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Optical fibres –
Part 1-34: Measurement methods and test procedures – Fibre curl

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OPTICAL FIBRES –

Part 1-34: Measurement methods and test procedures – Fibre curl

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International Standard IEC 60793-1-34 has been prepared by subcommittee 86A: Fibres and cables, of IEC technical committee 86: Fibre optics.

This third edition cancels and replaces the second edition published in 2006. This edition constitutes a technical revision.

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a) modification of several derivation equations for laser scattering;
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OPTICAL FIBRES –

Part 1-34: Measurement methods and test procedures – Fibre curl

1 Scope

This part of IEC 60793 establishes uniform requirements for the mechanical characteristic: fibre curl or latent curvature in uncoated optical fibres, i.e. a specified length of the fibre has been stripped from coating. Fibre curl has been identified as an important parameter for minimizing the splice loss of optical fibres when using passive alignment fusion splicers or active alignment mass fusion splicers.

Two methods are recognized for the measurement of fibre curl, in uncoated optical fibres:

- method A: side view microscopy;
- method B: laser beam scattering.

Both methods measure the radius of curvature of an uncoated fibre by determining the amount of deflection that occurs as an unsupported fibre end is rotated about the fibre's axis. Method A uses visual or digital video methods to determine the deflection of the fibre while method B uses a line sensor to measure the maximum deflection of one laser beam relative to a reference laser beam.

By measuring the deflection behaviour of the fibre as it is rotated about its axis and understanding the geometry of the measuring device, the fibre's radius of curvature can be calculated from simple circular models, the derivation of which are given in Annex C.

Both methods are applicable to types ~~A1, A2, A3 and~~ B optical fibres as described in IEC 60793 (all parts).

Method A is the reference test method, used to resolve disputes.

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.

IEC 60793 (all parts), *Optical fibres*

3 Terms and definitions

No terms and definitions are listed in this document.

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- IEC Electropedia: available at http://www.electropedia.org/
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4 Apparatus

4.1 Principle

An uncoated fibre end is mounted in a rotatable fixture so that the end extends freely into space by an overhang distance which will depend on the measurement device. The overhang distance is from the fibre fixture to the free endface of the uncoated fibre. The measurement distance from the fibre fixture to the measurement point is typically 10 mm to 20 mm, and the measurement point shall be close to the fibre's free endface. If the measurement device is designed with ~~overhang~~ measurement distances greater than this, care ~~must~~ shall be taken to avoid excessive degradation due to effects of vibration and gravity. The fibre is rotated and the deviations in the position of the ~~overhang~~ test point relative to a reference position are measured to obtain the fibre's radius of curvature, r_c.

Details pertaining to the two methods are given in the relevant Annex A or Annex B. Common apparatus requirements are given in 4.2 to 4.5.

4.2 Fibre holding fixture

Provide a fixture that holds the fibre on a constant axis at the holding position and allows the fibre to be rotated through 360°. The fixture may be a v-groove holder such as a vacuum chuck or a fibre ferrule. If a ferrule is used, take care to ensure that the inside diameter is sized closely enough to the fibre diameter to minimize variability in the deflection measurements.

4.3 Fibre rotator

Provide a device to grip and rotate the fibre through 360°. The device may be manually operated, or it may be driven by a rotational device such as a stepper motor.

4.4 Deflection measurement device

Provide a deflection measurement device according to either Annex A or Annex B.

4.5 Computer (optional)

A computer may be used to provide motion control, data collection and computation.

5 Sample preparation

Use an uncabled fibre of appropriate length for the instrument design. Remove enough coating from one end to allow mounting in the fibre fixture with the necessary overhang. The fibre should not extend much past the measuring device's required ~~overhang~~ measurement distance since excessive lengths can cause degradation as discussed in 4.1.

6 Procedure

6.1 General

Details for each method are given in Annex A and Annex B. Common procedures are described in 6.1 and 6.2.

6.2 Mounting of the fibre

Mount the fibre in the holding fixture so that the stripped end extends into free space with sufficient length to extend up to or beyond the ~~overhang~~ measurement distance. Typical ~~overhang~~ measurement distances range between 10 mm and 20 mm. Attach the other end of the fibre to the fibre rotator. If the ~~overhang~~ measurement distance is excessive, or the stripped fibre is substantially longer than the required ~~overhang~~ measurement distance, then the measurement may be degraded.

6.3 Rotation

Follow the procedure of Annex A or Annex B.

7 Calculation

Complete the detailed calculation of the fibre curl, r_c, using Annex A or Annex B.

NOTE Though the intermediate parameters used in the calculations are typically scaled in micrometres, the radius of curvature, r_c, is typically re-scaled in units of metres.

8 Result

8.1 The following information should be reported for each test:

- date of the test;
- fibre identification;
- fibre radius of curvature.

8.2 The following information should be available for each test:

- method used to determine curl;
- technique used for calculations;
- description of the equipment;
- calibration data.

9 Specification information

The detail specification shall specify the following:

- information to be reported;
- any deviations to the procedure that apply;
- failure or acceptance criteria.

Annex A
(normative)

Fibre curl by side view microscopy

A.1 Principle

This procedure measures the radius of curvature of an uncoated fibre by determining the amount of deflection that occurs as an unsupported fibre end is rotated about the fibre's axis. By knowing the amplitude of the deflection of the fibre and the ~~overhang~~ measurement distance from the fibre fixture to the measurement point, the fibre's radius of curvature can be calculated from a simple circular model, the derivation of which is given in Clause C.1. Schematic diagrams of typical test set-ups for these techniques are shown in Figure A.1, Figure A.2 and Figure A.3.

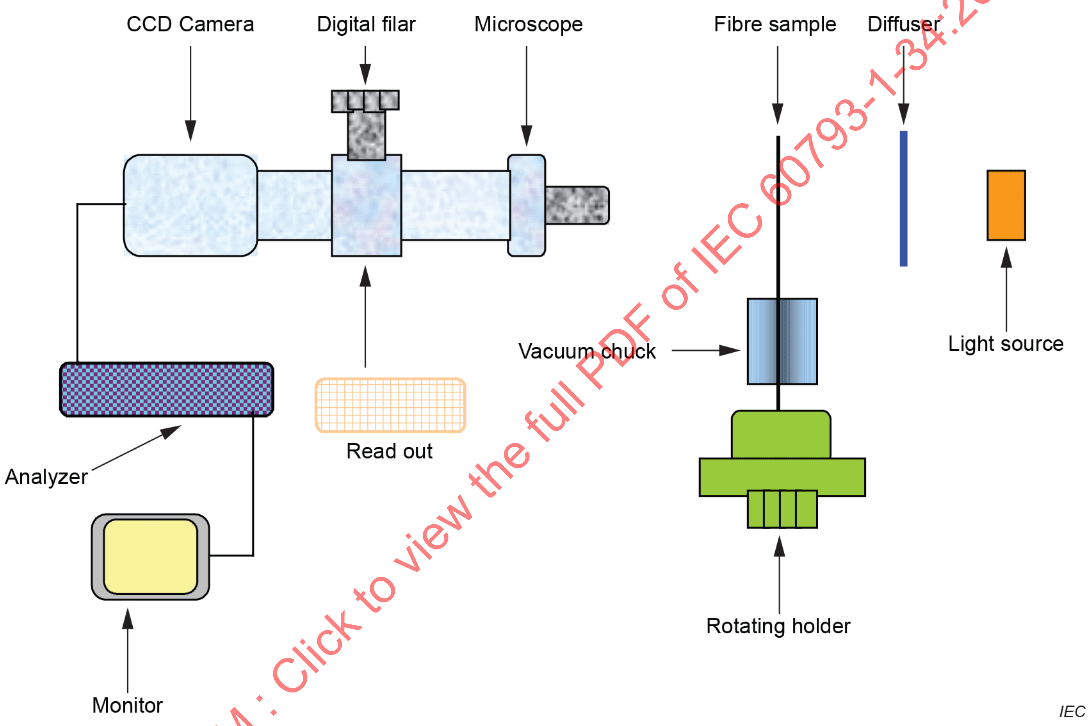

Figure A.1 – Schematic diagram for apparatus to measure fibre curl using an optical microscope

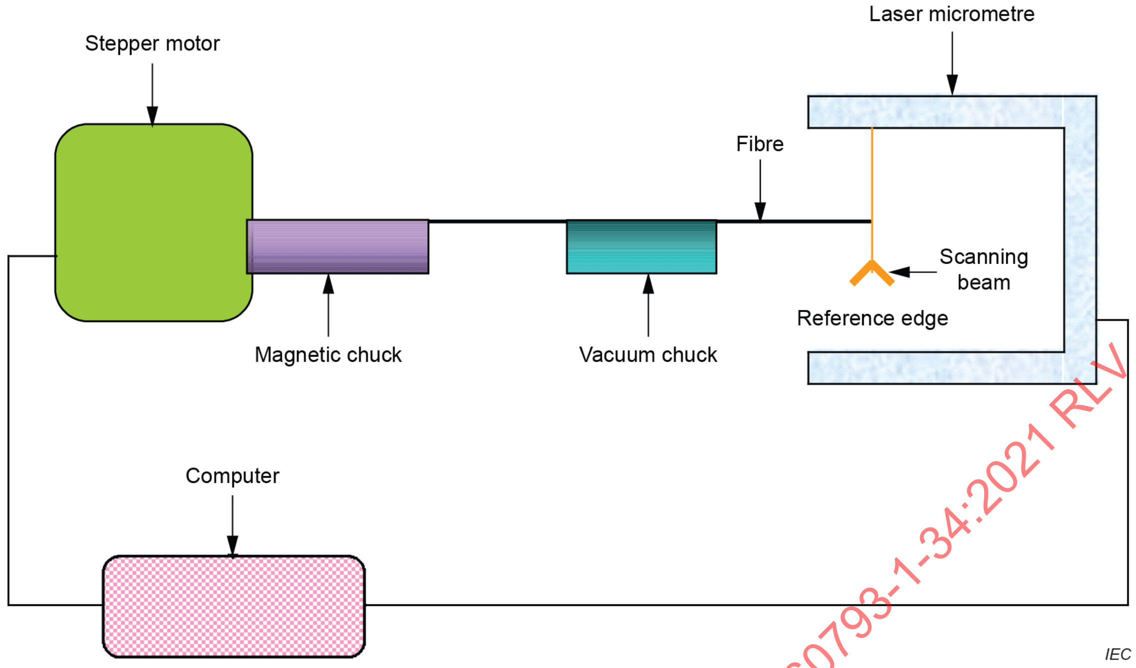

Figure A.2 – Schematic diagram for apparatus to measure fibre curl using a laser micrometre

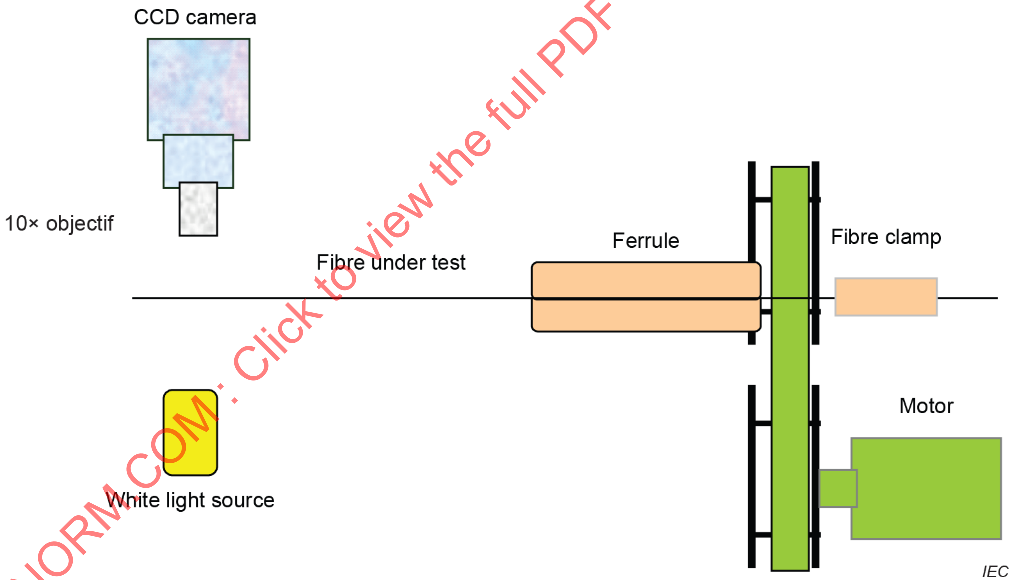

Figure A.3 – Schematic diagram for apparatus to measure fibre curl while securing the sample in a ferrule

A.2 Apparatus

A.2.1 Deflection measurement device

Provide a device to measure the fibre deflection as it is rotated through 360°. Such a device may consist of a viewing microscope or an optical measuring instrument such as a laser micrometre. If a viewing microscope is used, provide means to permit accurate measurement of fibre deflection, such as a filar eyepiece or a digital image analysis system.

A.2.2 Video camera and monitor

A video camera and monitor may be used to enhance the viewing system for manual or automated operation.

A.2.3 Digital image analysis system (optional)

A digital video analyser may be used to provide more precise location of the deflections than might be obtained by a filar eyepiece. Such a system might include an analogue or digital video camera, a frame grabber and associated software for the purpose of locating the fibre's position at the ~~overhang~~ measurement distance as the fibre is rotated.

A.3 Test procedure

A.3.1 General

Two techniques are provided for obtaining the deflection, δ_f. The first is an extrema technique that is limited by the precision with which the extremes of the deflection can be determined. The second is a Fourier fitting method.

A.3.2 Procedure for the extrema technique

Rotate the specimen until the deflection is at a maximum and record the deflection value, D_{max}. Rotate the specimen until the deflection is at a minimum, typically 180° from the angular position of the maximum, and record the deflection value, D_{min}.

A.3.3 Procedure for the Fourier fitting technique

Record the deflection of the specimen at its initial position, D_1, and angular position, θ_1. Rotate the specimen through 360° (do not duplicate the initial position in the data as the last angular position), stopping at equal angular increments and recording the deflection values at each increment, $D_{2...n}$, and its angular positions, $\theta_{2...n}$. Angular increments of 10° to ~~30~~ 45° are typically used.

A.4 Calculations

A.4.1 Extrema technique calculation

The fibre deflection δ_f is calculated by Formula (A.1):

$$\delta_f = \frac{D_{max} - D_{min}}{2} \tag{A.1}$$

where

D_{max} and D_{min} are the maximum and minimum deflection values, generally described in micrometres.

A.4.2 Fourier fitting technique calculation

Compute the first order Fourier coefficients:

$$I_1 = \frac{2}{n}\sum_{i=1}^{n} D_i \times sin\theta_i \tag{A.2}$$

$$R_1 = \frac{2}{n}\sum_{i=1}^{n} D_i \times cos\theta_i \tag{A.3}$$

Compute δ_f as the magnitude of the first-order Fourier component:

$$\delta_f = \sqrt{R_1^2 + I_1^2} \tag{A.4}$$

Least squares fitting of the set of θ_i and D_i may be used as an alternative. The Fourier technique described in A.4.2 and least squares fitting of the amplitude and phase are numerically equivalent.

A.4.3 Computation of fibre curl

Fibre curl, r_c, is computed as:

$$r_c = \frac{Z_m^2 + \delta_f^2}{2\delta_f} \tag{A.5}$$

where

Z_m is the ~~overhang~~ measurement distance.

Annex B
(~~informative~~ normative)

Fibre curl by laser beam scattering

B.1 Principle

This procedure measures the latent curvature (curl) in an optical fibre by laser beam scattering.

This procedure measures the radius of curvature of an uncoated fibre by determining the amount of deflection that occurs as an unsupported fibre end is rotated about the fibre's axis. By measuring the differential deflection of two beams separated by a known distance and the geometry of the measuring device, the fibre's radius of curvature can be calculated from a simple circular model, the derivation of which is given in Clause C.2. A schematic diagram is shown in Figure B.1.

B.2 Apparatus

B.2.1 Light source

Split He-Ne laser beams are used as the light source.

B.2.2 Detector

An image sensor such as CCD line sensor is used as the detector.

B.3 Test procedure

B.3.1 General

Two techniques are provided for obtaining the deflection difference, ΔS. The first is an extrema technique that is limited by the precision with which the extremes of the deflection can be determined. The second is a Fourier fitting method.

B.3.2 Procedure for the extrema technique

Rotate the specimen until the deflection is at a maximum and record the deflection value, ΔS_{max}.

B.3.3 Procedure for the Fourier fitting technique

Record the deflection of the specimen at its initial position, ΔS_1, and angular position, θ_1. Rotate the specimen through 360° (do not duplicate the initial position in the data as the last angular position), stopping at equal angular increments and recording the deflection values at each increment, $\Delta S_{2 \ldots n}$, and its angular positions, $\theta_{2 \ldots n}$. Angular increments of 10° to ~~30~~ 45° are typically used.

B.4 Calculations

B.4.1 Extrema technique calculation

$$S_{\text{A}} = \Delta S_{\text{max}} - \Delta Z \tag{B.1}$$

where

ΔZ is the separation distance of the two laser beams.

B.4.2 Fourier fitting technique calculation

Compute the first order Fourier coefficients:

$$I_1 = \frac{2}{n}\sum_{i=1}^{n} \Delta S_i \times sin\theta_i \tag{B.2}$$

$$R_1 = \frac{2}{n}\sum_{i=1}^{n} \Delta S_i \times cos\theta_i \tag{B.3}$$

Compute ~~ΔS~~ S_A as the magnitude of the first-order Fourier component:

$$S_A = \sqrt{R_1^2 + I_1^2} \tag{B.4}$$

Least squares fitting of the set of θ_i and ($\Delta S_i - \Delta Z$) may be used as an alternative. The Fourier technique described above and least squares fitting of the amplitude and phase are numerically equivalent.

B.4.3 Computation of fibre curl

$$r_c \approx \frac{2L\Delta Z}{S_A} \tag{B.5}$$

where

L is the distance between the fibre and the line sensor;

ΔZ is the laser beam separation distance.

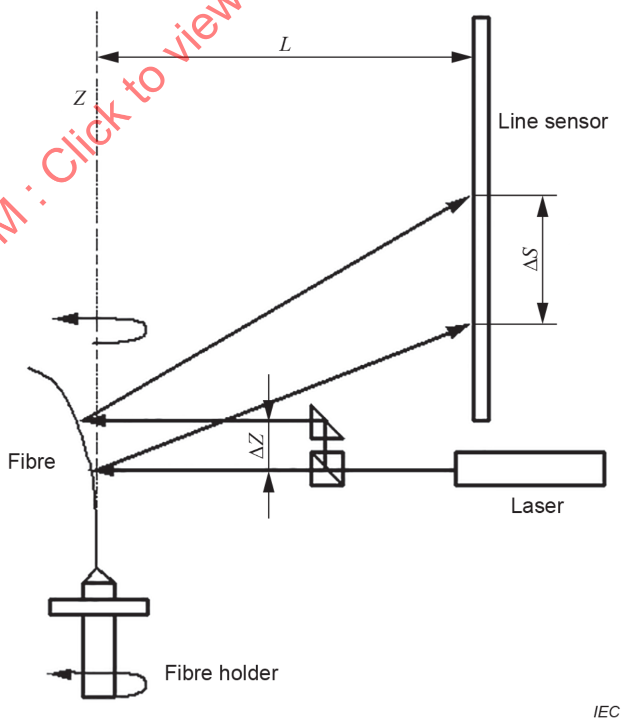

Figure B.1 – Schematic diagram of optical curl by laser beam scattering

Annex C
(informative)

Derivation of the circular fibre curl model

C.1 Derivation of equations for side view microscopy

Figure C.1 shows the geometrical layout of side view microscopy fibre curl measurement.

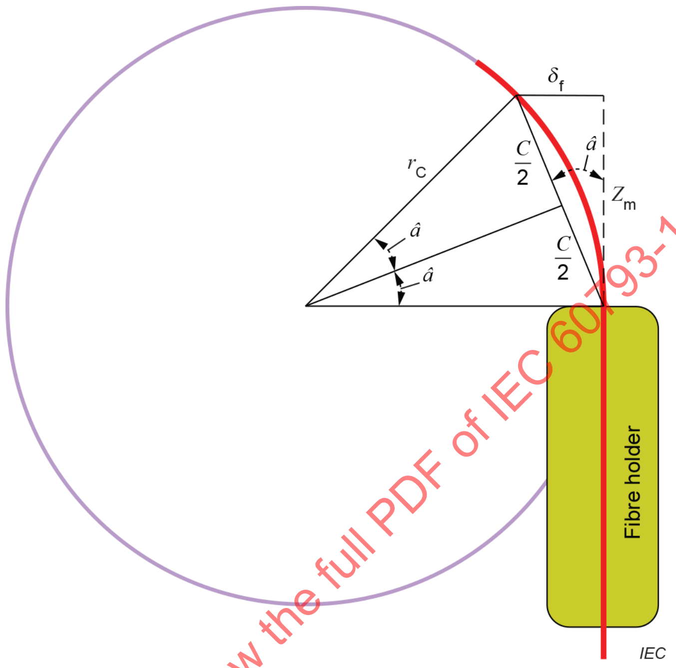

Figure C.1 – Geometrical layout of side view microscopy fibre curl measurement

We define the following:

Z_m is the ~~overhang~~ measurement distance;

δ_f is the fibre deflection from the fibre holder's axis measured at Z_m;

C is the hypotenuse of right triangle formed by Z_m, δ_f, and C.

Therefore,

$$C = \sqrt{Z_m^2 + \delta_f^2} \tag{C.1}$$

Form an isosceles triangle with C as the base and sides r_c extending from the centre of the circle. Bisect C and form two right triangles from the isosceles triangle. Angle $\hat{a}$ of the newly formed right triangles is equal to angle $\hat{a}$ of the Z_m, δ_f and C right triangle.

Therefore,

$$\sin\hat{a} = \frac{\delta_f}{C} = \frac{½\, C}{r_c} \tag{C.2}$$

Substituting Formula (C.1) into Formula (C.2) gives:

$$r_c = \frac{Z_m{}^2 + \delta_f{}^2}{2\delta_f} \quad \text{(C.3)}$$

C.2 Derivation of equations for the laser scattering method

Figure C.2 shows the deometrical layout of laser scattering fibre curl measurement.

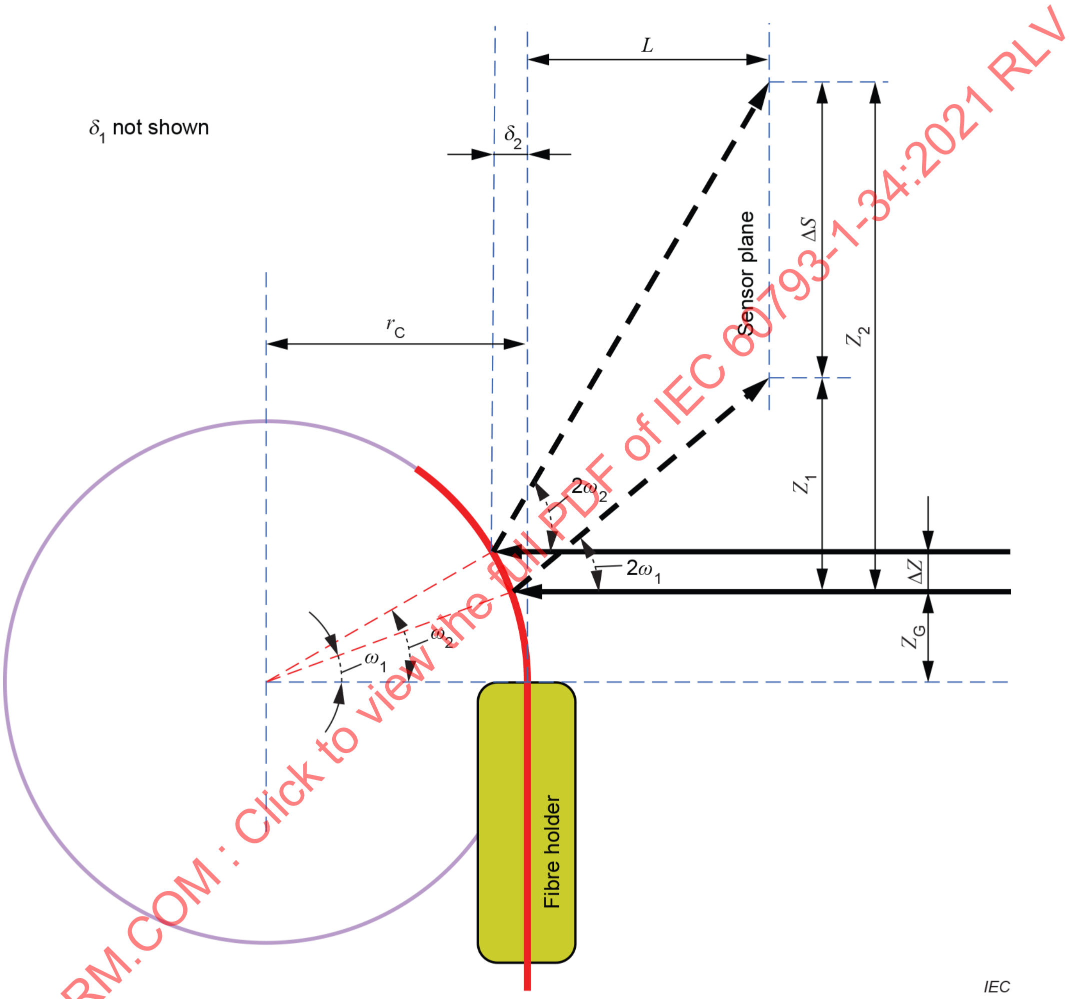

Figure C.2 – Geometrical layout of laser scattering fibre curl measurement

We define the following:

ΔZ is the separation distance between the two laser beams;

L is the distance between the fibre holder's axis of rotation and the sensor plane;

Z_G is the distance from the fibre holder to the first beam's impingement point.

Note that:

$$\Delta S = Z_2 - Z_1 \quad \text{(C.4)}$$

$$Z_1 = \left[L + Z_G \tan\frac{\omega_1}{2}\right]\tan 2\omega_1 \tag{C.5}$$

$$Z_1 = \left[L + (\Delta Z + Z_G)\tan\frac{\omega_2}{2}\right]\tan 2\omega_2 + \Delta Z \tag{C.6}$$

The small corrections to the parameter L in Formulae (C.5) and (C.6) are due to the fact that when the curled fibre is rotated to its maximum deflection point, the laser beams impinge on the fibre at a distance which depends on r_c, Z_G and ΔZ. These terms are on the order of $\Delta Z^2/r_c$, which for practical systems are very small, and can usually be ignored.

The z-coordinates of each beam relative to the fibre constraint point are

$$Z_G = r_c \sin\omega_1 \tag{C.7}$$

$$\Delta Z = r_c \sin\omega_2 - Z_G \tag{C.8}$$

The angle ω_1 can be expressed two different ways:

$$\sin\omega_1 = \frac{Z_G}{r_c} \tag{C.9}$$

$$\tan 2\omega_1 = \frac{Z_1}{L + Z_G \tan\frac{\omega_1}{2}} \approx \frac{Z_1}{L} \tag{C.10}$$

Likewise, the angle ω_2 can be expressed in two different ways:

$$\sin\omega_2 = \frac{Z_G + \Delta Z}{r_c} \tag{C.11}$$

$$\tan 2\omega_2 = \frac{Z_2 - \Delta Z}{L + (\Delta Z + Z_G)\tan\frac{\omega_2}{2}} \approx \frac{Z_2 - \Delta Z}{L} \tag{C.12}$$

It is convenient to measure the difference between the deflections of the two beams, ΔS, which will be invariant with the angle of entry of the fibre. When the fibre's curl radius is substantially larger than the geometrical parameters L, Z_G and ΔZ of the measuring device, we can successfully use small angle approximations to get the difference results.

If we assume for both ω_1 and ω_2 (a good assumption for practical fibres and implementations):

$$\sin\omega \approx \omega$$
$$\tan\frac{\omega}{2} \approx \frac{\omega}{2}$$
$$\tan 2\omega \approx 2\omega$$

then we can rewrite Formula (C.4) as:

$$\Delta S = 2L(\omega_2 - \omega_1) + (\Delta Z + Z_G)\omega_2^2 - Z_G\omega_1^2 + \Delta Z \tag{C.13}$$

and using Formulae (C.9) and (C.11) (and the small angle approximation), we get

$$\Delta S = \frac{2L\Delta Z}{r_c} + \Delta Z + \frac{(\Delta Z + Z_G)^3}{r_c^2} - \frac{Z_G^3}{r_c^2} \tag{C.14}$$

Inspecting Formula (C.14), we can see two cubic terms. If one considers a practical system with a very curled fibre (r_c = 1 m) and letting ΔZ and Z_G be 0,01 m (1 cm), then we can see that these cubic terms become very small compared with the first two terms. We can then write

$$\Delta S = \frac{SL\Delta Z}{r_c} + \Delta Z \tag{C.15}$$

and finally

$$r_c = \frac{2L\Delta Z}{\Delta S - \Delta Z} \tag{C.16}$$

For practical fibres and measuring device constraints, all of the above approximations will not contribute errors in excess of hundredths of percent. For fibres with curl radii in excess of 5 m, these errors become even smaller.

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- method A: side view microscopy;
- method B: laser beam scattering.

Both methods measure the radius of curvature of an uncoated fibre by determining the amount of deflection that occurs as an unsupported fibre end is rotated about the fibre's axis. Method A uses visual or digital video methods to determine the deflection of the fibre while method B uses a line sensor to measure the maximum deflection of one laser beam relative to a reference laser beam.

By measuring the deflection behaviour of the fibre as it is rotated about its axis and understanding the geometry of the measuring device, the fibre's radius of curvature can be calculated from simple circular models, the derivation of which are given in Annex C.

Both methods are applicable to type B optical fibres as described in IEC 60793 (all parts).

Method A is the reference test method, used to resolve disputes.

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.

IEC 60793 (all parts), *Optical fibres*

3 Terms and definitions

No terms and definitions are listed in this document.

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

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

4 Apparatus

4.1 Principle

An uncoated fibre end is mounted in a rotatable fixture so that the end extends freely into space by an overhang distance which will depend on the measurement device. The overhang distance is from the fibre fixture to the free endface of the uncoated fibre. The measurement distance from the fibre fixture to the measurement point is typically 10 mm to 20 mm, and the measurement point shall be close to the fibre's free endface. If the measurement device is designed with measurement distances greater than this, care shall be taken to avoid excessive degradation due to effects of vibration and gravity. The fibre is rotated and the deviations in the position of the test point relative to a reference position are measured to obtain the fibre's radius of curvature, r_c.

Details pertaining to the two methods are given in the relevant Annex A or Annex B. Common apparatus requirements are given in 4.2 to 4.5.

4.2 Fibre holding fixture

Provide a fixture that holds the fibre on a constant axis at the holding position and allows the fibre to be rotated through 360°. The fixture may be a v-groove holder such as a vacuum chuck or a fibre ferrule. If a ferrule is used, take care to ensure that the inside diameter is sized closely enough to the fibre diameter to minimize variability in the deflection measurements.

4.3 Fibre rotator

Provide a device to grip and rotate the fibre through 360°. The device may be manually operated, or it may be driven by a rotational device such as a stepper motor.

4.4 Deflection measurement device

Provide a deflection measurement device according to either Annex A or Annex B.

4.5 Computer (optional)

A computer may be used to provide motion control, data collection and computation.

5 Sample preparation

Use an uncabled fibre of appropriate length for the instrument design. Remove enough coating from one end to allow mounting in the fibre fixture with the necessary overhang. The fibre should not extend much past the measuring device's required measurement distance since excessive lengths can cause degradation as discussed in 4.1.

6 Procedure

6.1 General

Details for each method are given in Annex A and Annex B. Common procedures are described in 6.1 and 6.2.

6.2 Mounting of the fibre

Mount the fibre in the holding fixture so that the stripped end extends into free space with sufficient length to extend up to or beyond the measurement distance. Typical measurement distances range between 10 mm and 20 mm. Attach the other end of the fibre to the fibre rotator.

If the measurement distance is excessive, or the stripped fibre is substantially longer than the required measurement distance, then the measurement may be degraded.

6.3 Rotation

Follow the procedure of Annex A or Annex B.

7 Calculation

Complete the detailed calculation of the fibre curl, r_c, using Annex A or Annex B.

NOTE Though the intermediate parameters used in the calculations are typically scaled in micrometres, the radius of curvature, r_c, is typically re-scaled in units of metres.

8 Result

8.1 The following information should be reported for each test:

- date of the test;
- fibre identification;
- fibre radius of curvature.

8.2 The following information should be available for each test:

- method used to determine curl;
- technique used for calculations;
- description of the equipment;
- calibration data.

9 Specification information

The detail specification shall specify the following:

- information to be reported;
- any deviations to the procedure that apply;
- failure or acceptance criteria.

Annex A
(normative)

Fibre curl by side view microscopy

A.1 Principle

This procedure measures the radius of curvature of an uncoated fibre by determining the amount of deflection that occurs as an unsupported fibre end is rotated about the fibre's axis. By knowing the amplitude of the deflection of the fibre and the measurement distance from the fibre fixture to the measurement point, the fibre's radius of curvature can be calculated from a simple circular model, the derivation of which is given in Clause C.1. Schematic diagrams of typical test set-ups for these techniques are shown in Figure A.1, Figure A.2 and Figure A.3.

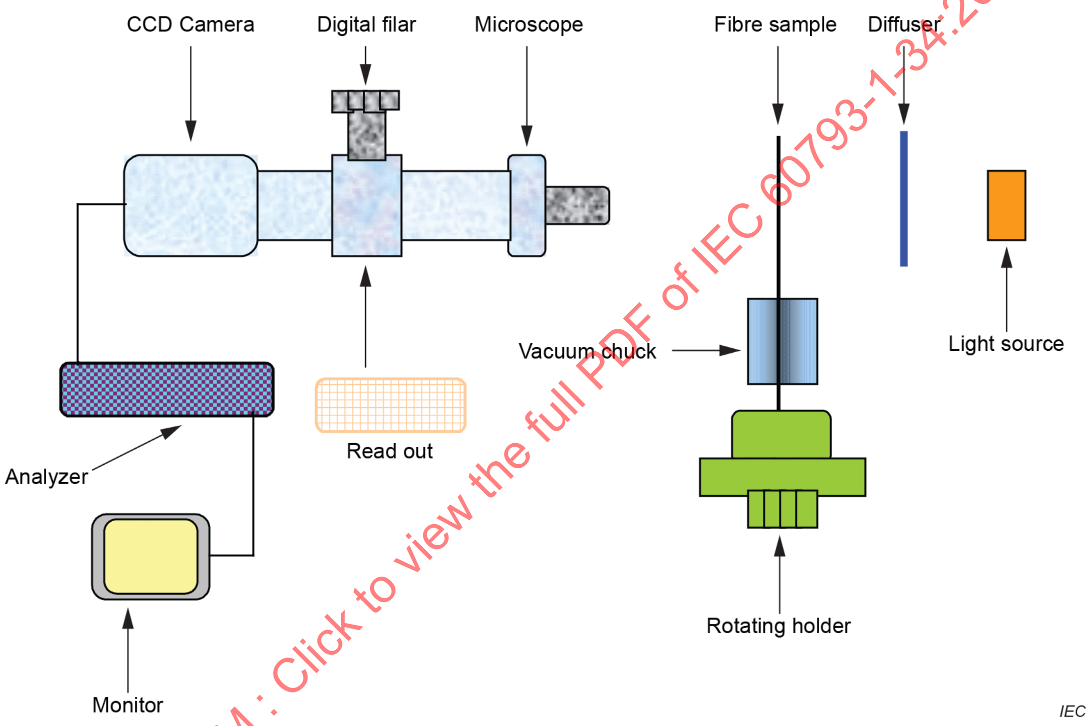

Figure A.1 – Schematic diagram for apparatus to measure fibre curl using an optical microscope

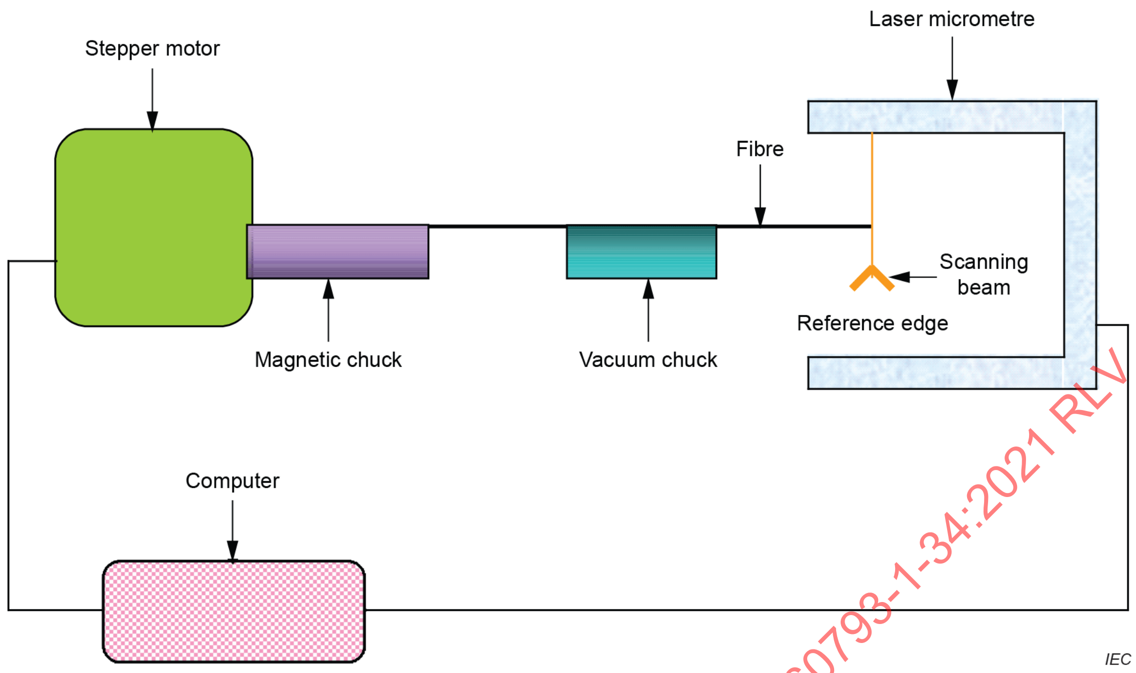

Figure A.2 – Schematic diagram for apparatus to measure fibre curl using a laser micrometre

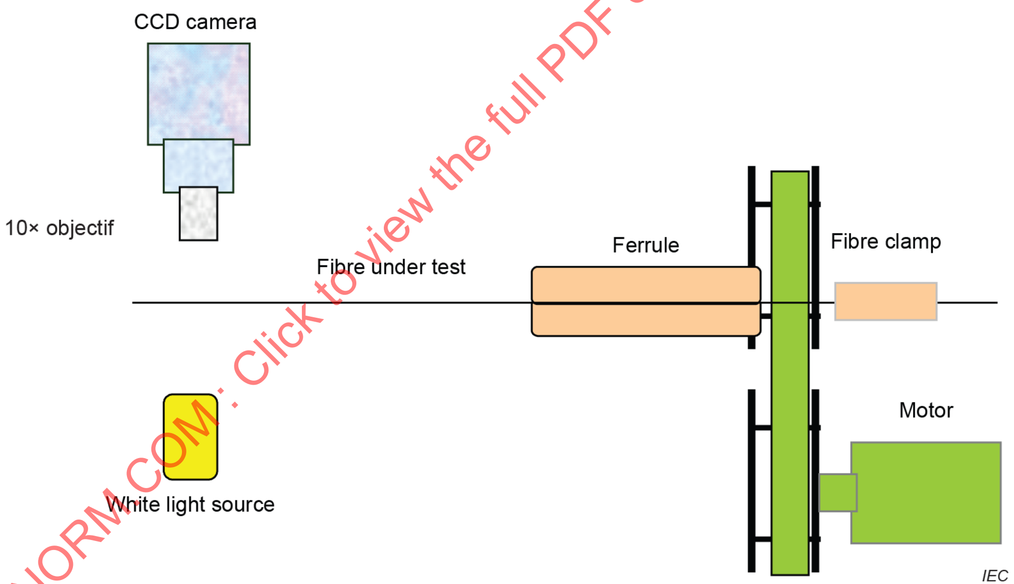

Figure A.3 – Schematic diagram for apparatus to measure fibre curl while securing the sample in a ferrule

A.2 Apparatus

A.2.1 Deflection measurement device

Provide a device to measure the fibre deflection as it is rotated through 360°. Such a device may consist of a viewing microscope or an optical measuring instrument such as a laser micrometre. If a viewing microscope is used, provide means to permit accurate measurement of fibre deflection, such as a filar eyepiece or a digital image analysis system.

A.2.2 Video camera and monitor

A video camera and monitor may be used to enhance the viewing system for manual or automated operation.

A.2.3 Digital image analysis system (optional)

A digital video analyser may be used to provide more precise location of the deflections than might be obtained by a filar eyepiece. Such a system might include an analogue or digital video camera, a frame grabber and associated software for the purpose of locating the fibre's position at the measurement distance as the fibre is rotated.

A.3 Test procedure

A.3.1 General

Two techniques are provided for obtaining the deflection, δ_f. The first is an extrema technique that is limited by the precision with which the extremes of the deflection can be determined. The second is a Fourier fitting method.

A.3.2 Procedure for the extrema technique

Rotate the specimen until the deflection is at a maximum and record the deflection value, D_{max}. Rotate the specimen until the deflection is at a minimum, typically 180° from the angular position of the maximum, and record the deflection value, D_{min}.

A.3.3 Procedure for the Fourier fitting technique

Record the deflection of the specimen at its initial position, D_1, and angular position, θ_1. Rotate the specimen through 360° (do not duplicate the initial position in the data as the last angular position), stopping at equal angular increments and recording the deflection values at each increment, $D_{2...n}$, and its angular positions, $\theta_{2...n}$. Angular increments of 10° to 45° are typically used.

A.4 Calculations

A.4.1 Extrema technique calculation

The fibre deflection δ_f is calculated by Formula (A.1):

$$\delta_f = \frac{D_{max} - D_{min}}{2} \tag{A.1}$$

where

D_{max} and D_{min} are the maximum and minimum deflection values, generally described in micrometres.

A.4.2 Fourier fitting technique calculation

Compute the first order Fourier coefficients:

$$I_1 = \frac{2}{n}\sum_{i=1}^{n} D_i \times sin\theta_i \tag{A.2}$$

$$R_1 = \frac{2}{n}\sum_{i=1}^{n} D_i \times cos\theta_i \quad \text{(A.3)}$$

Compute δ_f as the magnitude of the first-order Fourier component:

$$\delta_f = \sqrt{R_1^2 + I_1^2} \quad \text{(A.4)}$$

Least squares fitting of the set of θ_i and D_i may be used as an alternative. The Fourier technique described in A.4.2 and least squares fitting of the amplitude and phase are numerically equivalent.

A.4.3 Computation of fibre curl

Fibre curl, r_c, is computed as:

$$r_c = \frac{Z_m^2 + \delta_f^2}{2\delta_f} \quad \text{(A.5)}$$

where

Z_m is the measurement distance.

Annex B
(normative)

Fibre curl by laser beam scattering

B.1 Principle

This procedure measures the latent curvature (curl) in an optical fibre by laser beam scattering.

This procedure measures the radius of curvature of an uncoated fibre by determining the amount of deflection that occurs as an unsupported fibre end is rotated about the fibre's axis. By measuring the differential deflection of two beams separated by a known distance and the geometry of the measuring device, the fibre's radius of curvature can be calculated from a simple circular model, the derivation of which is given in Clause C.2. A schematic diagram is shown in Figure B.1.

B.2 Apparatus

B.2.1 Light source

Split He-Ne laser beams are used as the light source.

B.2.2 Detector

An image sensor such as CCD line sensor is used as the detector.

B.3 Test procedure

B.3.1 General

Two techniques are provided for obtaining the deflection difference, ΔS. The first is an extrema technique that is limited by the precision with which the extremes of the deflection can be determined. The second is a Fourier fitting method.

B.3.2 Procedure for the extrema technique

Rotate the specimen until the deflection is at a maximum and record the deflection value, ΔS_{max}.

B.3.3 Procedure for the Fourier fitting technique

Record the deflection of the specimen at its initial position, ΔS_1, and angular position, θ_1. Rotate the specimen through 360° (do not duplicate the initial position in the data as the last angular position), stopping at equal angular increments and recording the deflection values at each increment, $\Delta S_{2...n}$, and its angular positions, $\theta_{2...n}$. Angular increments of 10° to 45° are typically used.

B.4 Calculations

B.4.1 Extrema technique calculation

$$S_{\text{A}} = \Delta S_{\text{max}} - \Delta Z \quad \text{(B.1)}$$

where

ΔZ is the separation distance of the two laser beams.

B.4.2 Fourier fitting technique calculation

Compute the first order Fourier coefficients:

$$I_1 = \frac{2}{n}\sum_{i=1}^{n} \Delta S_i \times sin\theta_i \tag{B.2}$$

$$R_1 = \frac{2}{n}\sum_{i=1}^{n} \Delta S_i \times cos\theta_i \tag{B.3}$$

Compute S_A as the magnitude of the first-order Fourier component:

$$S_A = \sqrt{R_1^2 + I_1^2} \tag{B.4}$$

Least squares fitting of the set of θ_i and ($\Delta S_i - \Delta Z$) may be used as an alternative. The Fourier technique described above and least squares fitting of the amplitude and phase are numerically equivalent.

B.4.3 Computation of fibre curl

$$r_c \approx \frac{2L\Delta Z}{S_A} \tag{B.5}$$

where

L is the distance between the fibre and the line sensor;

ΔZ is the laser beam separation distance.

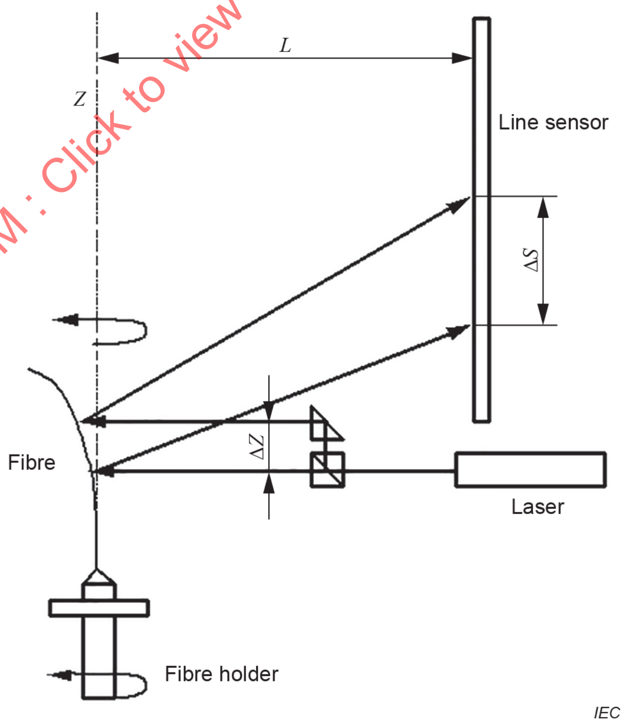

Figure B.1 – Schematic diagram of optical curl by laser beam scattering

Annex C
(informative)

Derivation of the circular fibre curl model

C.1 Derivation of equations for side view microscopy

Figure C.1 shows the geometrical layout of side view microscopy fibre curl measurement.

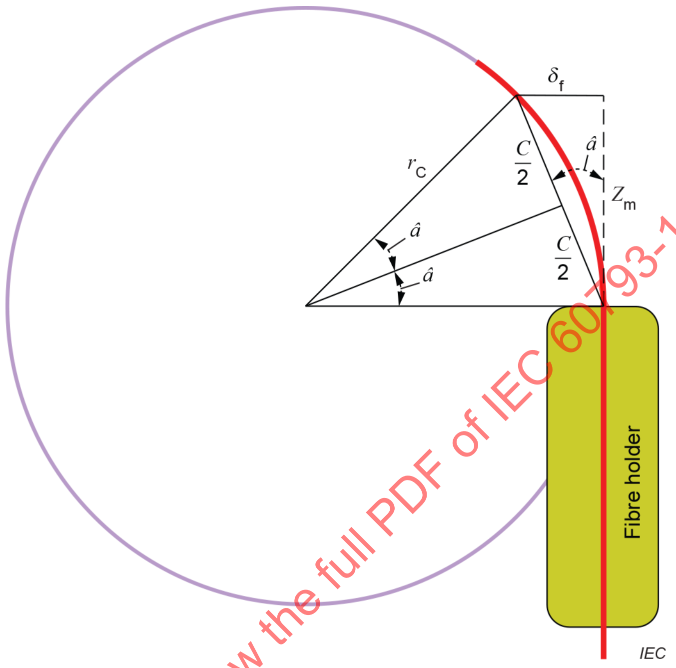

Figure C.1 – Geometrical layout of side view microscopy fibre curl measurement

We define the following:

Z_m is the measurement distance;

δ_f is the fibre deflection from the fibre holder's axis measured at Z_m;

C is the hypotenuse of right triangle formed by Z_m, δ_f, and C.

Therefore,

$$C = \sqrt{Z_m{}^2 + \delta_f{}^2} \tag{C.1}$$

Form an isosceles triangle with C as the base and sides r_c extending from the centre of the circle. Bisect C and form two right triangles from the isosceles triangle. Angle $\hat{a}$ of the newly formed right triangles is equal to angle $\hat{a}$ of the Z_m, δ_f and C right triangle.

Therefore,

$$\sin\hat{a} = \frac{\delta_f}{C} = \frac{½\,C}{r_c} \tag{C.2}$$

Substituting Formula (C.1) into Formula (C.2) gives:

$$r_c = \frac{Z_m^2 + \delta_f^2}{2\delta_f} \tag{C.3}$$

C.2 Derivation of equations for the laser scattering method

Figure C.2 shows the deometrical layout of laser scattering fibre curl measurement.

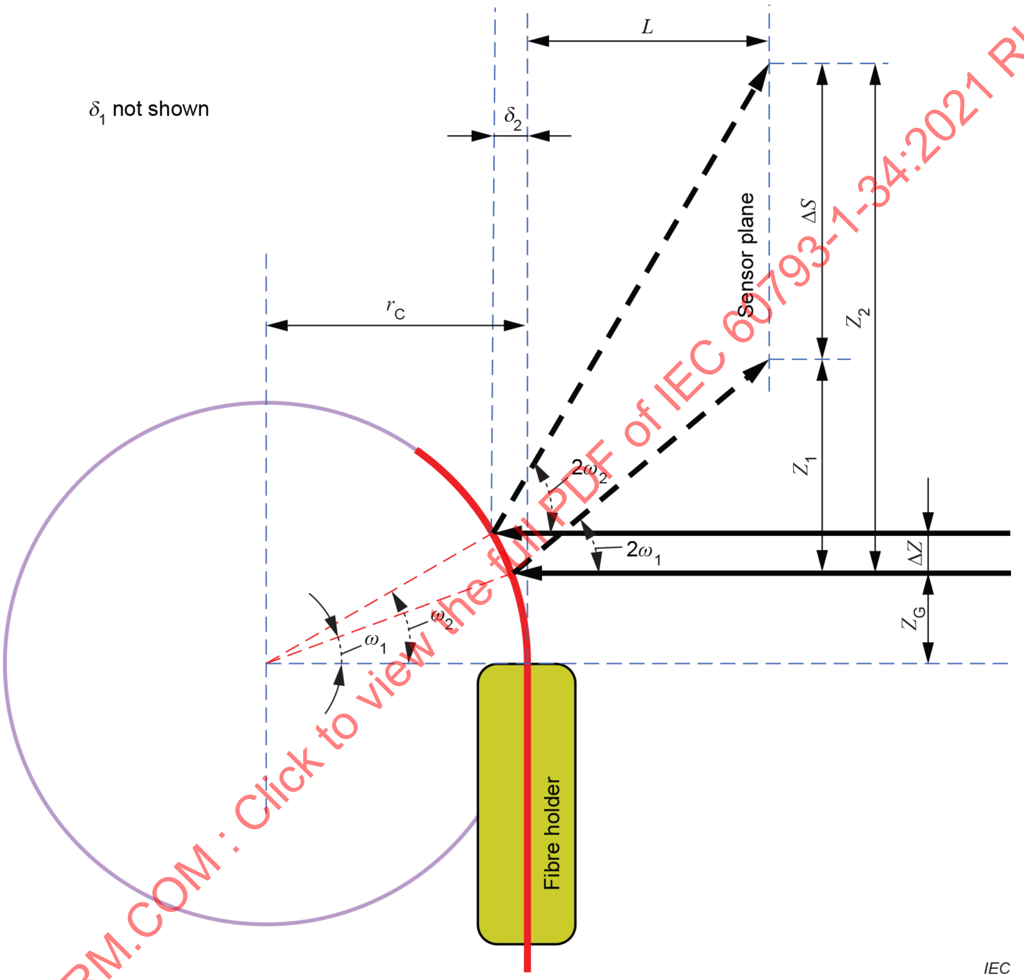

Figure C.2 – Geometrical layout of laser scattering fibre curl measurement

We define the following:

ΔZ is the separation distance between the two laser beams;

L is the distance between the fibre holder's axis of rotation and the sensor plane;

Z_G is the distance from the fibre holder to the first beam's impingement point.

Note that:

$$\Delta S = Z_2 - Z_1 \tag{C.4}$$

$$Z_1 = \left[L + Z_G \tan\frac{\omega_1}{2} \right] \tan 2\omega_1 \quad \text{(C.5)}$$

$$Z_1 = \left[L + (\Delta Z + Z_G) \tan\frac{\omega_2}{2} \right] \tan 2\omega_2 + \Delta Z \quad \text{(C.6)}$$

The small corrections to the parameter L in Formulae (C.5) and (C.6) are due to the fact that when the curled fibre is rotated to its maximum deflection point, the laser beams impinge on the fibre at a distance which depends on r_c, Z_G and ΔZ. These terms are on the order of $\Delta Z^2/r_c$, which for practical systems are very small, and can usually be ignored.

The z-coordinates of each beam relative to the fibre constraint point are

$$Z_G = r_c \sin\omega_1 \quad \text{(C.7)}$$

$$\Delta Z = r_c \sin\omega_2 - Z_G \quad \text{(C.8)}$$

The angle ω_1 can be expressed two different ways:

$$\sin\omega_1 = \frac{Z_G}{r_c} \quad \text{(C.9)}$$

$$\tan 2\omega_1 = \frac{Z_1}{L + Z_G \tan\frac{\omega_1}{2}} \approx \frac{Z_1}{L} \quad \text{(C.10)}$$

Likewise, the angle ω_2 can be expressed in two different ways:

$$\sin\omega_2 = \frac{Z_G + \Delta Z}{r_c} \quad \text{(C.11)}$$

$$\tan 2\omega_2 = \frac{Z_2 - \Delta Z}{L + (\Delta Z + Z_G)\tan\frac{\omega_2}{2}} \approx \frac{Z_2 - \Delta Z}{L} \quad \text{(C.12)}$$

It is convenient to measure the difference between the deflections of the two beams, ΔS, which will be invariant with the angle of entry of the fibre. When the fibre's curl radius is substantially larger than the geometrical parameters L, Z_G and ΔZ of the measuring device, we can successfully use small angle approximations to get the difference results.

If we assume for both ω_1 and ω_2 (a good assumption for practical fibres and implementations):

$$\sin\omega \approx \omega$$

$$\tan\frac{\omega}{2} \approx \frac{\omega}{2}$$

$$\tan 2\omega \approx 2\omega$$

then we can rewrite Formula (C.4) as:

$$\Delta S = 2L(\omega_2 - \omega_1) + (\Delta Z + Z_G)\omega_2^2 - Z_G\omega_1^2 + \Delta Z \tag{C.13}$$

and using Formulae (C.9) and (C.11) (and the small angle approximation), we get

$$\Delta S = \frac{2L\Delta Z}{r_c} + \Delta Z + \frac{(\Delta Z + Z_G)^3}{r_c^2} - \frac{Z_G^3}{r_c^2} \tag{C.14}$$

Inspecting Formula (C.14), we can see two cubic terms. If one considers a practical system with a very curled fibre (r_c = 1 m) and letting ΔZ and Z_G be 0,01 m (1 cm), then we can see that these cubic terms become very small compared with the first two terms. We can then write

$$\Delta S = \frac{SL\Delta Z}{r_c} + \Delta Z \tag{C.15}$$

and finally

$$r_c = \frac{2L\Delta Z}{\Delta S - \Delta Z} \tag{C.16}$$

For practical fibres and measuring device constraints, all of the above approximations will not contribute errors in excess of hundredths of percent. For fibres with curl radii in excess of 5 m, these errors become even smaller.

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SOMMAIRE

COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

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FIBRES OPTIQUES –

Partie 1-34: Méthodes de mesure et procédures d'essai – Ondulation de la fibre

AVANT-PROPOS

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La Norme internationale IEC 60793-1-34 a été établie par le sous-comité 86A: Fibres et câbles, du comité d'études 86 de l'IEC: Fibres optiques.

Cette troisième édition annule et remplace la deuxième édition parue en 2006. Cette édition constitue une révision technique.

Cette édition inclut les modifications techniques majeures suivantes par rapport à l'édition précédente:

a) modification de plusieurs équations de détermination pour la diffusion laser;
b) modification de l'incrément angulaire qui passe de 10° à 30° à 10° à 45°;
c) changement de statut de l'Annexe B qui devient normative.

Le texte de cette Norme internationale est issu des documents suivants:

CDV	Rapport de vote
86A/1971/CDV	86A/1994/RVC

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à l'approbation de cette Norme internationale.

Ce document a été rédigé selon les Directives ISO/IEC, Partie 2.

Une liste de toutes les parties de la série IEC 60793, publiées sous le titre général *Fibres optiques*, se trouve sur le site web de l'IEC.

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FIBRES OPTIQUES –

Partie 1-34: Méthodes de mesure et procédures d’essai – Ondulation de la fibre

1 Domaine d’application

La présente partie de l'IEC 60793 établit des exigences uniformes pour les caractéristiques mécaniques: ondulation de fibre ou courbure latente des fibres optiques sans revêtement, c'est-à-dire qu'une longueur spécifiée de la fibre a été dénudée. L'ondulation de fibre a été définie comme étant un paramètre important de réduction des pertes d'épissure des fibres optiques lors de l'utilisation de soudeuses par fusion avec alignement passif ou de soudeuses par fusion de masse avec alignement actif.

Deux méthodes sont reconnues pour la mesure de l'ondulation de fibre, pour les fibres optiques sans revêtement:

- méthode A: par microscopie latérale;
- méthode B: par diffusion d'un faisceau laser.

Les deux méthodes mesurent le rayon de courbure d'une fibre sans revêtement en déterminant la valeur de la flèche d'une extrémité de fibre non soutenue soumise à une rotation autour de son axe. La méthode A utilise des méthodes visuelles ou vidéo numériques pour déterminer la flèche de la fibre tandis que la méthode B utilise un capteur de ligne pour mesurer la flèche maximale d’un faisceau laser par rapport à un faisceau laser de référence.

En mesurant le comportement de la flèche de la fibre pendant qu’elle est soumise à une rotation autour de son axe et d’après la configuration du dispositif de mesure, le rayon de courbure de la fibre peut être calculé à partir de modèles circulaires simples, déterminés à l’Annexe C.

Ces deux méthodes sont applicables aux fibres optiques du type B telles que décrites dans la série IEC 60793 (toutes les parties).

La méthode A est la méthode d'essai de référence, utilisée en cas de litige.

2 Références normatives

Les documents suivants sont cités dans le texte de sorte qu’ils constituent, pour tout ou partie de leur contenu, des exigences du présent document. Pour les références datées, seule l’édition citée s’applique. Pour les références non datées, la dernière édition du document de référence s'applique (y compris les éventuels amendements).

IEC 60793 (toutes les parties), *Fibres optiques*

3 Termes et définitions

Aucun terme n'est défini dans le présent document.

L'ISO et l'IEC tiennent à jour des bases de données terminologiques destinées à être utilisées en normalisation, consultables aux adresses suivantes:

- IEC Electropedia: disponible à l'adresse http://www.electropedia.org/

- ISO Online browsing platform: disponible à l'adresse http://www.iso.org/obp

4 Appareillage

4.1 Principe

Une extrémité de fibre sans revêtement est montée dans un dispositif de fixation pouvant tourner de façon que l'extrémité sorte librement sur une longueur "de débord" qui dépend du dispositif de mesure. La longueur "de débord" est la distance entre le dispositif de fixation de la fibre et la face d'extrémité libre de la fibre sans revêtement. La distance de mesure entre le dispositif de fixation de la fibre et le point de mesure est généralement comprise entre 10 mm et 20 mm. Le point de mesure doit être proche de la face d'extrémité libre de la fibre. Si le dispositif de mesure est conçu avec des distances de mesure supérieures à celle indiquée ci-dessus, des précautions doivent être prises pour éviter une dégradation excessive en raison des effets des vibrations et de la gravité. La fibre est soumise à une rotation et les écarts de position du point d'essai par rapport à une position de référence sont mesurés pour obtenir le rayon de courbure de la fibre, r_c.

Des précisions ayant trait aux deux méthodes sont données dans l'Annexe A ou B selon le cas. Les exigences communes relatives à l'appareillage sont données dans 4.2 à 4.5.

4.2 Dispositif de fixation de la fibre

Utiliser un dispositif de fixation pour maintenir la fibre en position sur un axe constant et permettre une rotation de 360°. Le dispositif de fixation peut être un support à rainure en V, tel qu'un plateau de maintien à vide ou une férule pour fibre. Si une férule est utilisée, veiller à ce que son diamètre intérieur soit d'une taille aussi proche que possible du diamètre de la fibre pour réduire le plus possible la variabilité dans les mesures de la flèche.

4.3 Dispositif de rotation de la fibre

Utiliser un dispositif permettant de fixer la fibre et de lui appliquer une rotation de 360°. Le dispositif peut être activé manuellement ou par un dispositif tournant tel qu'un moteur pas à pas.

4.4 Dispositif de mesure de la flèche

Utiliser un dispositif de mesure de la flèche conforme à l'une ou l'autre des Annexes A ou B.

4.5 Ordinateur (facultatif)

Un ordinateur peut être utilisé pour assurer un contrôle des déplacements, collecter les données et effectuer les calculs.

5 Préparation de l'échantillon

Utiliser une fibre non câblée d'une longueur appropriée à l'appareil de mesure. Dénuder suffisamment la fibre à l'une de ses extrémités pour obtenir un débord suffisant une fois montée dans le dispositif de fixation. Il convient que la fibre ne dépasse pas trop la distance de mesure exigée du dispositif de mesure, sachant que des longueurs excessives peuvent provoquer une dégradation comme cela est expliqué au 4.1.

6 Mode opératoire

6.1 Généralités

Les informations détaillées concernant chaque méthode sont données à l'Annexe A et à l'Annexe B. Les procédures communes sont décrites au 6.1 et au 6.2.

6.2 Montage de la fibre

Monter la fibre dans le dispositif de fixation, en permettant à l'extrémité dénudée de sortir librement de sorte qu'elle dépasse d'une longueur suffisante et se prolonge jusqu'à la distance de mesure ou au-delà. Les distances de mesure types sont comprises entre 10 mm et 20 mm. Fixer l'autre extrémité de la fibre au dispositif qui applique la rotation. Si la distance de mesure est excessive, ou si la fibre dénudée est beaucoup plus longue que la distance de mesure exigée, alors la mesure peut être dégradée.

6.3 Rotation

Suivre la procédure de l'Annexe A ou de l'Annexe B.

7 Calcul

Faire le calcul détaillé de l'ondulation de fibre, r_c, en utilisant l'Annexe A ou l'Annexe B.

NOTE Bien que les paramètres intermédiaires utilisés dans les calculs soient généralement mis à l'échelle en micromètres, le rayon de courbure, r_c, est généralement remis à l'échelle en mètres.

8 Résultat

8.1 Il convient de consigner les informations suivantes pour chaque essai:

- la date de l'essai;
- l'identification de la fibre;
- le rayon de courbure de la fibre.

8.2 Il convient que les informations suivantes soient disponibles pour chaque essai:

- la méthode d'essai utilisée pour déterminer l'ondulation;
- la technique utilisée pour les calculs;
- la description de l'équipement;
- les données d'étalonnage.

9 Informations à mentionner dans la spécification

La spécification particulière doit spécifier les informations suivantes:

- les informations à consigner;
- tout écart par rapport à la procédure qui s'applique;
- les critères de défaillance ou d'acceptation.