TECHNICAL REPORT 8349

Published 1986-11-01

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION • МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ • ORGANISATION INTERNATIONALE DE NORMALISATION

Road vehicles — Measurement of road surface friction

Véhicules routiers — Mesure du coefficient d'adhérence

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ISO/TR 8349 was prepared by Technical Committee ISO/TC 22, *Road vehicles* with ISO/TC 31, *Tyres* and the PIARC technical committee on road surface characteristics.

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.

Contents

UDC 629.13 : 625.032.32 **Ref. No. ISO/TR 8349-1986 (E)**

Descriptors: road vehicles, roads, tests, friction tests, determination, friction factor, test equipment.

Printed in Switzerland

Price based on 13 pages

ISO/TR 8349-1986 (E)

0 Introduction

0.1 Historical background

During its work to establish vehicle handling test methods, sub-committee ISO/TC 22/SC 9, *Vehicle dynamics and road-holding ability* found a need to establish a method of evaluating the friction characteristics of a test surface for handling tests related more to peak friction than to the widely-used ASTM locked-wheel procedure.

The reason for this is that peak lateral and longitudinal friction determines the limits of handling and braking performance. Furthermore, research has shown that there is no general correlation between these properties and locked-wheel friction.

It was also considered desirable to establish a standardized test surface for high-friction tests and perhaps later also for low-friction tests : the work started with a "state of the art" survey.

The subject turned out to be very complicated, due to different philosophies concerning the use of the method and also a reluctance to favour any existing specific equipment or test tyre.

After an initial effort to establish a full method of characterizing the longitudinal and lateral force transmission between tyre and road surface, it was decided to leave this as a working document and continue with a simplified method.

The method chosen uses equipment with a test tyre running at constant slip or constant slip angle, because it allows the friction to be monitored easily along the whole test section, in contrast to peak measuring methods that only measure a very little part of the track at a time. There is equipment on which the slip and slip angle can be continuously controlled to find the peak values and hold them constant, but it was regarded as too expensive for a routine check device.

The reason for including both longitudinal and lateral friction coefficients is that certain test tracks may have different longitudinal and lateral characteristics due to grooving, or other surfaces with directional effects.

Regarding the cost and ease of operation of the equipment, the experience from aircraft runway friction evaluation shows that small and handy devices, which can be towed by a passenger car or are integrated in such a vehicle, are preferred. These devices have small test wheels and are test-specific. In connection with tyre and vehicle testing, there is also a need for evaluation of the tyre-to-road force transmission characteristics of tyres other than the special standardized reference test tyres. In this case the equipment should accommodate all passenger car tyre sizes if the interest is restricted to passenger cars. Equipment capable of handling truck tyres will be substantially larger and more expensive; it is not covered by this Technical Report.

A major question is what the coefficient of friction evaluated from the machine represents and how it can be used. In simple terms, the standardized reference tyre together with the test device is a reference test vehicle performing closely controlled braking and/or cornering continuously at constant or varying speed.

With a well-chosen reference test tyre, the coefficient of friction evaluated on a particular surface can be used as a non-dimensional reference performance level.

Since two surfaces with the same reference tyre coefficient of friction are not necessarily identical, they will give different values with another reference tyre that is sensitive to the difference.

Results from vehicle tests made on one test track can therefore not be compared absolutely based only on the reference tyre coefficient of friction measured on the two tracks. This is particularly evident on water-covered surfaces.

0.2 Reasons for publication of a Technical Report

The reasons for publishing the test methods for measurement of road surface friction as a Technical Report type 2 are the following.

There is a desire to establish a single measurement device with one type of reference tyre and further efforts should be made in order to avoid having four standards rather than one serving the same purpose. In this connection the question of how to specify test equipment and test tyre should be studied further.

Experience in using the method in connection with vehicle handling tests is, however, very limited and the validity of using the friction coefficients that are obtained as a measure of comparability of vehicle test results should be counter-checked carefully for the specific type of vehicle test by a large number of tests.

In certain cases it is of interest to consider what percentage of a theoretical maximum available tyre-to-road friction can be used. In this case, the tyres of the vehicle actually tested should be used instead of a reference tyre. This type of friction evaluation is required in the ECE regulation for antilock devices; it can therefore be considered an additional method, as it makes it possible to a large extent to separate tyre performance from the performance of the rest of the vehicle.

The addition of 100 % longitudinal slip has been suggested — the reason being that it is widely used as a measurement of road surface friction. The "optimum" constant slip and side slip angle method was established since the 100 % slip method did not reflect the friction properties relevant to handling tests.

Braking tests with vehicles equipped with antilock brake systems may, however, be taken up in future SC 9 work. In this case the result can be significantly influenced also by the locked wheel friction. The addition of this value to the other two can also be said to improve surface identification. The draw-back is a more complicated and time-consuming procedure. Furthermore, the problem of tyre wear is considerable with locked-wheel measurements on dry surfaces.

1 Scope and field of application

This Technical Report specifies a method of measuring the characteristic longitudinal and lateral friction force values with specified reference tyres. The method is suitable for a simplified evaluation of the friction properties of a test track surface.

This method uses measurements representing the steady state or quasi-steady state friction force on a test wheel operated at constant load either at a constant longitudinal reference slip or at a constant reference side-slip angle. The reference slip and slip angle are so chosen that, for the specified reference tyres, the friction coefficients obtained will be near the true peak values.

The values measured are intended to form reference numbers indicating certain friction properties of test tracks.

NOTE — The values measured by this method represent frictional data obtained with the equipment and procedures stated herein and do not necessarily agree or correlate directly with those obtained by other friction measurement methods.

The method has, in all essential parts, been used by road research institutes and road authorities and also by airport authorities for evaluating friction properties of roads and airport runways for more than 20 years.

Annexes A to C are integral parts of this Technical Report which, for reasons of convenience, are placed after the main text.

2 Principle

Driving an automotive vehicle or a suitable trailer towed by a vehicle, either of which have one or more test wheels fitted, with apparatus containing transducers, instrumentation, actuation controls, a water supply and its distribution system. The test wheel is equipped with a reference tyre (see 3.2).

The test apparatus is brought to the desired test speed along the desired test path. If applicable, water may be sprayed ahead of the reference tyre. The test wheel is brought to test condition by means of the actuation system. The resulting longitudinal and lateral friction force acting between the reference tyre and the pavement surface (or some other quantity that is directly related to this force), the speed of the test vehicle, the longitudinal slip, and side-slip angle (and lateral and longitudinal acceleration, if these influence measurements and must be corrected for) are recorded with the aid of suitable instrumentation. The test is made at least at two speeds.

The longitudinal and lateral force coefficients (see 7.1 and 7.2) of the paved surface are determined from the resulting recorded data and interpolated within the speed tolerance indicated in 6.1, to a reference speed for the vehicle test which is performed on the track. In addition to this, a speed gradient based on the highest and lowest speed is established.

3 Apparatus

3.1 Vehicle, capable of measuring longitudinal and/or lateral friction forces operating at the longitudinal slip and/or side-slip angles which define the longitudinal and/or lateral force coefficient using a reference tyre according to annex A. The test equipment shall meet the requirements given in annex B.

3.2 Tyre and rim, both meeting the requirements specified in annex A.

3.3 Instrumentation, meeting the requirements given in annex B.

3.4 Signal conditioning and recorder system, meeting the requirements given in annex B.

3.5 Pavement wetting system, as specified in annex B.

3.6 Wheel load : (See annex A.)

4 Calibration

In accordance with annex B and, where applicable, the manufacturer's instructions, calibration of speed, longitudinal slip and force, side-slip angle and lateral force, longitudinal and lateral acceleration, wheel load and water supply shall be made.

5 Test conditions

5.1 Tyres

Reference tyres shall conform to the requirements of annex A regarding use and operational requirements.

5.2 Test sections

Test sections shall basically coincide with the path followed by the vehicles tested on the track. The friction test wheel shall then follow the average wheel paths of the test vehicles in the test.

If vehicle tests are to be carried out on different parts of the test surface, then separate friction measurements shall be carried out on all parts which can be regarded as separate tracks from a friction point of view.

The length of the test section shall, if possible, be the same as that of the track section used for the vehicle test. However, in some cases it may not be possible to maintain the desired test speed throughout the track length used for the vehicle test. In these cases, shorter test sections may be used. The test sections shall, however, be representative and allow measurements for at least 20 m and at least 1 s.

The test section shall be in the same condition as that for which the friction values will serve as the reference.

5.3 Ambient conditions

Ambient conditions such as track surface temperature, air temperature and air humidity shall be within the limits specified for the vehicle test, or the following specifications :

- track surface temperature : 5 to 40 °C;
- air temperature : 5 to 40 °C;
- air humidity : up to 90 % (if the test is performed on a dry surface).

Measurements shall be made according to annex C.

6 Test procedure

Check the test wheel load (if adjustable) and adjust, if necessary, prior to each test to within the value specified in annex A. Set the reference tyre cold inflation pressure specified in annex A just before the warm-up as follows.

Prior to each series of tests, condition the tyre tread surface by travelling for at least 15 s at a speed of 60 km/h and specified conditions for measurement.

After each test, inspect the tyre for damage or other irregularities that could affect the test results; replace the tyre if it is damaged or worn below the wear limit specified in annex A.

6.1 Test speeds

Measurement shall always be made at 20 km/h and at one higher reference speed — which shall be 65 km/h, if the track so permits without exceeding a lateral acceleration of 3 m/s^2. If, for this or other reasons, a lower speed must be used, this should be as high as possible. If the test can be performed at a speed higher than 65 km/h and friction measurements taken at this speed without exceeding a lateral acceleration of 3 m/s^2, it is recommended that such a measurement also be included.

The following reference speeds may be used :

25, 35, 45, 55, 65, 75, 85, 95, 105, 115, etc., km/h

The measured speed shall be within ± 1 km/h of the nominal value.

6.2 Longitudinal force coefficient measurement

6.2.1 Bring the apparatus to the desired speed.

6.2.2 Record appropriate calibration signals.

6.2.3 Locate the vehicle laterally so that the reference tyre runs as far as possible over the left wheel path of the test course.

6.2.4 Start water delivery, if applicable.

6.2.5 Apply longitudinal slip and wheel load running at zero side-slip angle, so that test conditions are reached 3 to 5 s or at least 30 m before the test section.

6.2.6 Start recording at least 1 s before the entry into the test section. Record longitudinal force and, if applicable, wheel load and for control purposes, lateral force, lateral acceleration and forward speed, test section entry and end, and ambient conditions.

6.2.7 Repeat calibration procedure immediately after the end of the run.

6.2.8 Lift the test tyre or return to free rolling state.

6.2.9 Repeat the procedure with the reference tyre running as far as possible on the right wheel path of the test course.

6.3 Lateral force coefficient measurement

6.3.1 Repeat the procedure for left and right wheel path as in 6.2 but with slip angle and free rolling wheel. In these runs the lateral force and wheel load are the main parameters : longitudinal force measurement is not made.

6.3.2 This test is ended by lifting the reference tyre or returning to zero slip angle.

7 Data analysis

7.1 Longitudinal force coefficient, μ_x

Check that

- lateral tyre force does not exceed 20 % of the longitudinal force;
- temperatures are within limits;
- forward speed is within limits.

Average the longitudinal force and the normal force (if measured) between markings for entry and exit of the test section for both runs (left and right wheel path) and use the mean values for calculating the longitudinal force coefficient.

7.2 Lateral force coefficient, μ_y

Check that

- temperatures are within limits;
- forward speed is within limits.

Correct the lateral force data for the influence of lateral acceleration (if it exists).

Average the lateral force and the wheel load (if measured) data within the test section for the two test runs and use the mean values for calculating the lateral force coefficient.

7.3 Wheel load

If the wheel load is not measured, corrections for the influence of traction forces and lateral acceleration (if any) shall be made according to the manufacturer's specifications or computed by analysis of the statics and kinematics of the test vehicle.

For instrumentation systems that incorporate automatic dynamic calculation of the force coefficient, the horizontal tractive force is automatically divided by the vertical load in real time. The resultant force coefficient (longitudinal or lateral) is recorded in real time μ (see figure 1). Automatic averaging for the test sections over time may also be performed.

7.4 Speed gradients

With reasonable accuracy, speed dependence of friction may be written as

$$\mu = A e^{-Bv}$$

where A and B are constants connected to pavement texture, tyre characteristics, etc.

Thus friction measurements at the two speeds on a test section make it possible to estimate force coefficient and friction/speed gradient at an arbitrary speed. A relatively simple computer program may be used for this purpose. However, it is also quite simple to estimate force coefficient and gradient manually by plotting μ on a logarithm scale against v (see figure 1).

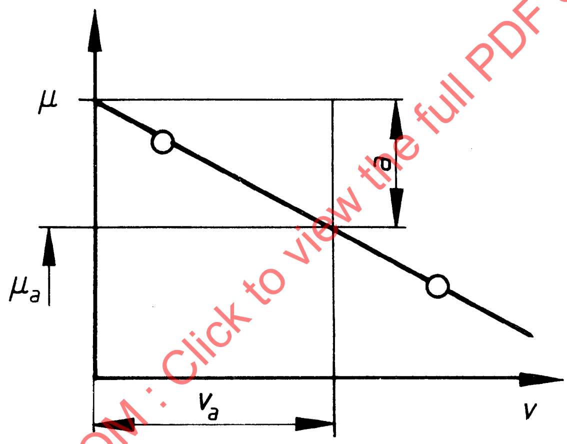

Figure 1

μ can be directly read in the graph, and the gradient calculated by

$$\frac{d\mu}{dv} = \frac{a}{v_a}\mu_a$$

8 Reports

8.1 Field report

The field report for each section shall contain the following items :

a) location and identification of test section;

b) date and time of day;

c) ambient conditions (principally road surface temperature, air temperature);

d) speed of test vehicle (for each test);

e) lateral and longitudinal force coefficient (for each test);

f) data recording containing forces or force coefficient and lateral acceleration in real time;

g) wet or dry surface measurement;

h) test tyre specification;

i) calibrated static wheel load.

8.2 Summary report

The summary report shall include, for each test section, the following items :

a) location and identification of test section;

b) slope and angle of test section;

c) if the surface is one specified in an International Standard, refer to it. If the test surface is not standard, specify mix of surface course, aggregate type (specific source, if available);

d) age of pavement and number of test runs made on it;

e) date and time of day;

f) ambient conditions (road surface temperature, air temperature, air humidity);

g) average longitudinal force coefficient for the two wheel paths of the test section at the speeds used in the test;

h) average lateral force coefficient for the two wheel paths of the test section at the speeds used in the test;

i) speed gradient for the longitudinal force coefficient calculated from the values at 20 and 65 km/h (or, if this is not reached, the highest test speed);

j) speed gradient for the lateral force coefficient calculated from the values at 20 and 65 km/h (or, if this is not reached, the highest test speed);

k) reference tyre specification;

l) reference speed.

Annex A

Reference tyre specifications

A.1 Reference tyres

One of the following reference tyres shall be used :

G 78-15: ASTM tyre, specifications are given in ASTM (American Society for Testing and Materials, USA) standard E 501.

165-15: PIARC Europe tyre, specifications can be obtained from PIARC (PIARC Committee of Road Surface Characteristics, France).

3.00-20: SCRIM tyre, specifications can be obtained from TRRL (Transport and Road Research Laboratory, United Kingdom).

4.00-8: VTI tyre, specifications can be obtained from VTI (National Swedish Road and Traffic Research Institute, Sweden).

A.2 Material and manufacture

The individual tyre shall meet the pertinent requirements for the material.

Fabric processing and all steps in tyre manufacturing shall be certified to ensure that the specifications are met.

After the manufacturing process, the tyres shall be cleaned and checked for uniformity as specified in clause A.3.

A.3 Uniformity

Tyres shall be without defects, produced according to the latest techniques.

Static imbalance shall not exceed 0,5 % of half the product of tyre mass and overall diameter.

No balance medium of any type may be added to any tyre to correct static balance after the final cure.

A.4 Tyre use and operational requirements

The tyre is intended for measuring purposes only; it is not designed for general use.

Tyre break-in of 300 km minimum shall be made on new tyres before using them for testing. During the break-in, harsh tyre use such as emergency braking and hard cornering should be avoided.

The tyre shall be operated with a test load and inflation pressure as shown in table 1.

When abnormal wear or damage results from testing or when the remaining groove depth in any groove is 6 mm or less, use as a test tyre shall be discontinued.

The age of the test tyre shall not exceed 2 years from the production date.

A.5 Preservation

The tyres shall be kept dry under ordinary atmospheric conditions, in subdued light, at an ambient temperature up to 20 °C.

The tyres shall be stacked vertically in a single row. Cradle-shaped storage supports are recommended.

Table 1 — Test load, test inflation pressure and test rim

Reference tyre	Test load N	Test inflation pressure kPa	Test rim
4.00-8	1 000 ± 100	140	8 × 2.50 C
165-15	2 250 ± 250	160	15 × 4.50 J
G 78-15	5 000 ± 500	165	15 × 6 JJ
3.00-20	2 250 ± 250	350	TRRL-SCRIM

Annex B

Test equipment

B.1 Introduction

This annex gives the basic requirements of the friction measuring device.

It would be desirable to specify the design of the friction device in great detail: however, there are already several measuring devices of different design but capable of measuring one or both of the desired friction quantities using one of the reference tyres specified in annex A at the test load, longitudinal slip or slip angle. In order to enable these existing devices to be used, in some cases with minor modifications, the specifications given in this annex are restricted to performance data rather than design data.

B.2 Technical specifications

The test unit shall be capable of measuring longitudinal and/or lateral friction forces operating at the longitudinal slip and/or side-slip angles which define the longitudinal and/or lateral force coefficient using a reference tyre according to annex A.

The measuring apparatus shall, where applicable, conform to the requirements given in table 2 at ambient temperatures that can be expected during measurements. The recommended temperature range is − 20 °C to + 40 °C. The equipment can then also be used on ice tracks under winter conditions.

Table 2 — Performance requirements of friction test apparatus

Parameter	Unit	Alternative reference tyres			
		G 78-15 ASTM	165-15 PIARC	3.00-20 SCRIM	4.00-8 VTI
Longitudinal slip:					
Mean value	%	15 ± 1	15 ± 1	15 ± 1	15 ± 1
Permitted range	% slip	± 3	± 3	±3	± 3
Side-slip angle:					
Mean value	degree	15 ± 1	15 ± 1	20 ± 1	15 ± 1
Vertical wheel load range	N	5 000 ± 500	2 250 ± 250	2 250 ± 250	1 000 ± 100
Max. error in load value used for friction force calculation[1)]	%	1	1	1	1
Longitudinal and/or lateral force measuring range	N	0 to 6 000	0 to 3 000	0 to 3 000	0 to 1 200
Max. combined transducer/recorder error	%	1.5	1.5	1.5	1.5
Min. bandwidth of transducer/recorder system[2)]	Hz	10^{-3} to 8	10^{-3} to 8	10^{-3} to 8	10^{-3} to 8
Measuring speed	km/h	20 to 135	20 to 135	20 to 135	20 to 135
Max. error of speed record	km/h	± 1	± 1	± 1	± 1

1) Within the whole range of longitudinal or lateral forces.

2) Flat within 1 %.

B.2.1 Wheel load system

Specific suspension requirements in terms of natural frequencies and damping factors have been avoided. The reason for this is that, from current experience, these properties are not critical for handling and braking tests on smooth, even road surfaces like test tracks. However, in general a high natural frequency and efficient damping are recommended. The most commonly used test equipment has a sprung/unsprung weight ratio higher than 2 : 1.

Great care should also be taken that the static calibration is valid for the dynamic test condition.

B.2.2 Force and/or torque transducers

These are recommended to provide an output directly proportional to the force or torque with a hysteresis of less than 1 % of the applied load, non-linearity of less than 1 % of the applied load up to maximum expected loading, and sensitivity to any cross-axis loading of less than 1 % of the applied load.

B.2.3 Signal conditioning and recorder system

All signal conditioning and recording equipment shall provide linear output and shall allow data reading resolution to meet the requirements given in table 2.

All strain gauge transducers shall be equipped with resistance shunt calibration resistors or equivalent that can be connected before and after test sequences. The calibration signal shall be at least 50 % of the normal vertical load and shall be recorded.

Tyre friction force or torque and any additional desired inputs, such as vertical load, wheel speed, etc. shall be recorded in phase (± 5°) over a bandwidth of 10^{-3} to 8 Hz.

Vehicle speed shall also be recorded. All signals shall be referenced to a common time base. A signal to electrical noise ratio of at least 20 : 1 is desirable.

B.2.4 Static calibration of wheel load and longitudinal or lateral force

Under conditions which simulate real steady-state conditions, measuring shall be carried out by means of a friction test wheel support placed on a vertical load transducer. The wheel support is recommended to be of air cushion type, but a ball-bearing type is adequate. The contact area of the supported reference tyre shall be in the same plane as the rest of the wheels of the test vehicle, when longitudinal or lateral forces are applied to the support. This type of calibration shall be made at least once a year. Daily calibrations may be restricted to simple force or torque transducer checking. The maximum error of the calibration instrumentation shall be less than 0,5 %.

B.2.5 Pavement wetting system

The water being applied to the pavement ahead of the reference tyre shall be supplied by a nozzle, suitably designed to ensure that the water layer encountered by the reference tyre has a uniform cross-section at all test speeds, with minimum splash and over-spray. The height of this cross-section shall be 0,55 ± 0,05 mm. The water layer shall be at least 25 mm wider than the reference tyre tread and applied so that the tyre is centrally located between the edges. The volume of water per millimetre of wetted width shall be directly proportional to the test speed.

Water used for testing shall be reasonably clean and have no chemicals such as wetting agents or detergents added. Drinking water is acceptable.

Annex C

Measurement of ambient conditions

C.1 Purpose

Annex C describes suitable methods for measuring temperature and humidity data relevant to friction measurement.

C.2 General

Tyre/road friction is affected by the temperature of the tyre/road interface and of the humidity content of this interface.

The ambient air temperature in combination with well-defined pre-test tyre conditioning is a rough, indirect measure of the tyre/road interface temperature.

It is recommended, however, that road surface temperature and tyre tread temperature be measured with sensors installed in the test vehicle.

A significant drop in friction can occur on some surfaces for very small amounts of water. When dry surface measurements are required and the wet surface has to dry under the influence of the sun, it may be difficult to see whether the surface is dry. A surface humidity measurement near the surface solves this difficulty.

C.3 Ambient air temperature

The ambient temperature of the air shall be taken at a height of 1,25 to 2 m above ground level.

The thermometer shall be protected from radiation from the sun, sky, ground and other surrounding objects with temperatures diverging from the air temperature. The protection device shall be appropriately ventilated.

A recommended protection device is a louvred shelter (see figure 2) or of the Stevenson type commonly used for meteorological observations.

C.4 Track surface temperature

Measurement of track surface temperature is recommended to be made by means of a pyrometer mounted on the friction test machine, so that it measures the track surface temperature immediately in front of the test wheel. A response time of 1 s is adequate. The average value during the friction measurement shall be calculated and used as a reference surface temperature.

Alternatively, a stationary measuring device can be used. The instrument can then also be a thermocouple or a thermistor bedded in the track surface on a place subjected to the same ambient conditions (sun radiation, etc.) as the part of the track where the friction measurement is made. The track surface where the temperature is measured shall also be of the same type as the friction test surface. The reference value shall coincide in time with the friction measurement within ± 60 s.

During measurements with water ejection in front of the test tyre, the water temperature in the jet can be used instead.

C.5 Tyre tread temperature

As the tyre tread temperature has a significant influence on tyre/road friction, especially under dry measuring conditions, it is desirable also to measure this temperature during friction measurement. This can be done by means of a thermocouple inserted in the shoulder part of the tread rubber near the surface or with a pyrometer measuring the radiation from the tread. The average value during the friction measurement is used as reference value.

Recommended instrument precision : ± 2 °C.

C.6 Relative humidity of the air in contact with the track surface

Water, even in small amounts, influences the tyre/road friction significantly on some types of road surface. When dry friction measurements are to be made on such surfaces, it is therefore important that the relative humidity of the air in contact with the test surface is well below 100 % (the temperature above the dew point). As the relative humidity is highest where the surface temperature is low, the measurement shall be made on the part of the track with the lowest temperature, if a temperature difference cannot be avoided. The measurement is recommended to be made with a thin film-type sensor in contact with or not more than 10 mm from the surface. The necessary instrument precision shall be such that the measured value maximum error stays below 90 % for dry measurement conditions.

If the test track surface is warmer than the ambient air and the relative humidity of that air is below 70 %, no special measurements are required near the surface.