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TECHNICAL REPORT

colour inside

Guidelines for the measurement of high-power damage sensitivity of single-mode fibre to bends – Guidance for the interpretation of results

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

GUIDELINES FOR THE MEASUREMENT OF HIGH-POWER DAMAGE SENSITIVITY OF SINGLE-MODE FIBRE TO BENDS – GUIDANCE FOR THE INTERPRETATION OF RESULTS

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IEC 62547, which is a technical report, has been prepared by subcommittee 86A: Fibres and cables, of IEC technical committee 86: Fibre optics.

This second edition cancels and replaces the first edition published in 2009, and constitutes a technical revision.

The main changes with respect to the previous edition are listed below:

– updates related to B6 (bend-insensitive) category single-mode fibres);
– update to analysis for test method 2: Maximum temperature specification.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
86A/1494/DTR	86A/1508/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
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GUIDELINES FOR THE MEASUREMENT OF HIGH-POWER DAMAGE SENSITIVITY OF SINGLE-MODE FIBRE TO BENDS – GUIDANCE FOR THE INTERPRETATION OF RESULTS

1 Scope

This technical report describes two methods for the measurement of the sensitivity of single-mode optical fibres to high-power damage at bends:

- test method 1 – Failure time characterisation as a function of the launch power and bend conditions (bend angle and bend diameter);
- test method 2 – Equilibrium temperature measurement.

Results from the two methods can only be compared qualitatively.

The results in this report are predominantly on un-cabled and un-buffered fibres. Cabled and buffered fibres are expected to respond differently, because the outer layers can affect the ageing process. Note also that test method 2 testing cannot be applied to buffered or cabled fibres.

These methods do not constitute a routine test to be used in the evaluation of optical fibre.

The parameters derived from the two methods are not intended to be specified within a detailed fibre specification.

The catastrophic failure modes arising and which are described in this document in general occur at bending radii much smaller than specified in the single-mode fibre specification IEC 60793-2-50 or than would be recommended based on mechanical reliability considerations alone.

This report includes several annexes, including a discussion on the rationale for the approaches adopted, metrics for assessment, guidance, examples and some conclusions from initial studies.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60793-1-47, *Optical fibres – Part 1-47: Measurement methods and test procedures – Macrobending loss*

IEC 60793-2-50, *Optical fibres – Part 2-50: Product specifications – Sectional specification for class B single-mode fibres*

IEC 60825-1, *Safety of laser products – Part 1: Equipment classification and requirements*

IEC 60825-2, *Safety of laser products – Part 2: Safety of optical fibre communication systems (OFCS)*

IEC 61300-2-14, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-14: Tests – High optical power*

IEC/TR 61292-4, *Optical amplifiers – Part 4: Maximum permissible optical power for the damage-free and safe use of optical amplifiers, including Raman amplifiers*

3 Background

Optical network operators have been considering the use of high-power lasers, for example fibre Raman amplifiers, in the central office with typical launch powers in the region of 500 mW to ~ 2 W. For standard installation practices where optical fibre minimum bend diameters are limited to 60 mm, these powers have not constituted a problem. However there is good evidence that bends tighter than the recommended 50 mm minimum bend diameter mistakenly occur in practice. It is believed that these generally arise after installation from maintenance practices which are difficult to mitigate against as the technicians servicing such networks often work independently and can come from different organizations.

Tight bends arising at system installation stage should generally be identified and eliminated following provisioning by OTDR testing or from link loss measurements. Experimental evidence shows that high-power damage can occur relatively quickly at bends less than 15 mm diameter using standard single-mode fibres (e.g. category B1.3). Damage occurs when the coating temperature increases at tight bends as the coating absorbs the light lost at the bend. Damage can take the form of coating ageing, pyrolysis[1] and burning and (if the temperature increases above 700 °C) catastrophic softening of the glass. Burning of the coating can result in a fire. Background references are available in references [1][2] to [15] and in IEC/TR 61292-4.

The rationale for studying the resilience of optical fibre and coatings to high-power damage at bends is described in Clause A.1. Telecommunications operators can adopt a range of options to avoid the risk of damage, see Clause A.2. There is now a broad agreement from a number of laboratories on the catastrophic failure modes of the optical fibre including the thresholds for damage at high powers in bent optical fibres. Some observations are given in the following list:

- Research has clearly shown that high optical power at tight fibre bends can cause catastrophic damage within a few days. Tests on a range of different fibres including B1, B4 and B6 primary coated fibre categories have shown that catastrophic damage can conveniently be grouped into two regimes:
  - Regime 1. Catastrophic failure of the glass (R1);
  - Regime 2. Catastrophic failure to the fibre coating (R2).

  A third regime, R3, has been identified in which catastrophic damage does not occur. Here the temperature does not reach a sufficient level to cause short-term catastrophic damage but over the longer term, coating ageing and a change in some of the physical properties of the coating may result.

  A further description of the observed regimes of damage is included in Clause A.5.
- R1 and R2 failures have been observed in both primary and secondary coated fibres. Some single-mode fibre categories and coating types are more resilient than others, See references [1], [2], [3], [4], [5], [6], [7], [8], [9], [10], [11], and [12].
- Coating ageing can take a considerable time (e.g. reference [2]). However, it is an indicator of potential R1 or R2 damage. Refer to Clause A.5.

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1 Pyrolysis is a thermochemical decomposition of organic material at elevated temperatures without the participation of oxygen.

2 Figures in square brackets refer to the bibliography.

- Arguably at present, the greatest risk of damage to single-mode fibre systems is due to the use of high-power Raman pumps at 1 480 nm, hence much of the testing has been carried out at this wavelength. Whilst there are general indications that the absorption spectra of cured coating materials are generally flat in the 1 450 nm to 1 625 nm range, in specific coating formulations absorption features could make a coating especially sensitive at a particular wavelength.

  Also, bend loss in single-mode fibres generally increases with wavelength, so risk of damage due to high carried power at tight bends may increase at longer wavelengths. More testing is needed to examine fibre bend loss characteristics and the absorption spectra of cured coating materials to ensure that wavelength dependent effects are accounted for.

- For laboratory testing and high-power system operation, there are important safety issues to be considered including a risk of flame and fire. These issues are addressed in 4.1.
- The subject of high-power damage sensitivity is in development and the following are areas for further work:
  - As discussed above, much of the testing so far has been carried out at or near to 1 360 nm or 1 480 nm and the effect of a significant change to the test wavelength is not known. Experimental results for damage testing at wavelengths near 1 550 nm and 1 625 nm would be useful; see also reference [11].
  - Coating absorption. Some studies have examined the effects of changing coating composition and the ambient environment, see – references [13] and [14].
  - The testing of fibres with different primary coatings (both coloured) and of different outer diameter (OD), e.g. 200 μm.
  - The effect of fibre production variability and for example, testing the effect of fibres with different MAC (MFD [μm]/cut-off wavelength [μm]) numbers but with the same profile type. Similarly testing of fibres with small differences in coating uniformity, composition or degree of coating cure needs to be considered.
  - Testing diverse bend geometries; the impact of bend loss variations.
  - The impact of ambient temperature.
- For the most sensitive fibre tested so far the threshold for damage (R2) for a bend loss of 4 dB bend is ~ 200 mW, see reference [15].
- The use of different fibre secondary coatings (buffer layers to an OD of ~ 800 μm) can lower or raise damage thresholds, see reference [15].

NOTE 1 Catastrophic failure occurs when the bend loss and consequent coating absorption drives the fibre temperature far above the maximum temperature for environmental tests of conventional UV curable acrylate coatings, as specified in IEC 60793-2-50.

The purpose of this report is to define measurement techniques to characterize the robustness of optical fibre to damage of this type. However, if new fibres are developed to minimize the possibilities of high-power damage at bends, other transmission and compatibility issues shall be considered – see Clause A.3.

NOTE 2 Also in ITU-T, a recommendation associated with high-power optical systems has been developed, see ITU-T Recommendation L.68 [16].

Throughout this technical report, illustrative data is presented for particular B1 and B4 fibre categories identified by letter from A to G from studies documented in references [2], [3], [7], [15]. Data on B6 category fibres is present in reference [11].

4 Test procedures

4.1 Safety

4.1.1 Safety issues

There are a number of important issues both for testing and for operational systems use:

- eye safe working;
- risk of fire/flame;
- risk of atmospheric pollution from coating by-products;
- risk of fibre fuse initiation;
- risk of damage to downstream components.

Some discussion on these issues is covered. However, an individual assessment of risk should be carried out prior to commencing a programme of tests depending on previous experience with high-power lasers, the local working practices and the test laboratory configuration. Also, it is recommended for first tests that an operator monitors the experiment continually so that the failure conditions with specific fibre categories and/or coating types can be correctly determined. The use of a video camera to monitor the fibre bend at high power can provide a safer working environment.

4.1.2 Eye safe working

All necessary safety procedures shall be taken in accordance with IEC 60825-1 and IEC 60825-2. These test procedures involve the use of optical powers that can constitute potential ocular and skin hazards for test personnel.

At 1 480 nm, the risk of retinal damage is much reduced compared with shorter wavelengths, as incoming radiation will mainly be absorbed in the cornea, see reference [17]. Nevertheless, care shall be taken to ensure that accidental exposure cannot occur and that high powers are only switched on once the fibre (and test condition) has been set up. Also, the use of optical instruments for viewing can be more hazardous than not.

Laser light blocks should also be used to trap and mask radiation leaking from the test bend.

4.1.3 Risk of fire/flame

WARNING In the case of samples that can sustain a flame, care shall be taken to ensure that sample holders are non-flammable and robust clamps are used to hold the fibres in position during testing.

4.1.4 Risk of atmospheric pollution from coating by-products

At high powers and elevated coating temperatures, volatile components in the fibre coating will be driven off. As this occurs, and with time, the coating volume reduces, oxidation occurs and the coating discolours. The aged or damaged coating volumes involved are small as the damage region at a fibre bend is generally extremely localized. To reduce the risk of local atmospheric pollution, it is recommended that the fibre bend test zone is hooded and an extract fan is run continuously to capture particulate and purge potentially hazardous air borne coating by-products.

4.1.5 Risk of fibre fuse initiation

At high optical powers and with appropriate triggering, it is possible to initiate the ‘fibre fuse effect’ (see reference [18]). Generally, launch powers of ~ 2 W to 3 W are required to trigger this effect and the laser supply can be protected from such a risk by incorporating an optical isolator or a fibre taper just after the laser source.

4.1.6 Risk of damage to downstream components

With some fibre samples and with the high power being lost from the fibre at a bend, there may be a risk to downstream components, for example where a test fibre is jointed to a different fibre category or at a further bend. To mitigate this risk, all components used shall be rated at the power to which they could be exposed.

4.1.7 Risk avoidance

A number of steps can be taken to reduce identified risks:

- Access to the test laboratory can be restricted to authorized users.
- Warning lights external to the laboratory can alert visitors of the high-power laser hazard. Laser safety spectacles can be made available for lab users and visitors.
- A video camera can be used to monitor the test bend and reduce the need to view the test fibre directly. This reduces the risk of exposure to high-power radiation.
- The laser control system could incorporate optical monitoring for the duration of the experiment. This can allow the driving PC to auto-shutdown the laser when a failure event is identified.
- Fibres can be carefully clamped and/or taped in position in robust clamps for the duration of the tests.
- Fire extinguishing equipment should be on-hand.

4.2 General

A suitable experimental arrangement for high-power damage testing is illustrated in Figure 1. The apparatus description applies to both test methods. However, in test method 1 the infra-red (IR) camera is not necessary and can be replaced by a normal colour camera – useful for experimental monitoring purposes. The test condition suggested is as follows:

- two-point bend geometry (where the fibre is fixed at two points and allowed to form a bend in free space);
- 180° configuration.

Other test conditions are discussed in Clause A.4.

4.3 Apparatus

4.3.1 Light source

A suitable high-power source at 1 360 nm or 1 480 nm is proposed for the nominal test wavelength (although the performance at other, typically longer, wavelengths needs to be considered as discussed in Clause 3). Launch powers from 100 mW to 1 500 mW or even to 5 W (reference [15]) need to be considered.

4.3.2 Isolator

An optical isolator or fibre taper that can act as a ‘fuse’, protecting the laser shall be used.

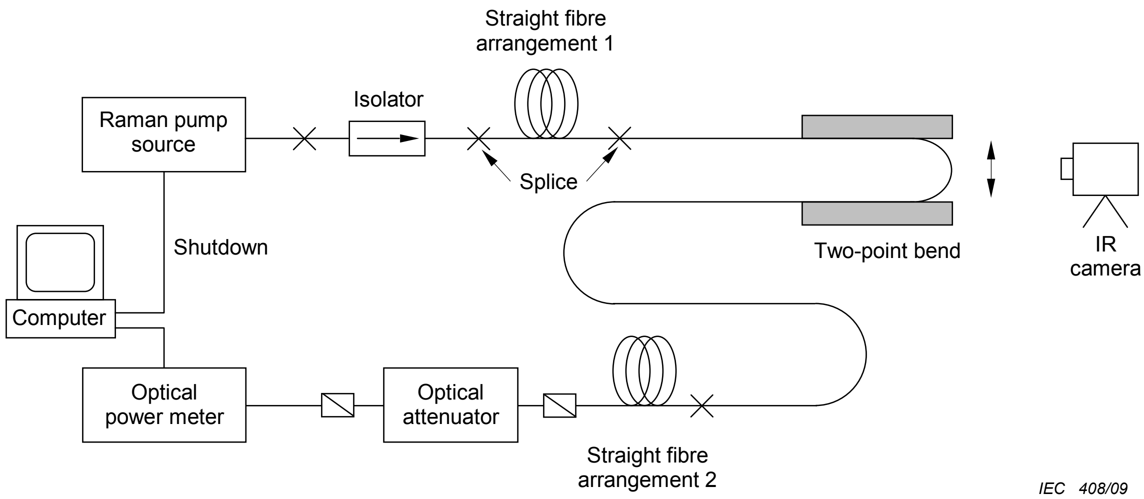

Figure 1 – Example of experimental layout

4.3.3 Bend jig

The fibre is constrained according to the two-point bend method, forcing the fibre into an oval configuration (see A.7.3 and reference [19] for a detailed discussion), of 180° although, the performance in other bend geometries and angles needs to be considered, see A.5.3. Detail on the clamping of fibres is described in A.4.2.

4.3.4 Receiver

Optical power monitoring device, which ensures stability and consistency between tests.

4.3.5 Attenuator

A 99:1 fused fibre coupler and/or a variable attenuator can be used to reduce the power level for conventional optical detectors. Alternatively a suitable high-power detector could be used for monitoring purposes.

4.3.6 Computer

Supervisory software on the controlling computer can be used to automatically shut down the laser within a few seconds in the event of signal loss and/or fibre failure.

4.3.7 Camera

The use of a video camera to monitor the fibre bend at high power can provide a safer working environment.

4.3.8 Thermal imaging camera

The maximum fibre temperature near to the bend apex can be measured using a forward looking infrared (FLIR) camera. Suitable cameras include the Thermacam™ PM695 from FLIR Systems with a sensitivity of ~1 °C.

4.3.9 Oven

A temperature controlled oven can provide a high temperature ageing environment for fibre and coatings.