of the evaluation range for a braking action
t_d	s	time window in which values of interest are measured
t_e	s	time at the end of the evaluation range for a braking action
T_i	N·m	mean torque within the time window i
t_S	s	time at the end of a braking action
v_air	km/h	velocity of the cooling air
v_b	km/h	vehicle speed at 0,8 v_p
v_e	km/h	vehicle speed at 0,1 v_p
v_i	km/h	mean speed within the time window i
v_max	km/h	max. vehicle speed
v_p	km/h	prescribed vehicle speed
v_t	km/h	vehicle test speed at initiation of braking
v_1	km/h	initial speed at beginning of braking for heating procedures with repeated braking
w_S	—	necessary pulse-rate of one revolution for the measurement of the stopping distance
w_v	—	necessary pulse-rate of one revolution for the measurement of the speed
w_d	—	necessary pulse-rate of one revolution for the measurement of the deceleration

4 General

4.1 The test method described can be applied in the event of a modification of vehicle type resulting from the fitting of alternative types of brake linings on the original equipment of vehicles which have been approved in accordance with UN-ECE Regulation No. 13-09.

4.2 The alternative types of brake linings shall be checked by comparing their performance with that obtained from the brake linings with which the vehicle was equipped at the time of approval and conforming to the components identified in the relevant information document, a model of which is given in UN-ECE Regulation No. 13-09, Annex 2.

4.3 The technical service which is responsible for conducting approval tests may, at its discretion, require that comparison of the performance of the brake linings be carried out in accordance with UN-ECE Regulation No. 13-09, Annex 4.

4.4 Application for approval by comparison shall be made by the vehicle manufacturer (in the case of category O vehicles the application shall be made by the axle or brake manufacturer) or by the manufacturer's duly accredited representative.

4.5 For the purposes of this International Standard, the term "vehicle" means the vehicle type which has been approved according to UN-ECE Regulation No. 13-09, and for which the comparison is required to lead to satisfactory results.

4.6 The vehicle (or axle/brake) manufacturer shall ensure that all requirements of UN-ECE Regulation No. 13-09 for the vehicle (or axle/brake) fitted with the alternative types of linings are fulfilled.

5 Test equipment

5.1 An inertia dynamometer having the characteristics specified in 5.2 to 5.5 shall be used for the test.

5.2 The dynamometer shall be capable of generating the inertia specified in 6.1 and have the capacity to meet the requirements specified in 1.5, 1.6 and 1.7 of UN-ECE Regulation No. 13-09, Annex 4, with respect to Type-I, Type-II and Type-III tests.

5.3 The brake fitted shall be identical with that of the original vehicle type. Inconsequential changes to the lining configuration are permitted e.g. chamfers, slots, wear indicators, anti-noise devices).

5.4 Air cooling, if provided, shall be in accordance with 6.4.

5.5 The instrumentation for the test shall be capable of providing at least the following data:

a) continuous recording of disc or drum rotational speed;

b) number of revolutions completed during a stop, with a tolerance as described in Annex B;

c) stopping time;

d) continuous recording of the temperature measured at the centre of the path followed by the lining or at mid-thickness of the disc or drum or lining;

e) continuous recording of control line pressure or force during brake application;

f) continuous recording of brake output torque.

6 Test conditions

6.1 The inertia dynamometer shall be set as close as possible, with a tolerance of ± [5] %, to the rotary inertia which corresponds to that part of the total inertia of the vehicle braked by the wheel(s) under consideration, according to the following formula:

$$I = m\,r^2 \qquad (1)$$

where m is that part of the maximum mass of the vehicle braked by the wheel(s) under consideration. This mass shall be calculated from the design braking force distribution for vehicles of categories M and N when deceleration corresponds to the appropriate value given in 2.1 of UN-ECE Regulation No. 13-09, Annex 4. For category O vehicles the value of m is that of the mass acting on the ground for the wheel(s) under consideration, when the vehicle is stationary and loaded to its maximum mass as given in 3.1 of UN-ECE Regulation No. 13-09, Annex 4.

6.2 The initial rotational speed of the inertia dynamometer shall correspond to the vehicle speed as specified in UN-ECE Regulation No. 13-09 Annex 4, and shall be based on the dynamic rolling radius of the tyre.

6.3 Brake linings shall be at least 80 % bedded and shall not have exceeded a temperature of 180 °C during bedding, or alternatively, at the vehicle manufacturer's request, be bedded in accordance with his recommendations.

6.4 Cooling air may be used, directed perpendicularly to the axis of rotation of the wheel. The velocity of the cooling air flowing over the brake shall be

$$v_{\text{air}} = 0{,}33 v_t \qquad (2)$$

where: v_t = vehicle test speed at initiation of braking.

The cooling air shall be at ambient temperature.

6.5 The same dynamometer and equipment shall be used to conduct the tests described in Clause 7.

7 Test method

7.1 General

7.1.1 Five (or less as agreed with the technical service, but at least three) sample sets of the alternative types of brake linings shall be subjected to the comparison test; they shall be compared with the same number of sample sets of the original equipment brake linings conforming to the original components identified in the information document for the first approval of the vehicle.

For category O vehicles, the information document concerning the appropriate axle or brake type approval test shall be used as the basis.

7.1.2 Brake lining equivalence shall be based on comparison of the results achieved using the test methods in this International Standard and in accordance with the requirements of 7.2 to 7.5.

7.2 Type-0 test (cold performance test)

7.2.1 The brake applications shall be made when the initial temperature is between 50 °C and [100] °C measured in accordance with 5.5 d).

7.2.2 Brake applications shall be made from an initial rotational speed equivalent to the specified test speed of the vehicle [see Tables 1 a) and 1 b)]. This test shall consist of at least five stops from the specified speed and use reasonably spaced increments of input to generate a graph of “braking performance” (measured as mean fully developed deceleration, or MFDD) versus “input” (force, line pressure, etc.) for each sample. One measurement shall be at least equal to the specified braking performance [see Tables 1 a) and 1 b)] which will be used as the “Type-0 test reference value”.

Table 1 — Legal requirements

a) for vehicle categories M and N

Vehicle category	**Specified test speed** km/h	**MFDD** m/s^2
M1	80	5,8
M2	60	5,0
M3	60	5,0
N1	80	5,0
N2	60	5,0
N3	60	5,0

b) for vehicle category O

Vehicle type	**Specified test speed** km/h	**Specified braking Performance**	
		Braking rate	**MFDD** m/s^2
O (semi-trailer)	60/40 [a]	0,45	4,4
O (full trailer)	60/40 [a]	0,50	4,9
O (centre axle trailer)	60/40 [a]	0,50	4,9

[a] 40 km/h for cold performance test as comparison for Type-I test.

7.2.3 The MFDD assessed during the cold performance test on the alternative types of brake linings being tested for the purposes of comparison shall be, for the same input, within the test limits ± [15] % of the MFDD assessed with the original equipment brake linings (see 8.2 and Figure 1).

7.3 Type-I test (fade test)

7.3.1 With repeated braking

The correct input shall generate a deceleration within [3] m/s^2 to 3,3 m/s^2 on the first snub of the heating procedure and shall be taken from the graph of “braking performance” versus “input” generated in 7.2.2 (see Figure 2).

7.3.2 Heating procedure with repeated braking (categories M and N)

7.3.2.1 The brake shall be heated by carrying out the following procedure.

7.3.2.2 The brake shall be cold, i.e. the initial temperature shall be between 50 °C and [100] °C (at the beginning of the first snub only) measured in accordance with 5.5 d).

7.3.2.3 The initial rotational speed at the beginning of braking should be v_1, where v_1 = [80] % v_{max}, but without exceeding:

- [120] km/h for categories M1 and N1;
- [100] km/h for category M2;
- [60] km/h for other categories M and N.

7.3.2.4 The input shall be constant and shall generate a deceleration within [3] m/s^2 to 3,3 m/s^2. It should remain constant for subsequent snubs (although possibly generating different deceleration levels).

7.3.2.5 Release the brake when the speed reaches [0,5] v_1.

7.3.2.6 Immediately after releasing the brake the speed, v_1, shall be regained in the shortest possible time, allowing at least [10] s to stabilize this speed before initiating the next braking cycle.

7.3.2.7 The next braking cycle shall be initiated [45] s (category M1), [55] s (category N1, M2) or [60] s (other categories) after initiating the previous braking cycle.

7.3.2.8 Execute a total of [15] braking cycles (categories M1, N1, M2) or [20] braking cycles (categories M3, N2, N3).

7.3.3 Heating procedure with continuous braking (categories O2 and O3)

7.3.3.1 The brake shall be cold, i.e. the initial temperature shall be between 50 °C and [100] °C (at the beginning of the heating procedure) measured in accordance with 5.5 d).

7.3.3.2 The rotational speed shall be equivalent to [40] km/h and kept constant for a period of [153] s (i.e. time elapsed travelling a distance of [1 700] m) with a constant braking torque equivalent to the torque required to keep the vehicle speed constant on a 6 % gradient (i.e. [7] % gradient minus [1] % rolling resistance).

7.3.4 Braking efficiency test with hot brakes (hot braking performance for categories M, N and O)

7.3.4.1 This hot performance test shall be carried out under the same conditions as for the Type-0 test.

7.3.4.2 Immediately after completing the heating procedure, regain the prescribed test speed in the Type-0 test [see Tables 1 a) and 1 b)] in the shortest time possible.

7.3.4.3 Within [60] s after completing the heating procedure, execute one stop with an input corresponding to the specified braking performance [see Tables 1 a) and 1 b)].

7.3.4.4 The average of the MFDDs evaluated during the hot performance test of the alternative types of brake linings tested for the purpose of comparison shall be, for the same input, within ± [15] % of the average of the MFDDs evaluated with the original equipment brake linings (see 8.3).

7.4 Type-II test (downhill behaviour test)

7.4.1 General

7.4.1.1 This test is required only if, on the vehicle type in question, the friction brakes are used for the Type-II test.

7.4.1.2 Brake linings for vehicles of category M3 (except those vehicles required to undergo a Type-IIA test) and category N3 shall be tested according to the method given in 7.4.2 to 7.4.3.4.

7.4.2 Heating procedure for vehicles of categories M3 and N3

The input into the brake shall be equal to that which was used for the basic vehicle test and shall be taken from the homologation test. The corresponding braking torque shall be applied at a constant rotational speed equivalent to a vehicle speed of [30] km/h for a period of [12] min (i.e. time elapsed travelling a distance of [6] km).

7.4.3 Braking efficiency test with hot brakes (hot braking performance for categories M3 and N3)

7.4.3.1 This hot performance test shall be carried out under the same conditions as for the Type-0 test.

7.4.3.2 Immediately after completing the heating procedure, regain the prescribed test speed in the Type-0 test [see Table 1 a)] in the shortest possible time.

7.4.3.3 Within [60] s after completing the heating procedure, execute one stop with an input corresponding to the specified braking performance [see Table 1 a)].

7.4.3.4 The average of the MFDD assessed during the hot performance test of the alternative types of brake linings tested for the purpose of comparison shall be, for the same input, within ± [15] % of the average of the MFDD assessed with the original equipment brake linings (see 8.3).

7.5 Type-III test (fade test)

7.5.1 General

This test is applicable for brake linings/pads for towed vehicles of category O4.

7.5.2 Test with repeated braking

The correct input shall generate a deceleration within [3] m/s^2 to 3,3 m/s^2 on the first snub of the heating procedure and shall be taken from the graph of “braking performance” versus “input” generated in 7.2.2 (see Figure 2).

7.5.3 Heating procedure with repeated braking (category O4)

7.5.3.1 The brake shall be heated by carrying out the following procedure.

7.5.3.2 The brake shall be cold, i.e. the initial temperature shall be between 50 °C and [100] °C (at the beginning of the first snub only) measured in accordance with 5.5 d).

7.5.3.3 The initial rotational speed at the beginning of braking shall be v_1 = [60] km/h.

7.5.3.4 The input shall be constant and shall generate a deceleration within [3] m/s^2 to 3,3 m/s^2. It should remain constant for subsequent snubs (although possibly generating different deceleration levels).

7.5.3.5 Release the brake when the speed reaches [0,5] v_1.

7.5.3.6 Immediately after releasing the brake, the speed v_1 shall be regained in the shortest possible time, allowing at least [10] s to stabilize this speed before initiating the next braking cycle.

7.5.3.7 The next braking cycle shall be initiated [60] s after initiating the previous braking cycle.

7.5.3.8 Execute a total of [20] braking cycles.

7.5.4 Braking efficiency test with hot brakes (hot braking performance)

7.5.4.1 This hot performance test shall be carried out under the same conditions as for the Type-0 test.

7.5.4.2 Immediately after completing the heating procedure, regain the prescribed test speed in the Type-0 test [see Table 1 b)] in the shortest possible time.

7.5.4.3 Within [60] s after completing the heating procedure, execute one stop with an input corresponding to the specified braking performance [see Table 1 b)].

7.5.4.4 The average of the MFDDs evaluated during the hot performance test of the alternative types of brake linings tested for the purpose of comparison shall be, for the same input, within ± [15] % of the average of the MFDDs evaluated with the original equipment brake linings.

8 Assessment of test data and presentation of results

8.1 Legal requirements and evaluation of test results

UN-ECE Regulation No. 13-09 prescribes in Annex 4, paragraphs 1.1.1 and 1.1.2 that the performance of a braking system shall be determined by measuring the stopping distance and/or by measuring the MFDD. That means the MFDD is relevant for the inertia dynamometer test method.

The MFDD shall be calculated as the deceleration averaged with respect to distance over the interval v_b to v_e according to the following formula:

$$d_m = \frac{v_b^2 - v_e^2}{2\left(S_{pe} - S_{pb}\right)} \qquad (3)$$

where:

v_p is the prescribed vehicle speed;

v_b is the vehicle speed at 0,8 v_p;

v_e is the vehicle speed at 0,1 v_p;

S_{pb} is the distance travelled between v_p and v_b;

S_{pe} is the distance travelled between v_p and v_e.

The speed and the distance shall be determined using instrumentation having an accuracy of ± 1 % at the prescribed speed for the test. The MFDD may be determined by other methods than the measurement of speed and distance; in this case, the accuracy of the MFDD shall be within ± 3 %.

Fundamental considerations concerning this accuracy are outlined in Annex B by way of example.

In case v_b, v_e, S_{pb} and S_{pe} are known, Equation (3) must be taken for the evaluation of the test results. Based only on the principle in this equation for d_m, further equations would appear to be unnecessary since v_b and v_e are known as required by the UN-ECE Regulation No. 13-09. Also, measurement of S_{pe} and S_{pb} is quite a simple distance measurement; however, it may be an advantage to have alternative means of evaluation which may improve the accuracy of calculation of d_m and may confirm the correct running of the dynamometer. To this end, further equations are suggested in Annex A.

8.2 Type-0 test

The average MFDD from the results of the different samples shall be calculated for each chosen input (see Tables 2 and 3 and Figure 1). From these MFDD values, trace a straight line in the “MFDD versus Input diagram” (see Figure 1). The graph for the alternative type of brake linings shall be within ± [15] % of the graph obtained for the original equipment brake linings.

Alternatively, for comparison purposes, the value may be chosen such that it is equal to or greater than the specified braking performance [see Table 1 a) or 1 b)] with the same input [see Tables 2 and 3)]. The value for the alternative type of brake linings shall be within ± [15] % of the value obtained for the original brake linings.

8.3 Type-I, Type-II and Type-III test

8.3.1 Vehicles of category M, N and O4

For each sample generate a separate graph of the “MFDD versus Input” from the values given in Tables 2 and 3 (see Figure 2). From these graphs take the correct input for the heating procedures and for executing the stop specified in 7.3.4.3 and 7.4.3.3 or 7.5.4.3.

Calculate the average of the results of the hot performance tests of the original brake linings. Do the same for the alternative type of brake linings (see Table 4 and Figure 3).

The average values from the Type-I and Type-II tests shall be compared with the respective result of the original equipment brake linings and shall be within ± [15] %.

8.3.2 Vehicles of category O2 and O3

8.3.2.1 General

For each sample generate a separate graph of the “MFDD versus input” from the values given in Tables 5 and 6 (see Figure 2). From these graphs take the correct input for the heating procedures and for executing the stop specified in 7.3.4.3 and 7.5.4.3.

Calculate the average of the results of the hot performance tests of the original brake linings. Do the same for the alternative type of brake linings (see Tables 5 and 6 and Figure 3).

The average values from the Type-I and Type-III tests shall be compared with the respective result of the original equipment brake linings and shall be within ± [15] %.

8.3.2.2 Type-0 test (40 km/h), reference values for hot performance

For each sample generate a separate graph from the values shown in Tables 2 and 3 and in the “MFDD versus input” diagram (see Figure 3).

From these graphs take the correct input for executing the stop specified in 7.3.4.3.

Calculate the average of the results of the hot performance tests of the original brake linings. Do the same for the alternative type of brake linings (see Tables 5 and 6).

The average values from the Type-I test shall be compared with the respective result of the original equipment brake linings and shall be within ± [15] %.

8.3.2.3 Hot performance test

For each sample calculate the average MFDD of the original equipment brake linings with hot brakes (column 3 of Table 5). Calculate the limits of ± [15] % for column 3 of Table 5.

With hot brakes the average MFDD of the alternative type of brake linings (column 3 of Table 6) shall be within ± [15] % of that of the original equipment brake linings.

8.4 Example of an assessment

8.4.1 Example of an assessment for vehicles of categories M, N and O4

See Tables 2, 3 and 4 and Figures 1, 2 and 3.

8.4.2 Example of an assessment for vehicles of categories O2 and O3

See Tables 5 and 6 and Figure 3.

9 Inspection of brake linings or pads

Brake linings or pads shall be visually inspected on completion of the above tests to check that they are in satisfactory condition for continued use in normal service.

Table 2 — Results of Type-0 test using original equipment material

Test stop No.	Input	MFDD [m/s²]					
		Column No.					
		1	2	3	4	5	6
		Sample No.					
		1	2	3	4	5	Average for samples 1 to 5
1							
2							
3							
4							
5							

Table 3 — Results of Type-0 test using the alternative material

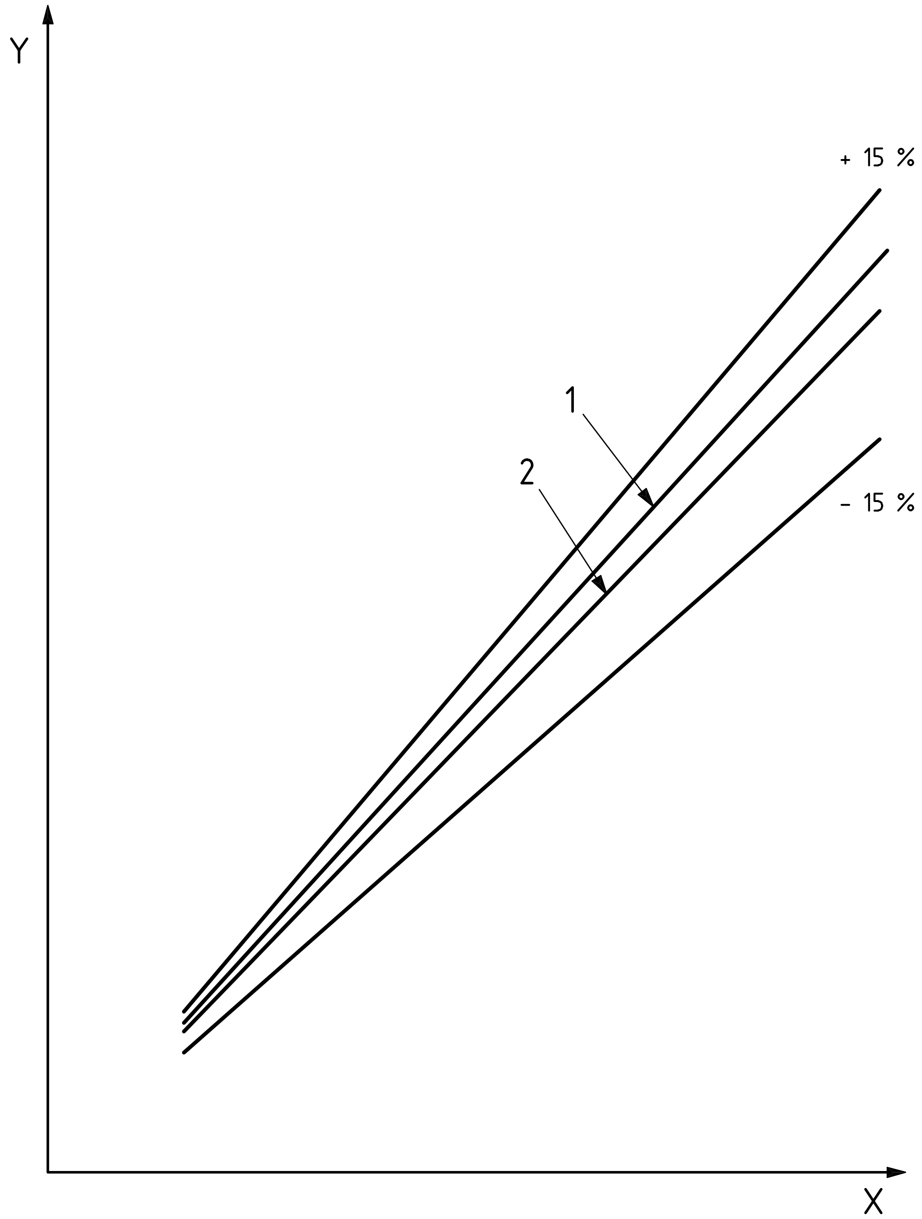
Test stop No.	Input	MFDD [m/s²]					
		Column No.					
		1	2	3	4	5	6
		Sample No.					
		1	2	3	4	5	Average for samples 1 to 5
1							
2							
3							
4							
5							

Table 4 — Results of Type-I, Type-II or Type-III test

Sample No.	Hot performance					
	Original equipment material			Alternative material		
	Reference MFDD [m/s^2]	**Corresponding input**	**MFDD** [m/s^2] **under hot conditions**	**Reference MFDD** [m/s^2]	**Corresponding input**	**MFDD** [m/s^2] **under hot conditions**
1						
2						
3						
4						
5						
Average						

Maximum value (average of original equipment material +15 %): ………………………….

Minimum value (average of original equipment material –15 %): ………………………….



Key

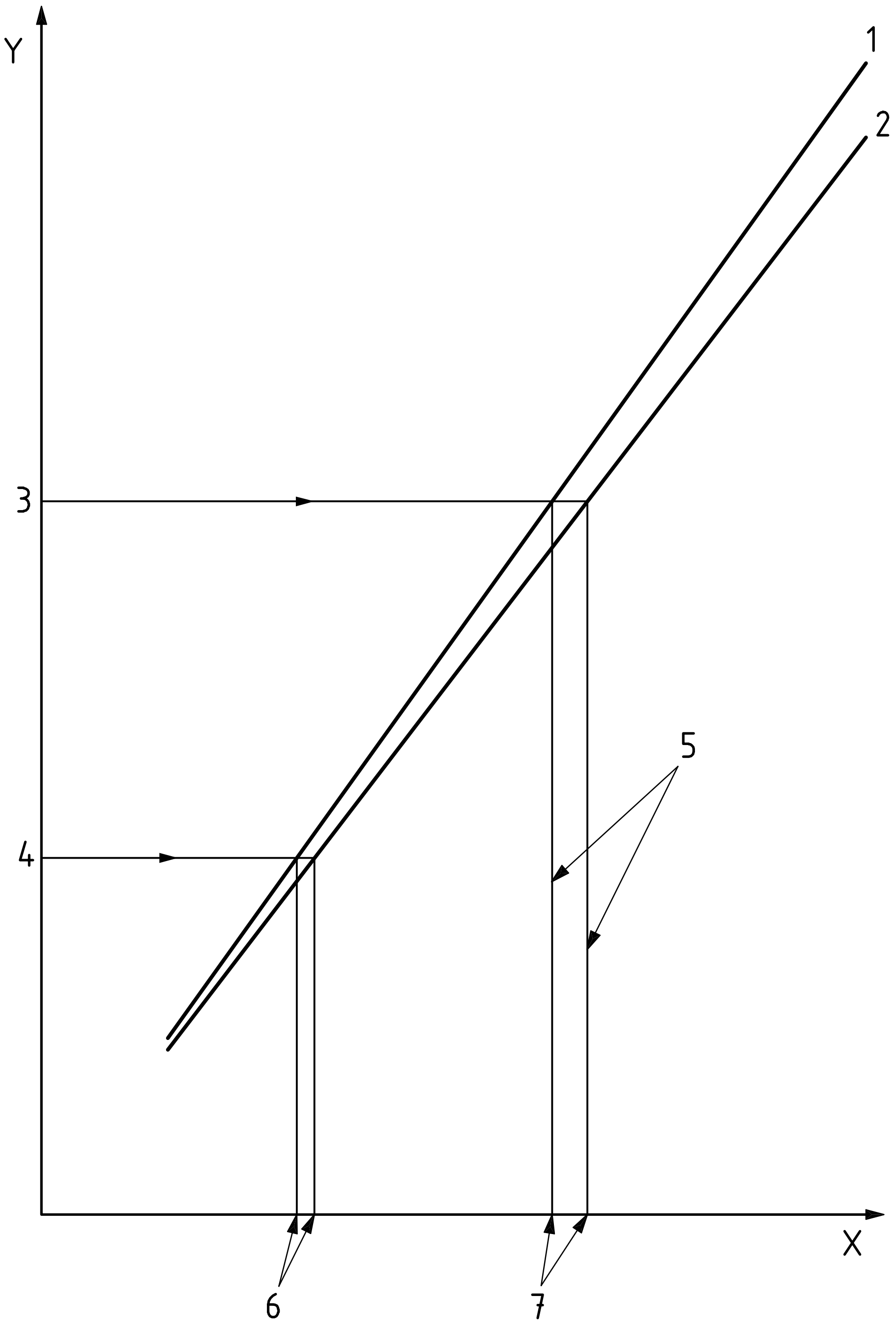
X input

Y braking performance

1 original equipment material

2 alternate material

Figure 1 — Cold performance test: Example of brake performance input diagram for a Type-0 test
(comparison of the results in column 6 in Tables 2 and 3)



Key

X input

Y MFDD (m/s^2)

1 sample 1

2 sample 2

3 required stop MFDD

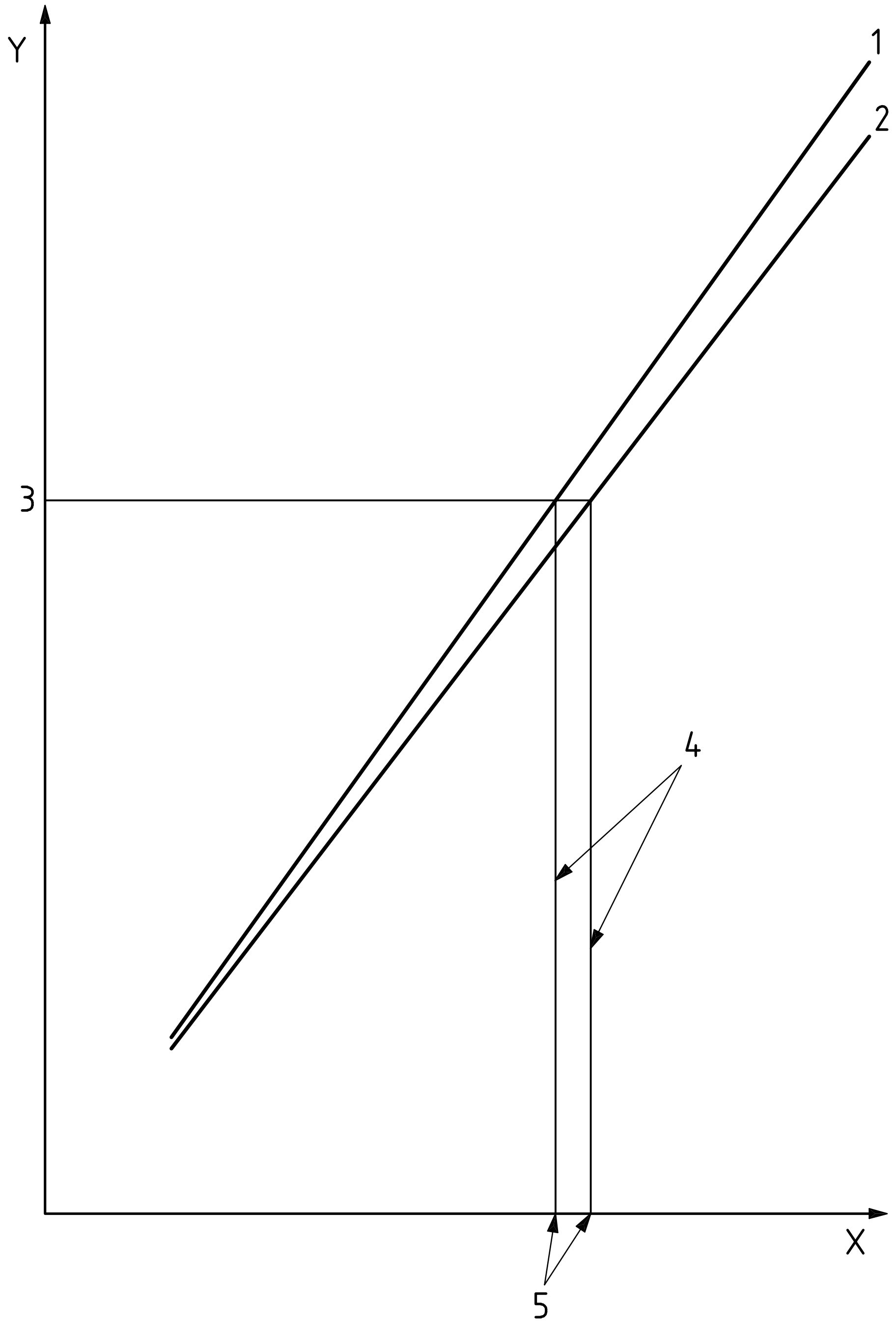
4 required MFDD for the heating procedure

5 results under hot conditions

6 corresponding input for different samples for the heating procedure

7 corresponding input for different samples for the stops

Figure 2 — Hot performance test (Type-I/Type-II/Type-III) using original equipment material



Key

X input

Y MFDD (m/s²)

1 sample 1

2 sample 2

3 required stop MFDD

4 results under hot conditions (see Table 4)

5 corresponding input for different samples for the stops

Figure 3 — Hot performance test (Type-I/Type-II/Type-III) using alternative material

Table 5 — Results of Type-I test using the original equipment material

Sample No.	Type-I, Required braking torque / MFDD for the			
	heating procedure		hot performance	
	Column No.			
	1	2	3	4
	Braking torque [N·m]	Corresponding input	MFDD [m/s^2]	Corresponding input
1				
2				
3				
4				
5				

Average of column 3: .... m/s^2

Maximum value (+15 % of above) .... m/s^2

Minimum value (–15 % of above) .... m/s^2

Table 6 — Results of Type-I test using the alternative material

Sample No.	Type-I, Required braking torque / MFDD for the			
	heating procedure		hot performance	
	Column No.			
	1	2	3	4
	Braking torque [N·m]	Corresponding input	MFDD [m/s^2]	Corresponding input
1				
2				
3				
4				
5				

The average of column 3 shall be within [± 15 %] of the average of column 3 of Table 5.

Annex A
(informative)

Alternative equations for the calculation of the MFDD

A.1 In case the time t_b at the speed v_b, t_e at the speed v_e, t_S at the full stop and the braking torques T_i are known (with the help of equation (B.17, Equations A.1 and A.2) can be used:

$$d_m = \frac{2\int_{t_e}^{t_S} d(t)\,dt \int_{t_b}^{t_e} d(t)\,dt + \left(\int_{t_b}^{t_e} d(t)\,dt\right)^2}{2\left[(t_e - t_b)\int_{t_b}^{t_S} d(t)\,dt - \int_{t_b}^{t_e}\int_{t_b}^{t} d(\tau)\,d\tau\,dt\right]} \quad (A.1)$$

Using the chordal-trapezoidal formula Equation (A.1) can be transformed to Equation (A.2) which allows the numerical determination of d_m:

$$d_m = \frac{2\sum_{i=E}^{S-1}\frac{d_{i+1}+d_i}{2}\,t_d \times \sum_{i=B}^{E-1}\frac{d_{i+1}+d_i}{2}\,t_d + \left(\sum_{i=B}^{E-1}\frac{d_{i+1}+d_i}{2}\,t_d\right)^2}{2\left[(t_e - t_b)\sum_{i=B}^{S-1}\frac{d_{i+1}+d_i}{2}\,t_d - \sum_{i=B}^{E-1}\sum_{j=B}^{i}\frac{d_{j+1}+d_j}{2}\,t_d^2 - \sum_{i=B}^{E-1}\frac{d_{i+1}+d_i}{2}\,t_d^2\right]} \quad (A.2)$$

where the values $i =$ values B, E and S are the pulse count values for the time windows at the times t_b, t_e and t_S.

A.2 Under the assumption that t_e for a full stop braking operation is very close to t_S the Equations (A.1) and (A.2) can be simplified to:

$$d_m = \frac{\left(\int_{t_b}^{t_e} d(t)\,dt\right)^2}{2\left[(t_e - t_b)\int_{t_b}^{t_e} d(t)\,dt - \int_{t_b}^{t_e}\int_{t_b}^{t} d(\tau)\,d\tau\,dt\right]} \quad (A.3)$$

$$d_m = \frac{\frac{1}{2}\left(\sum_{i=B}^{E-1}\frac{d_{i+1}+d_i}{2}\right)^2}{(t_e - t_b)\sum_{i=B}^{E-1}\frac{d_{i+1}+d_i}{2}\,t_d - \sum_{i=B}^{E-1}\sum_{j=B}^{i}\frac{d_{j+1}+d_j}{2}\,t_d^2 - \sum_{i=B}^{E-1}\frac{d_{i+1}+d_i}{4}\,t_d^2} \quad (A.4)$$

This approximation has an advantage in that braking down to actual standstill is not required. This can avoid the jarring stress on the dynamometer bearings which is caused by the torque impulse which often occurs at the final cessation of movement. Equations (A.5) and (A.6) also offer this advantage but do not incur any loss of accuracy such as is the case with Equation (A.3) and (A.4).

A.3 In case v_b, t_b, t_e and T_i are known, Equations (A.5) or (A.6) can also be used:

$$d_m = \frac{v_b \int_{t_b}^{t_e} d(t)dt - \frac{1}{2}\left(\int_{t_b}^{t_e} d(t)dt\right)^2}{(t_e - t_b)v_b - \int_{t_b}^{t_e}\int_{t_b}^{t} d(\tau)d\tau dt} \qquad \text{(A.5)}$$

$$d_m = \frac{v_b \sum_{i=B}^{E-1} \frac{d_{i+1}+d_i}{2} t_d - \frac{1}{2}\left(\sum_{i=B}^{E-1} \frac{d_{i+1}+d_i}{2} t_d\right)^2}{(t_e - t_b)v_b - \sum_{i=B}^{E-1}\sum_{j=B}^{i} \frac{d_{j+1}+d_j}{2} t_d^2 - \sum_{i=B}^{E-1} \frac{d_{i+1}+d_i}{4} t_d^2} \qquad \text{(A.6)}$$

The chosen formula shall be used for the assessment of the results of the complete comparison test.

Annex B
(informative)

Accuracy considerations

Since the accuracy requirements significantly determine the design of the inertia dynamometers, this influence shall be more precisely explained depending on the chosen measurement strategies. Such strategies could be based for example on the measurement of the stopping distances and speeds by means of analogous or digital generators connected with the shaft of the dynamometers. Digital registrations speeds shall be determined

— by the preselection of the time increments, in which the digital signals indicating the accompanying way are counted, or

— by the preselection of the digital signals, for which the necessary time must be detected.

It will not be possible to offer accuracy analyses for all conceivable measurement strategies. Bearing in mind that even one example can indicate the universally valid rules for the general set-up of the dynamometers by the accuracy requirements, this annex is limited to the preselected time increments and the corresponding digital signals for the ways.

For this purpose, the consecutive index i shall characterize all events which can be consecutively allocated to a time window with a given duration t_d. In this sense, S_i is the distance travelled during the i^th time window, v_i the mean speed and d_i the mean deceleration both within that time window.

The revolutions of the inertia dynamometer usually are counted by a pulse generator connected to the dynamometer shaft. The number of pulses for one full revolution may be identified by w and the registered pulses within the i^th time window by n_i. Since the necessary pulse-rates w may vary for the different evaluation purposes, we introduce the pulse-rate w_S for the measurement of the stopping distances, w_v for the speeds and w_d for the decelerations. Now we can say:

$$\sum s_i = 2\pi r \frac{\sum n_i}{w_\mathrm{S}} \tag{B.1}$$

$$v_i = 2\pi r \frac{n_i}{w_\mathrm{v} t_\mathrm{d}} \tag{B.2}$$

$$d_i = 2\pi r \frac{n_i - n_{i-1}}{w_\mathrm{d} t_\mathrm{d}^2} \tag{B.3}$$

With respect to the accuracy requirements ($f_\mathrm{S} = 0{,}01$ shall be assigned here to the accuracy of the stopping distance, $f_\mathrm{v} = 0{,}01$ to the speed and $f_\mathrm{d} = 0{,}03$ to the deceleration) the conditions shall be checked (the symbol Δ shall characterize always the permissible deviations of the relevant physical quantity):

$$\frac{\sum \Delta s_i}{\sum s_i} = \frac{\sum \Delta n_i}{\sum n_i} \leqslant f_\mathrm{S} \left(= 0{,}01\right) \tag{B.4}$$

$$\frac{\Delta v_i}{v_i} = \frac{\Delta n_i}{n_i} \leqslant f_\mathrm{v} \left(= 0{,}01\right) \tag{B.5}$$

$$\frac{\Delta d_i}{d_i} = \frac{\Delta n_i}{n_i - n_{i-1}} \leqslant f_\mathrm{d} \left(= 0{,}03\right) \tag{B.6}$$

(B.1) and (B.4) together result in:

$$w_{\mathrm{S}} \geqslant 2\pi\, r \, \frac{\sum \Delta n_i}{\sum s_i \cdot f_{\mathrm{S}}} \tag{B.7}$$

(B.3) and (B.6) together result in:

$$w_v \geqslant 2\pi\, r \, \frac{\Delta n_i}{v_i t_{\mathrm{d}} f_{\mathrm{v}}} \tag{B.8}$$

(B.2) and (B.5) together result in:

$$w_d \geqslant 2\pi\, r \frac{\Delta n_i}{d_i t_{\mathrm{d}}^2 f_{\mathrm{d}}} \tag{B.9}$$

In addition the conditions for the duration t_{d} of the time window shall be considered in order to fulfil the required accuracy of f_{d}. To simplify our considerations, the following values shall be introduced:

— $v_{\mathrm{b}} = 0{,}8\ \mathrm{v}_{\mathrm{p}}$

— $\mathrm{v}_{\mathrm{e}} = 0{,}1\ \mathrm{v}_{\mathrm{p}}$

— $s_{\mathrm{d}} = s_{\mathrm{pe}} - s_{\mathrm{pb}}$

directly in Equation (3) and receive:

$$d_{\mathrm{m}} = 0{,}315 \, \frac{v_{\mathrm{p}}^2}{S_{\mathrm{d}}} \tag{B.10}$$

With respect to the error propagation law:

$$\frac{\Delta d_{\mathrm{m}}}{d_{\mathrm{m}}} = \frac{1}{d_{\mathrm{m}}} \sqrt{\left(\frac{\delta d_{\mathrm{m}}}{\delta v_{\mathrm{p}}} \, \Delta v_{\mathrm{p}} \right)^2 + \left(\frac{\delta d_{\mathrm{m}}}{\delta S_{\mathrm{d}}} \Delta S_{\mathrm{d}} \right)^2} \tag{B.11}$$

or

$$\frac{\Delta d_{\mathrm{m}}}{d_{\mathrm{m}}} = \sqrt{\left(2 \frac{\Delta v_{\mathrm{p}}}{v_{\mathrm{p}}} \right)^2 + \left(\frac{\Delta S_{\mathrm{d}}}{S_{\mathrm{d}}} \right)^2} \tag{B.12}$$

Introducing $\frac{\Delta d_{\mathrm{m}}}{d_{\mathrm{m}}} \leqslant f_{\mathrm{d}}$ one gets from (B.12):

$$\sqrt{\left(2 \frac{\Delta v_{\mathrm{p}}}{v_{\mathrm{p}}} \right)^2 + \left(\frac{\Delta S_{\mathrm{d}}}{S_{\mathrm{d}}} \right)^2} \leqslant f_{\mathrm{d}} \tag{B.13}$$

The time window t_{d} shall be chosen in such a way that the relation (B.13) can be fulfilled. The decelerations d_i are fully effective at the decisive measuring points in Equation (3), that is $v_{\mathrm{b}} = 0{,}8\ v_{\mathrm{p}}$ and $v_{\mathrm{e}} = 0{,}1\ v_{\mathrm{p}}$, and therefore the time window t_{d} shall be so narrow that the speed change Δv_{p} within this window does not injure the condition (B.13). To verify this requirement, we introduce in (B.13) the relation:

$$\Delta v_{\mathrm{p}} = d_i \ t_{\mathrm{d}} \tag{B.14}$$

(B.14) is analogous to the definitions of the acceleration or the deceleration, $a = \frac{d_{\text{v}}}{d_{\text{t}}}$, in which one gets:

$$\sqrt{\left(2\frac{d_i\, t_{\text{d}}}{v_{\text{p}}}\right)^2 + \left(\frac{\Delta S_{\text{d}}}{S_{\text{d}}}\right)^2} \leqslant f_{\text{d}} \tag{B.15}$$

or

$$t_{\text{d}} \leqslant \frac{v_{\text{p}}}{2\,d_i}\sqrt{f_{\text{d}}^2 - \left(\frac{\Delta S_{\text{d}}}{S_{\text{d}}}\right)^2} \tag{B.16}$$

To get an impression of the influence of the accuracy, the following values are used for the calculations:

— $\sum \Delta n_i$ in respect to $\Delta n_i = 1$ (the smallest possible digit differing from zero)

— $\sum S_i = 40$ [m];

— $\frac{\Delta S_{\text{d}}}{S_{\text{d}}} = f_{\text{S}} = 0{,}01$.

The following table is set up on the basis of these values:

r [m]	v_{i} w/respect to v_{p} [km/h]	d_{i} [m/s^2]	$t_{\text{d}} \leqslant$ [s]	$w_{\text{S}} \geqslant$ [pulses/rev.]	$w_{\text{v}} \geqslant$ [pulses/rev.]	$w_{\text{d}} \geqslant$ [pulses/rev.]
0,3	60	4	0,058 9	4,7	192	452 8
0,3	60	8	0,029 5	4,7	383	902 5
0,3	80	4	0,078 6	4,7	108	254 3
0,3	80	8	0,039 3	4,7	216	508 5
0,6	60	4	0,058 9	9,4	384	905 6
0,6	60	8	0,029 5	9,4	767	180 50
0,6	80	4	0,078 6	9,4	216	508 5
0,6	80	8	0,039 3	9,4	432	101 70

The pulse-rates for w_{S} can be fulfilled by every inertia dynamometer. Modern inertia dynamometers should be able to keep to the results for w_{v}.

It is unlikely, however, that existing dynamometers could fulfil the results for w_{d} and it is impossible to calculate the MFDD directly on the basis of the values for d_{i} which derive from the measurements of existing pulse generators. Only indirectly by the measurement of the braking torques T_i we can derive the decelerations d_i on the basis of the formula:

$$d_i = \frac{T_i}{rm} \tag{B.17}$$

where m = part of the maximum vehicle mass braked by the wheel under consideration. In addition, all decelerations shall be inserted as positive values in the relevant equations here.

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