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Characterization of pavement texture by use of surface profiles —

Part 6: Verification of the performance of laser profilometers used for pavement texture measurements

Caractérisation de la texture d'un revêtement de chaussée à partir de relevés de profils de la surface —

Partie 6: Vérification de la performance des profilomètres lasers utilisés pour les mesurages de la texture d'un revêtement

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*.

A list of all parts in the ISO 13473 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Pavement texture data are often used in research and surveys of pavement surface properties, such as tyre/road noise, rolling resistance, skid resistance, as well as splash and spray. Measurements of pavement texture are used in several other ISO standards; mostly to characterize test or reference surfaces.

For the measurement of pavement surface texture, laser profilometers are most frequently used. In recent years, it has appeared that, despite the use of standard methods (such as those in other parts of ISO 13473), there can be differences between results measured by various equipment, exceeding normal uncertainty estimations. One of the reasons for this can be that the equipment does not fully meet the intentions of the standards; for example ISO 13473-3[3].

To deal with this problem, this document specifies how one can verify that a particular device meets the intended characteristics of laser profilometer systems used for pavement texture measurements.

WARNING — Emitted laser beams could be hazardous for the eye and all tests done according to this standard shall be done with the appropriate safety precautions for the specific sensor.

Characterization of pavement texture by use of surface profiles —

Part 6: Verification of the performance of laser profilometers used for pavement texture measurements

1 Scope

This document describes methods for checking laser profilometer performance with respect to the capability of such equipment in measuring pavement texture.

The objective of this document is to make available an internationally accepted procedure by which performance of various laser-based equipment for pavement texture measurements can be evaluated. The document includes guidelines and recommendations intended to assist users of laser profilometers in verification of their equipment. This document is not intended as the basis for qualifying or approving laser profilometers. The procedure aims at providing tools for verifying that such systems perform satisfactory in all respects important for the correct measurements of texture, as well as to detect when and in what way the performance is unsatisfactory. This document also provides some general information about the limitations and trade-offs of laser profilometer systems.

Modern profilometers in use for measurements on pavements are almost entirely of the contactless type (such as laser point or line triangulation) designed for two- or three-dimensional measurements, and this document is intended for evaluating the performance of this type of profilometers. However, some other contactless types of profilometer can use applicable parts of ISO 13473.

This document has been prepared as a result of a need identified to correct for unacceptable differences in results measured by various equipment, even if the operators of these claim that they meet the applicable part of ISO 13473. It is not intended for other applications than pavement texture measurement. To be able to exclude errors influenced by programming mistakes or wrong interpretation of ISO 13473-1 a reference program code, digital profiles and calculated reference MPD-values can be reached via Annex A. This document is a complement to other parts of ISO 13473 in which some specifications are given but methods to check them are not included.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 13473-1, *Characterization of pavement texture by use of surface profiles — Part 1: Determination of mean profile depth*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13473-1 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
laser profilometer
equipment for contactless pavement texture measurement using a laser spot or line projected on the surface captured by a device that accurately digitizes and records texture profiles when the system is moved over the pavement surface

3.2
background noise
variation of the signal when the measurement system is at rest

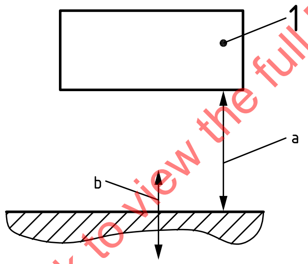
Note 1 to entry: Such noise often is of the type that is called white noise.

3.3
measurement range
range of values of vertical distance covered by the sensor,

Note 1 to entry: See Figure 1.

3.4
standoff
distance between middle of the *measurement range* (3.3) and pavement

Note 1 to entry: See Figure 1.



Key

1 sensor

a Standoff.

b Measurement range.

Figure 1 — Illustration of the terms measurement range and standoff

4 Symbols and abbreviated terms

A list of symbols and abbreviations used in this document is given in Table 1.

Table 1 — The meaning of symbols and abbreviations

Symbol or term	Reference document	Meaning
DAC	EN 13108-1	Dense Asphalt Concrete (pavement)
MPD	ISO 13473-1	Mean Profile Depth
MSD	ISO 13473-1	Mean Segment Depth
PA	EN 13108-7	Porous Asphalt (pavement)
RMS	ISO 13473-1	Root Mean Square
SMA	EN 13108-5	Stone Mastic Asphalt (pavement)

5 Methodology and its use

The important technical characteristics of laser profilometers used for measurements of pavement texture are identified, and for each one a procedure is proposed that intends to check that particular performance of the device and, where appropriate, compare it with limits for acceptable performance.

When a device or system has been checked according to this document, it is possible to refer to this document and claim to what extent the device meets the given requirements.

6 Identification and evaluation of design and performance parameters

This clause identifies design and performance parameters that are of interest in the subject of pavement texture measurements by laser profilometers. Some of the parameters are subject to evaluation in this document, while others are left to the manufacturers' own specifications.

The following fundamental design parameters are not intended to be evaluated according to this specification, but it should be checked that they are all listed in a specification by the manufacturer. The items considered include:

— operating temperature range;

— standoff;

— triangulation angles;

— laser light wavelength;

— sampling frequency;

— existence of antialiasing filter;

— horizontal resolution in longitudinal direction (usually determined by the setting of an encoder);

— horizontal resolution in transversal direction (in 3D equipment, usually determined by the number of points sampled across the laser line);

— vertical resolution;

— vertical measurement range.

The results are important for the user and are provided as information; no judgement of conformity to requirements is made for these parameters.

The following parameters are intended to be evaluated according to this specification:

a) laser power;

b) laser spot size;

c) calibration (scale) factor;

d) linearity;

e) background noise;

f) horizontal position measurement accuracy;

g) sensitivity to abrupt change in surface reflectivity;

h) spike content of measured signal;

i) effect of ambient light;

j) dropout rate;

k) validation of dropout detection system;

l) synchronization between invalid parts of the profile and dropout indications.

7 Test methods and instruments

7.1 General conditions

The following subclauses suggest test methods to be used, while Clause 9 suggests the frequency of testing.

If the equipment can operate at different modes optimized for certain pavements (such as on bright or dark surfaces), the tests described below should be performed in the modes which are relevant for the intended pavements.

When performing the following tests, where relevant, the laser system shall be mounted at an angle typical of its normal operation.

All tests described in this clause can be done with both spot and line lasers. Regarding line lasers, all tests should be done at the part of the line that is used to measure the texture properties.

7.2 Laser power

7.2.1 Test method

The power of a spot laser should be measured and integrated over the entire laser spot. The spot should be measured in a position located at standoff. The physical design of receivers (laser power sensors) for laser power meters are not adapted for measuring the power of a laser line at standoff. Instead, it is recommended to use a receiver with a large area and measure the power of a line laser as close as possible to emitted laser source.

Follow the recommendations from the supplier to decide a limit of approval for the laser power.

It is recommended to apply ISO 13694[6] for this purpose.

NOTE 1 In order to monitor the progress of laser deterioration with time, measure this power when the sensor is new and then periodically monitor how the laser diode deteriorates. The period depends on the type of laser and the use of the laser, but if the laser is in operation frequently or during long periods over a year, a suitable period would be a test every year. If the measured laser power is less than half of the initially measured laser power this is an indication why the performance in the other tests can be insufficient.

NOTE 2 Loss of laser power might, for example, have the effect of increasing background noise and the rate of drop-outs.

NOTE 3 When measuring the laser power, search for the maximum power by moving the receiver of the laser power meter and register the value.

7.2.2 Instruments

There are commonly used instruments to measure laser power, which integrate over the entire area, including the appropriate laser wavelength, and give the total time-averaged power. It is up to the user to find such an instrument.

NOTE Use the same type of instrument to follow the deterioration of the laser power since different instruments tend to give different results.

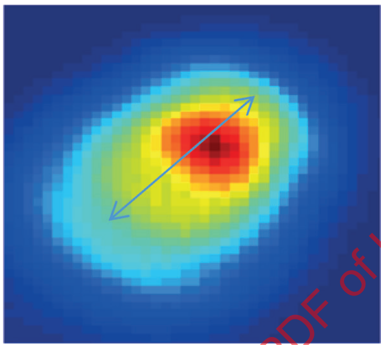
7.3 Laser spot size

7.3.1 Test method

Check the vertical measurement range of the sensor, according to the manufacturer's specifications. Measure laser spot size at standoff and near the two ends of the range (at 10 % and 90 % of the vertical range).

For spot lasers:

The effective spot is taken as that contained within an area limited by a contour line where the intensity of the spot is 1/e (approximately 37 %) of the maximum intensity within the spot. The laser spot size is the maximum diameter of the spot within this contour line; see Figure 2.



NOTE The maximum laser spot size is the diameter indicated by a straight line in the figure.

Figure 2 — Example of enlarged laser spot, where light intensity is indicated by colour (dark red is the highest and dark blue is the weakest)

For line lasers:

A line laser's effective line width is taken as that contained within a distance limited by where the intensity of the line width is 1/e (approximately 37 %) of the maximum intensity.

Regarding the required maximum laser spot size, refer to the appropriate standard; for example ISO 13473-1 for MPD and ISO 13473-5[5] for megatexture measurements, and also to ISO 13473-3[3] for various classes of profilometers.

It is recommended to consider the method in ISO 11146-1[2] for this purpose.

NOTE For 3D equipment using a continuous line, the size of the line is determined in the direction perpendicular to the line.

7.3.2 Instruments

Use a laser beam analyser or any other system designated for the purpose of measuring laser spot sizes.

NOTE It is possible to make this kind of measurement by using a razorblade to shade off part of the illuminated spot and moving this in the laser spot plane by a micrometer screw. See Reference [10] for hints and instructions.

7.4 Accuracy of the calibration (scale) factor

7.4.1 General

Each sensor is normally delivered with a "scale factor"; i.e. how to convert the output values of the sensor to a displacement in millimetres. Alternatively, the output is presented directly as a displacement or position in millimetres. The accuracy of this should be checked.

7.4.2 Method and instruments

One of many ways of performing this test is to use the table of a metal workshop milling machine, the vertical position of which can be moved with very high precision and resolution (tolerance ±10 µm). The laser sensor is mounted firmly above the table at a height appropriate with respect to the standoff. Then the output of the sensor is observed when the table is in a lower position and in a higher position; at a height difference equal to a major fraction of the vertical measurement range (not outside 10% to 90 % of the range). The scale factor is expressed in mm per output unit.

Another way is to make a measurement of a step in vertical displacement from a lower to an upper surface; by putting a gauge block, with a known and very precise thickness (tolerance ±10 µm), on top of another block under the laser spot or line; thick enough to cover a major fraction of the vertical measurement range. It is preferred that this measurement is static, and one shall make sure that there is no effect of a slope of these surfaces or of the mounting of the sensor. Limits of approval depends on the application of the measurement and can be found in ISO 13473-3.

7.5 Nonlinearity

7.5.1 General

A line laser is checked at the part of the laser line used to measure texture while the spot laser obviously is checked where the spot is.

7.5.2 Test method

This parameter is easily checked by extending the calibration procedure using gauge blocks, by putting gauge blocks on top of each other to cover the measurement range, with each step being 1/5 or less of the measurement range. Make this test within 10 % and 90 % of the measurement range. The measurement time on each step should be enough to reduce noise influence and reach a stable signal. For example, the output signal can then be plotted against the height of the steps, and one may calculate how much each point deviates from a perfect 1:1 relation. The maximum non-linearity should be reported as a percentage of the full range. Limits of approval depends on the application of the measurement and can be found in ISO 13473-3.

7.5.3 Instruments

Use gauge blocks as mentioned above. Another possibility is to produce a very accurate metal block with steps of known height (tolerance ±10 µm) and make a profile recording of this object. A third option is to use a table of a metal workshop milling machine, the vertical position of which can be moved with very high precision and resolution (tolerance ±10 µm) and moving the table vertically in certain regular steps.

7.6 Background noise

7.6.1 Method

For 2D systems, a useful method is to operate the device over a matte white paper at standstill and measure the output of the sensor when the sensor is triggered in a way which is typical of its operation on pavement surfaces. This includes a common simulated operating speed. For mobile measurements on road surfaces a normal speed may be 20 m/s (72 km/h). A duration of the measurement corresponding to an equivalent distance of 100 m is recommended.

General option: Measure the RMS value of the output signal, calculated in millimetres.

MPD option: For devices measuring/calculating MPD, calculate the MPD in millimetres for this signal, pretending that the device is operating on a perfectly smooth pavement surface and at an appropriate speed. In this case, the spike removal procedure should be deactivated.

For 3D systems (line lasers), one can use the same principle as above, but one would get MPD or RMS values for each point on the line. Since the resulting noise may vary between the centre part and the edges, one shall report both an average and the maximum value.

7.6.2 Evaluation of the result

The present experience of laser sensor systems is that they give artificial MPD values in the range 0,03 mm to 0,18 mm. Newer technology is expected to give lower noise. The system is working very well if the artificial MPD is below 0,10 mm. If the system gives an artificial MPD value higher than 0,18 mm, the system is probably not working properly. The corresponding maximum for an RMS value is approximately 0,10 mm, while values below 0,07 mm are considered as very good.

It is useful to measure the noise output when the system is new and then when the system is aged, for example annually, repeat the measurement to see if there is a deterioration.

Even if the artificial MPD value is (say) 0,18 mm, the influence on MPD measurements on pavement surfaces is much lower; normally it would not increase the MPD value more than 0,05 mm, for “true” MPD values in the range 0,4 mm to 2,0 mm.

7.7 Horizontal position measurement accuracy

7.7.1 Test method for mobile (continuous) systems

This parameter determines the precision by which the longitudinal measurement is performed, and is not directly related to the laser sensor, but is yet important in many road applications. In this case, the influential properties are the dynamical wheel radius, wheel slip ratio, and encoder accuracy (if applicable).

Measurement may be made for example by running the system over a certain distance, at least 1 000 m which is known with a high accuracy (±0,1 %) and comparing the distance recorded by the system with the actual road distance. A maximum deviation allowed from the stated section length should be within ±0,1 %. If the length is not within the tolerance, a new distance calibration should be done and the test should be repeated until an accepted result has been achieved.

7.7.2 Test method for stationary (spot) systems

Systems considered here could be either those measuring along a straight line (maybe 1 m to 5 m long), or those measuring in a circular way. Measurement may be made for example by running the system over a certain distance (normally the full distance measured by the system) which is known with low uncertainty (±0,5 %) and comparing the distance recorded by the system with the actual running distance.

Stationary snapshot systems that make a three-dimensional point-cloud over a certain area can be tested by putting a tape measure, or an object of a well-known length within the measurement area. Then the recorded length in the resulting picture is compared to the actual object dimension. This should be made in both the longitudinal and transversal directions; i.e. perpendicularly to each other.

7.8 Sensitivity to abrupt change in surface reflectivity

7.8.1 Method

Depending on what is most practical, one may consider either a measurement over a certain (straight) path, or over a circular path (such as on a rotating disc). When moving this surface under a stationary sensor or moving the sensor over a stationary surface, the light spot should move over sharp transitions between perfectly smooth surfaces with various reflection properties, but with the same vertical level. Such transitions should include the following:

From matte white to matte black and vice versa (a paint with 5 GU to 15 GU is recommended).

From glossy white to glossy black and vice versa (a paint with 80 GU to 90 GU is recommended).

NOTE Gloss unit (GU) is defined in ISO 2813[1].

If there would be a vertical level difference, between the white and black areas, such level difference shall be corrected for when evaluating the result.

This test should be made when the sensor is subject to daylight typical in the middle of the day, or preferably even in sunshine.

The speed of such movements should be similar to the speed of normal operation of the system on pavement surfaces; yet each coloured surface should be long enough to enable the sensor output to become stable over each colour.

One should check the potential vertical displacement between the various colours (which ideally should be zero) and the amplitude and duration of a possible transient (which is normally occurring unavoidably at the transition). If a transient occurs, the potential effect on MSD should be reported.

7.8.2 Instruments

One practical solution would be to produce such surfaces as sectors on a disc that is rotated below the sensor at an appropriate speed. One must then assure that the disc is flat and not distorted during the rotation. Another option is to put the colours as wide strips after each other over (for example) a rectangular plate.

7.9 Spike content of measured signal

Spikes are defined in ISO 13473-1. As spike detection and removal would be required in most, if not all, measuring systems in pavement surface applications, one should simply count the number or frequency of spikes detected by such systems, reported as the number of samples in the tested profile. Thus, no special method or instrument is necessary to define here.

The spike content is an indication of the performance of the sensor system. Therefore, making rather frequent tests of this is recommended, using the same kind of road surface.

7.10 Effect of ambient light

7.10.1 Method

The test should simulate a dynamic case. It is recommended to place the sensor in sunshine (on a clear day when illumination is close to the maximum annual sunlight exposure) over a reflective white matte, smooth surface (as defined in 7.8), keep the sensor at standstill, and then quickly move a non-transparent plate to block the direct sunlight for a fraction of a second. During this procedure, the apparent variation in the vertical displacement (if any) is measured. Ideally it should not exceed the resolution of the system.

This test is not relevant to systems designed with a cover or shroud that completely blocks the target surface from sunlight.

7.10.2 Instruments

Only a blocking plate and bright sunshine are needed.

7.11 Dropout rate

7.11.1 Method

Dropouts occur when the amount of laser light returning to the camera is low. There are three major reasons for this:

a) laser light being partly absorbed by the surface (such as on a black or other dark surface)

b) laser light being reflected by the surface in mainly other directions than toward the sensor (such as on a glossy surface)

c) there are occlusions (laser light reflected back to the camera is blocked within the surface texture). This depends on the angular arrangements related to outgoing and incoming laser radiation paths of the system, as well as the macrotexture (deep valleys or near-vertical slopes) of the pavement surface.

As dropout detection and removal would be required in most, if not all, measuring systems in pavement surface applications, one should simply count the number or frequency of dropouts detected by such systems on a typical and rather glossy surface. These are a few options:

— Make the test at the normal operating speed on a newly laid SMA pavement, or similar asphalt surface, soon after traffic was allowed. The MPD value should be at least 0,80 mm.

— Make the test on a plate with a similar SMA pavement recently produced in an asphalt laboratory at least 1 m long and run the vehicle with the sensor at the normal operating speed over this plate. The MPD value should be at least 0,80 mm.

— For sensors operating in a circular motion, the test can be made on the same plate as described above, but at the normal operating speed of the sensor.

— In case one wishes to determine the performance without occlusions, as a supplement to the above surfaces, one may simply make the measurements on two flat, black surfaces: one matte (GU 5 to 15) and one glossy (GU 80 to 90).

During the measurement, record the percentage of dropouts that are detected on the profile.

NOTE 1 It can be useful to make, for comparison purposes, a similar dropout rate measurement on an older asphalt surface (having an MPD of at least 0,80 mm) on which the glossiness of the bitumen has been lost.

NOTE 2 This method will give dropout rates for one of the worst cases occurring on dense asphalt pavements. For pavement surfaces exposed to traffic a few months and for cement concrete surfaces the dropout rates would normally be much lower.

7.11.2 Instruments

No special instrument is needed.

7.12 Validation of dropout detection system

7.12.1 Method

The purpose is to check if a very short invalid signal will create a dropout. For this test, a disc which is rotated under the laser at a speed corresponding to the normal operation of the sensor on roads is used. It has a slit or deep groove which will create a profile featuring a typical short dropout. This should create a dropout notification.

7.12.2 Instruments

For this test, use a flat and smooth disc, which is rotated under the laser at a speed corresponding to the normal operation of the sensor on roads. The disc shall have a slit or deep groove (deep enough to create a dropout) which has a width equal to twice the sampling rate (in the trace where the laser spot hits the disc), see Figure 3.

Figure 3 — Disc with a slit for testing dropout detection system

Another option is operating the laser at typical measurement speed over a long, flat plate with grove or slit of similar dimension to that suggested above; ideally, repeated at certain interval(s).

7.13 Synchronization between invalid parts of the profile and dropout indications

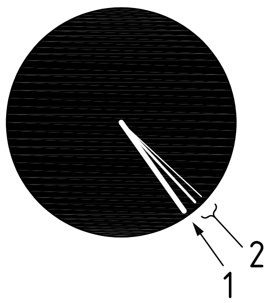
7.13.1 Method

This is valid only for sensor systems in which the invalid signal and the profile signal are independent. The purpose is to check if a very short invalid signal at location, x_1, will create a dropout at the same location, x_1.

In this case, the same disc as in the previous clause can be used but a feature shall be added which will be easily detected in order to provide a reference position.

7.13.2 Instruments

Use the same disc as in 7.12 but make a groove in it near the slit creating the dropout (see Figure 4). The groove shall be such that it does not create a dropout. For example, it may be a groove with a triangular profile about 5 mm wide and with its deepest part 2,5 mm under the main surface. Alternatively, it may be some kind of mark that is easily detected by the sensor but does not create a dropout.



Key

1 wide line: slit through the disc

2 double line: marker on the disc

Figure 4 — Disc with a slit and a marker for testing the synchronization between invalid parts of the profile and dropout indications

Another option is operating the laser at typical measurement speed over a long, flat plate with grove and slit of similar dimension to that suggested above; ideally, repeated at certain interval(s).

8 Ambient testing conditions

Sometimes there is a risk that ambient conditions potentially can influence the results of the tests. All tests should be done in ambient conditions in which the sensor is intended to operate, according to the supplier of the sensor. It is recommended to take notes about ambient conditions potentially relevant for the test, such as ambient light and ambient temperature.

9 Frequency of testing

Table 2 suggests how often testing should be made for each parameter. However, the client may request more frequent testing by the Inspection Centre, and this may be different for different parameters.

In case any major changes are made to the measuring system, normally this should result in testing of the above parameters immediately afterwards, in case these changes potentially can affect the performance of the system.

If the laser power has dropped more than 50 % of its initial power, a full set of tests as in Table 2 is needed.

Table 2 — Suggested frequency of testing

Tested parameter	Appear in this document	Suggested frequency of testing	Notes
Laser power	7.2	1 year	If the laser is used only occasionally, it is enough with testing every 2nd year
Laser spot size	7.3	6 years	
Calibration (scale) factor	7.4	2 years	
Linearity	7.5	4 years	
Background noise	7.6	1 year	If the laser is used only occasionally, it is enough with testing every 2nd year
Horizontal position measurement accuracy	7.7	1 year	It is good practice to do it more often, if max. precision is needed in road locations
Sensitivity to abrupt change in surface reflectivity	7.8	4 years	
Spike content of measured signal	7.9	1 year	
Effect of ambient light	7.10	4 years	If the effect occurs more frequently it can be detected by the laser power test
Dropout rate	7.11	2 years	
Validation of dropout detection system	7.12	Once	Tested only when system is new
Synchronization between invalid parts of the profile and dropout indications	7.13	Once	Tested only when system is new

10 Test report

The following results should be reported, if tested:

General information: The type and serial number (or corresponding identification) of the sensor which is subject of testing shall be reported. The date and location of the testing shall also be reported, along with the name of the person responsible for the testing.

Laser power: The laser power is reported in milliwatts, together with information about the instrument used and its settings (if appropriate).

Laser spot size: The spot size (maximum diameter) is reported in mm, together with information of the method used. Optionally, a figure such as in Figure 1 can be useful.

