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Edition 2.0 2010-03

TECHNICAL REPORT

colour inside

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

IEC/TR 61292-4:2010(E)

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland
Email: inmail@iec.ch
Web: www.iec.ch

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OPTICAL AMPLIFIERS –

Part 4: Maximum permissible optical power for the damage-free and safe use of optical amplifiers, including Raman amplifiers

FOREWORD

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IEC 61292-4, which is a technical report, has been prepared by subcommittee 86C: Fibre optic systems and active devices, of IEC technical committee 86: Fibre optics.

This second edition cancels and replaces the first edition published in 2004 and constitutes a technical revision with updates reflecting new research in the subject area.

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

Enquiry draft	Report on voting
86C/889/DTR	86C/921/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.

A list of all parts of the IEC 61292 series, published under the general title *Optical amplifiers,* can be found on the IEC website.

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- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

This technical report is dedicated to the subject of maximum permissible optical power for damage-free and safe use of optical amplifiers, including Raman amplifiers. Since the technology is quite new and still evolving, amendments and new editions to this document can be expected.

Many new types of optical amplifiers are entering the marketplace and research on it is also stimulating many new types of fibre and non-fibre based optical amplifier research. With the introduction of such technologies as long-haul, 40 Gb/s, WDM transmission and Raman amplification, some optical amplifiers may involve optical pump sources with extremely high optical power – up to, possibly, several watts.

Excessively high optical power may cause physical damage to the fibres/optical components/equipment as well as present medical danger to the human eye and skin.

The possibility of fibre damage caused by high optical intensity has recently been discussed at some technical conferences. IEC technical committee 86 (Fibres optics) and subcommittee 86A (Fibres and cables) has published IEC 62547: *Guidelines for the measurement of high-power damage sensitivity of single-mode fibres to bends – Guidance for the interpretation of results*. IEC technical committee 31 (Equipment for explosive atmospheres) is also discussing the risk of ignition of hazardous environments by radiation from optical equipment.

The medical aspects have long been discussed at standards groups. IEC technical committee 76 (Optical radiation safety and laser equipment) precisely describes in IEC 60825-2 the concept of hazard level and labelling and addresses the safety aspects of lasers specifically in relation to tissue damage.

ITU-T study group 15 (Optical and other transport networks) has published Recommendation G.664, which primarily discusses the automatic laser power reduction functionality for safety.

With the recent growth of interest in fibre Raman amplifiers, however, some difficulties have been identified among optical amplifier users and manufacturers in fully understanding the technical details and requirements across all such standards and agreements.

This technical report, therefore, provides a simple informative guideline on the maximum optical power permissible for optical amplifiers.

OPTICAL AMPLIFIERS –

Part 4: Maximum permissible optical power for the damage-free and safe use of optical amplifiers, including Raman amplifiers

1 Scope and object

This part of IEC 61292, which is a technical report, applies to all commercially available optical amplifiers (OAs), including optical fibre amplifiers (OFAs) using active fibres, as well as Raman amplifiers. Semiconductor optical amplifiers (SOAs) using semiconductor gain media are also included.

This technical report provides a simple informative guideline on the threshold of high optical power that causes high-temperature damage of fibre. Also discussed is optical safety for manufacturers and users of optical amplifiers by reiterating substantial parts of existing standards and agreements on eye and skin safety.

To identify the maximum permissible optical power in the optical amplifier from damage-free and safety viewpoints, this technical report identifies the following values:

– the optical power limit that causes thermal damage to the fibre, such as fibre fuse and fibre-coat burning;
– the maximum permissible exposure (MPE) to which the eyes/skin can be exposed without consequential injury;
– the optical power limit in the fibre that causes MPE on the eyes/skin after free-space propagation from the fibre;
– the absolute allowable damage-free and safe level of optical power of the optical amplifier by comparing (a) and (c).

The objective of this technical report is to minimize potential confusion and misunderstanding in the industry that might cause unnecessary alarm and hinder the progress and acceptance of advancing optical amplifier technologies and markets.

It is important to point out that the reader should always refer to the latest international standards and agreements because the technologies concerned are rapidly evolving. In fact, the concept of hazard level and labelling is still evolving: more rigorous labelling requirements are under discussion in IEC Technical Committee 76 as of October 2008.

The present technical report will be frequently reviewed and will be updated by incorporating the results of various studies related to OAs and OA-supported optical systems in a timely manner.

2 Normative references

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

IEC 60825-1:2007, *Safety of laser products – Part 1: Equipment classification and requirements*

IEC 60825-2:2006, *Safety of laser products – Part 2: Safety of optical fibre communication systems (OFCS)*
Amendment 1(2006)

IEC/TR 60825-14:2004, *Safety of laser products – Part 14: A user's guide*

ITU-T Recommendation G. 664, *Optical safety procedures and requirements for optical transport systems*

3 Abbreviated terms

For the purposes of this document, the following abbreviated terms apply.

ALS	automatic laser shutdown
APR	automatic power reduction
DSF	dispersion shifted fibre
LOS	loss of signal
MFD	mode field diameter
MPE	maximum permissible exposure
MPI-R	single channel receive main path interface reference point
MPI-S	single channel source main path interface reference point
NOHD	nominal ocular hazard distance
NZ-DSF	non-zero dispersion shifted single-mode optical fibre
OA	optical amplifier
OFA	optical fibre amplifier
SMF	single mode fibre
SOA	semiconductor optical amplifier

4 Maximum transmissible optical power to keep fibres damage-free

4.1 General

The use and reasonably foreseeable misuse of high intensity optical amplifiers may cause problems in the fibre such as:

a) fibre fuse and its propagation;
b) heating in the splice point/connection point;
c) fibre end-face damage due to dust and other contamination;
d) fibre coat burning and ignition of hazardous environments due to tight fibre bending or breakage.

This clause introduces the experiments and their results concerning the above issues to give guidelines for the damage-free use of optical amplifiers. However, it must be noted that the following results are only valid under the conditions tested and that a higher power might be allowed under different conditions.

NOTE The test method for the failure time (the time until the catastrophic failure of the glass, or the catastrophic failure to the fibre coating happens) characteristics as a function of the launch power and bend conditions (bend angle and diameter) is described in IEC 62547.

4.2 Fibre fuse and its propagation

4.2.1 Introduction

The safety of optical amplifiers should be discussed from the viewpoint of laser hazard to the eyes and skin as well as fibre damage such as fibre-coat burning and fibre fusing. This technical report experimentally analyzes the fibre fuse and its propagation caused by high optical power and discusses the threshold of optical power.

4.2.2 Experiment and results

The experimental setup is shown in Figure 1, in which the fibre fuse was initiated by heating the optical fibre from outside of the fibre by using an independent heat source, while a high optical power was continuously launched into the fibre. The wavelength of the high-power optical source was 1 467nm, which is a typical pump wavelength for distributed Raman amplification.

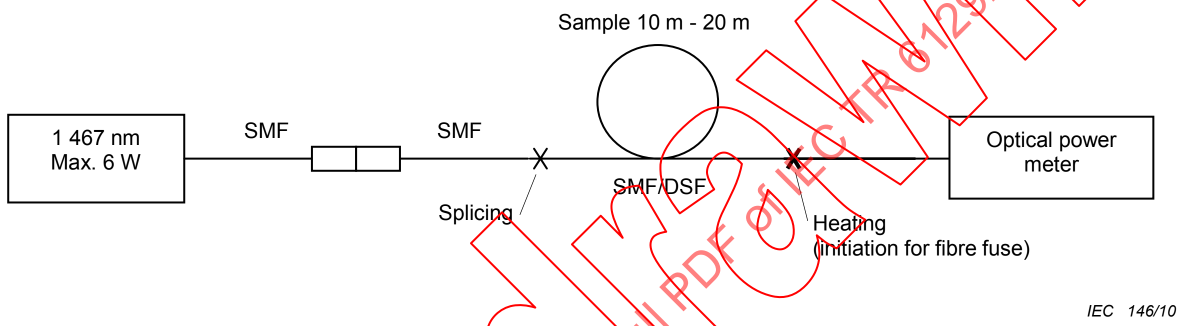


Figure 1 – Experimental setup for fibre fuse propagation

It was confirmed that the temperature of the fibre portion heated when the fuse initiated was greater than 1 000 °C. Once the fibre fuse began propagating, the optical source power was continuously reduced until the fuse propagation stopped. The threshold power for the fuse propagation was 1,4 W and 1,2 W for standard single mode fibre (SMF) and dispersion shifted fibre (DSF) respectively as shown in Table 1. The results for three trials are shown.

Table 1 – Experimental results of the threshold power of fibre fuse propagation

Standard single mode fibre	1,41 W, 1,45 W, 1,51 W
Dispersion shifter fibre	1,19 W, 1,19 W, 1,20 W

The difference in the fibre mode-field diameter might have been the major reason for the difference in the threshold powers because the fibre fuse depends on the power density [1][1]. The threshold power for the fibre fuse propagation was quite reproducible.

On the other hand, it was difficult to identify the threshold power for the fibre fuse initiation based on the above experiments because it varied significantly.

Although the mechanism of fibre fuse initiation is not yet well understood, the threshold seems to depend on the conditions, i.e., clean or dirty, of the fibre end faces where the very first fibre fuse takes place.

It was confirmed through repeated experiments, however, that the initiation threshold well exceeded 1,2 W and 1,4 W for various fibre end-face conditions.

1 Figures in square brackets refer to the Bibliography.

The above information was made available from Furukawa Electric (Japan in Oct. 2002) and was reported [1] at the 2003 International Laser Safety Conference in Jacksonville, FL, USA.

This issue was also discussed in other literature [2] [3] as follows.

The main physical mechanism responsible for the fibre fuse phenomenon and its propagation is optical discharge propagation due to thermal conductivity. It can be initiated in most fibre types by launching a CW laser into a fibre and ensuring contact of the fibre output end face with some absorbing surface or by heating a section of the fibre.

The temperature of the optical discharge plasma is about 5 000 °K to 10 000 °K. The speed of its propagation is about 1m/s in typical single mode fibres at a laser power of approximately 1 W. Examination of the fibre core after such discharge reveals extensive damage in the form of voids which have the form of bubbles (sometimes periodic) or long non-periodic filaments.

Because the most probable reason for optical discharge is a contaminated end face, fusion splicing is the most reliable way to reduce the risk of high-power damage. Optical isolators used in some schemes can also be damaged. Unfortunately, their survivability at high power is an open question.

The literature [3] includes a figure reporting the measured dependencies of threshold intensity for the propagation of optical discharge through the fibre (the power at which such propagation is terminated) on the mode field diameter of single-mode fibres of different core compositions.

The figure includes 21 data points among which, however, just one experimental point using 1,48 micrometer wavelength for silica-based single-mode fibre is applicable [2] to typical optical transmission systems.

The threshold intensity I_{th} for this experimental point was 1,0 (MW/cm^2) for MFD (mode field diameter) Dm = 12,6 micrometer. The threshold power is calculated as 1,3 W.

4.2.3 Conclusion

The threshold optical powers of fibre fuse propagation reported in Figure 1 and Table 1 were found to be 1,4 W and 1,2 W for SMF and DSF respectively under the conditions tested. On the other hand, the fuse-initiation threshold varied significantly, although they well exceeded 1,4 W and 1,2 W. Another report identified that 1,3 W could be allowed for SMF, although the information available on the fibre was limited.

4.3 Loss-induced heating at connectors or splices

4.3.1 Introduction

In extremely high power optical amplifiers, the loss-induced heating at fibres and connectors or splices could lead to damage, including fibre-coat burning, fibre fuse, etc. This subclause provides experimental data [4] and considerations for information.

4.3.2 Experiment on the connector

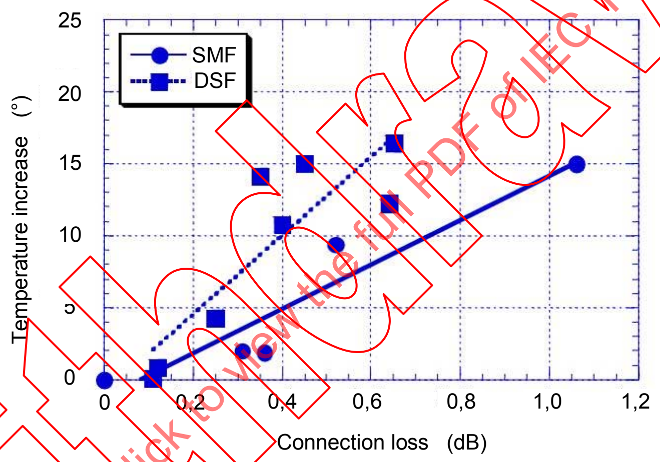
Table 2 summarizes the measurement conditions. The experiment used MU type optical connectors for standard single mode fibre (SMF) and dispersion-shifted fibre (DSF), where loss was increased by optical fibre misalignment. The optical source used was a 2-W Raman pump at 1 480 nm. The connector temperature was measured by a thermocouple placed on the sleeve. Since the MU ferrule diameter was only 1,25 mm, the sleeve temperature was almost the same as that of the ferrule; ferrule temperature is the most important factor determining the long-term reliability of optical connectors [5].

Table 2 – Measurement conditions

Parameter	Conditions
Fibre	SMF, DSF
Connectors	MU type
Ferrule	Zirconia
Connector/splice loss	Imperfect alignment
Wavelength	Raman pump – 1 480 nm
Power	2 W
Temperature measurement	Thermocouple on the sleeve

4.3.3 Results and considerations

Figure 2 shows temperature increase versus connection loss. More temperature increase was observed in DSF than in SMF due to higher power density.



IEC 147/10

Figure 2 – Connection loss versus temperature increase

The data suggest that the temperature increase could be within 10 °C under realistic conditions of loss and power. A commercial dry-type connector cleaner was used each time.

During repeated connection-disconnection of the connectors, neither damage nor fibre fuse was observed. The experiments with the use of the cleaner identified no problems in terms of fibre/connector damage and reliability. Without the cleaner, however, the experiment with the DSF connector indicated that fibre fuse could occur after repeated connection-disconnection of more than 200 times.

Such temperature increase, and accordingly the danger of fibre fuse, for non-zero dispersion shifted single-mode optical fibre (NZ-DSF) connectors will be worse than SMF connectors but better than DSF connectors; the effective areas are SMF>NZDSF>DSF. Further quantitative studies are needed. Other types of physical contact (PC) connectors such as SC connectors will show similar temperature responses because only their ferrule radii differ.

4.3.4 Conclusion

It was shown that the thermal effects induced by connector and splice losses in high-power amplifiers could be acceptable under any practical conditions foreseeable at this moment. However, special care should be taken to eliminate dust and contamination from the connector end faces and splice points that could locally induce high-temperature increases according to the power density absorbed.

4.4 Connector end-face damage induced by dust/contamination

4.4.1 Introduction

The purpose of this measurement is to evaluate the increase in attenuation of the connector under test when the light power into the fibre is extremely high. This technical report summarizes the document available from Telecom Italia Lab [6].

4.4.2 Test setup

Figure 3 shows the scheme of the measurement set up used in the test. The laser pump of a Raman amplifier was used with a maximum nominal power of 2 W, at a wavelength of 1 455 nm.

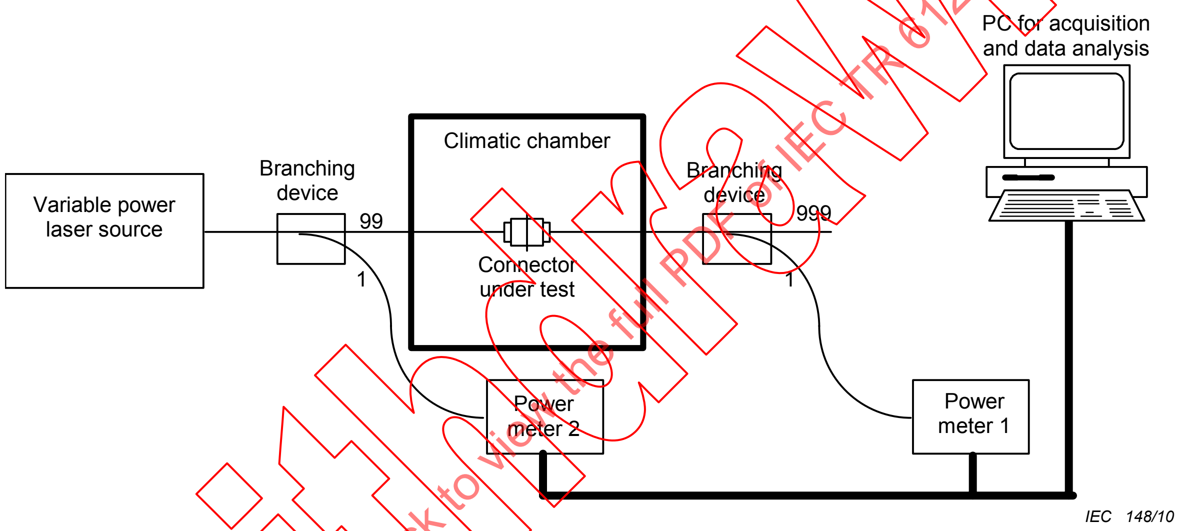


Figure 3 – Test setup

4.4.3 Measurements

Each step was maintained for 2 h. The optical connectors used were SC-PC type with a perfectly clean surface, with skin grease (from operators), with dust (from the floor of the lab) and with metal filings (from a metallic sleeve).

4.4.4 Test on clean connectors

Two plugs without defects on the polished fibre surface were used. The laser power was increased in steps to 1,2 W after a thorough cleaning. The test was conducted at ambient temperature and in a chamber at 70 °C. During the entire test, the variation of the attenuation was less then 0,02 dB and the visual examination of the fibre surface at the microscope did not show any damage.

4.4.5 Test on connectors contaminated with skin grease

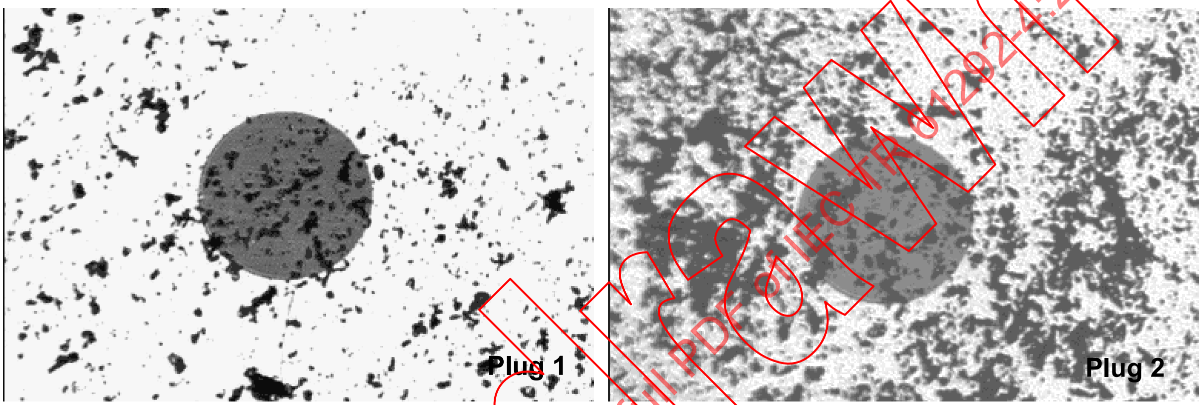
A layer of grease was put down on two plugs without any defect, by simply touching the polishing surface with the hands. When increasing the power from 100 mW to 1 200 mW at ambient temperature, the attenuation varied within a few hundredths of a dB. The visual inspection with a microscope after the test showed a cleaning effect, probably due to high temperature near the fibre. After the surface cleaning, no damage was observed.

4.4.6 Test on connectors contaminated with dust

In this case, dust from the laboratory floor was put on the polishing surface of the plugs. After the initial increase of the attenuation from zero (= normalized value) to 0,06 dB with 200 mW input power, the attenuation started to decrease with the increase in the power until –0,15 dB with 1,2 W input power. This effect of improvement in power transmission could be due to a cleaning action of the high temperature on the finest particles. Also in this case, after the cleaning at the end of the test, the surfaces did not show any damage.

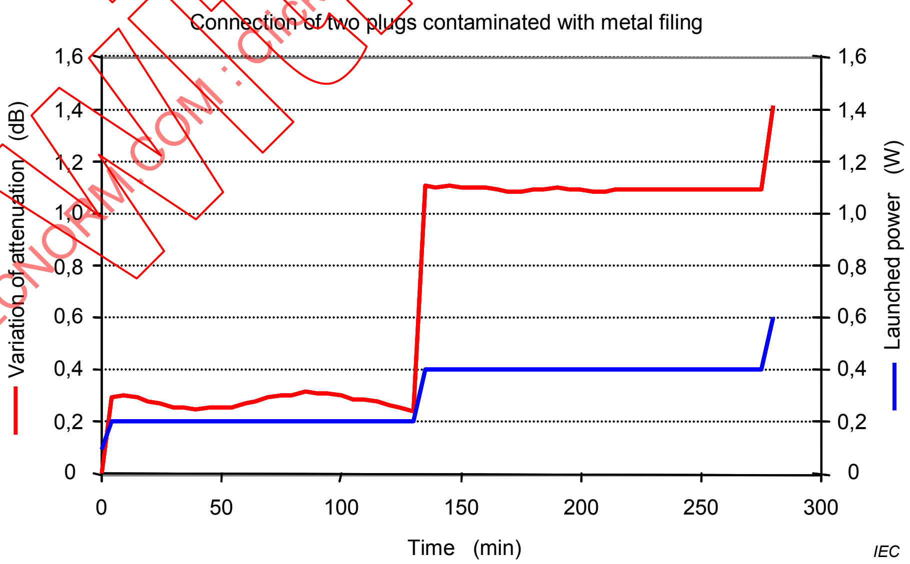
4.4.7 Test on connectors contaminated with metal dust

In this test, we put down on the plug surfaces metal dust obtained by filing a metallic sleeve of an adapter. This condition simulates the presence of metallic particles produced by the friction of the ferule during the insertion into a metallic sleeve.



IEC 149/10

Figure 4 – Surface condition contaminated with metal filings, before the test

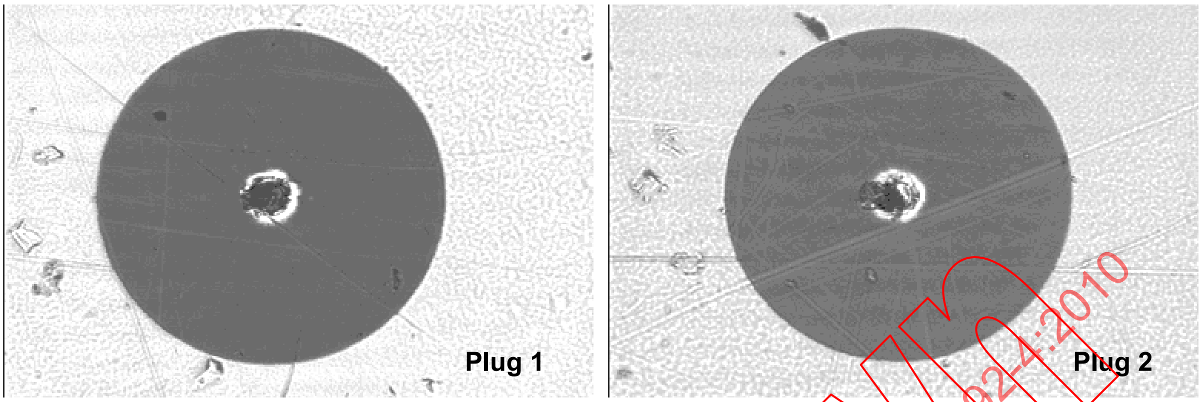


IEC 150/10

Figure 5 – Variation of the power attenuation during the test at several power input values for plugs contaminated with metal filings

The first test was performed by heavily contaminating the surfaces, as Figure 4 shows. This is clear from the initial attenuation value that was 3 dB to 4 dB higher than the ones for the other conditions.

During the test, already at 200 mW, the attenuation increased by about 0,3 dB. At the 400 mW step, the damage was evident with attenuation increased to 1,1 dB (Figure 5). As failure occurred, the test was stopped to visually inspect the surfaces.



IEC 151/10

Figure 6 – Polishing surface condition contaminated with metal filing, after the test

Obvious signs of burning were observed on the core of both fibres that could not be eliminated by cleaning the surface. The polishing surface visual inspection by a microscope (Figure 6) shows fused metal glued on the fibre cores. These clots are not removable by cleaning the surfaces.

4.4.8 Conclusion

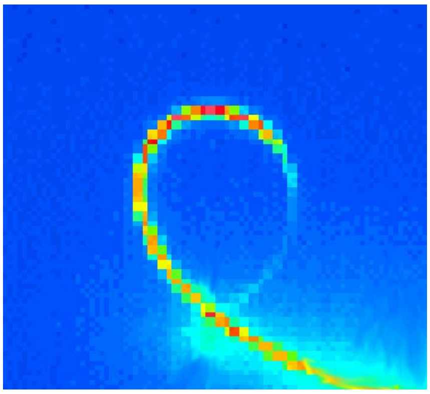
It was confirmed that there is no risk of damage on the connectors due to high optical power under the conditions tested, if the connectors are correctly used and handled. In particular, it is recommended never to open connectors while high optical power is passing through them. However, a correct cleaning procedure and visual analysis of the polishing connector surface is fundamental for a good and reliable network, particularly when metallic sleeves are used.

4.5 Fibre-coat burn/melt induced by tight fibre bending

This subclause [1] provides some examples of the fibre coat burn/melt induced by tight fibre bending where the fibre coatings used were (1) UV curable resin: white, blue, green and uncoloured, and (2) nylon white. The fibre used was single mode (SMF).

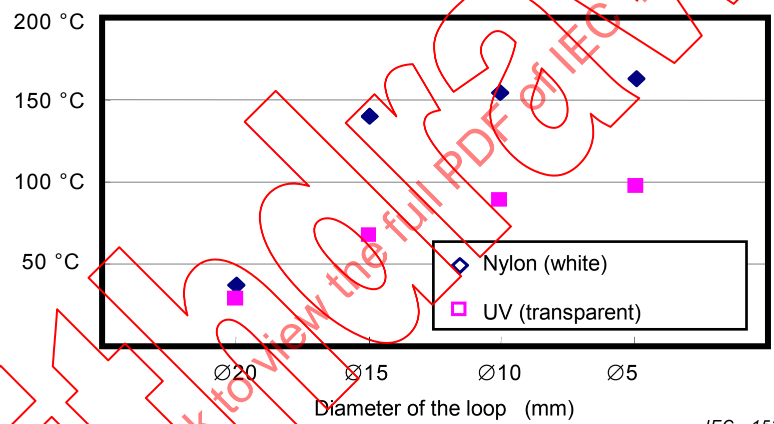
By using a thermo-viewer image of the bent fibre, the highest temperature at the surface of each fibre coating was measured. Figure 7 shows an image of the tightly bent fibre with an optical power of 3 W at 1 480 nm. Shown in Figure 8 is the temperature at the coating surface versus bending diameter for 3 W at 1 480 nm. The temperature of the nylon-coat surface reached 150 °C or higher; the nylon coating melted or even burned. The nylon coat burned in the test after the fibre break at the point where the fibre coat melted.

By considering the test results together with the long-term reliability degradation of coated SMF, it is suggested that the coated fibre bend diameter should be kept at >20 mm and >30 mm for the optical powers of 1 W and 3 W, respectively, under the conditions tested. Another test revealed that transparent UV-resin was more durable than coloured UV-resin against tight bending.



IEC 152/10

Figure 7 – Thermo-viewer image of tightly-bent SMF with optical power of 3 W at 1 480 nm



IEC 153/10

Figure 8 – Temperature of the coating surface of SMFs against bending with optical power of 3 W at 1 480 nm

4.6 Summary of the fibre-damage experiments

In 4.2, it was found that fibre fuse, once it is initiated for any reason, propagated if the input signal power was higher than 1,4 W and 1,2 W for SMF and DSF, respectively, under the conditions tested. However, care should be taken not to momentarily push the fibre across a sharp edge that may induce a tight bend and trigger fibre fuse even at a lower power than the above.

In 4.3, it was shown that the thermal effects induced by the connector and splice losses in high-power amplifiers could be acceptable under any practical conditions.

In 4.4, the connectors were tested with the input powers up to 1,2 W. It was discovered that the only case that caused permanent damage to the fibre core was when surfaces were contaminated by metal particles.

In 4.5, fibre coat burning induced by fibre tight bending was addressed. It is suggested to keep the bend diameter of coated fibre over 20 mm and 30 mm for optical powers of 1 W and 3 W, respectively, under the conditions tested.

Based on 4.2 to 4.5, it is concluded that power levels up to at least 1,2 W can be used without damaging OAs; the actual upper limit of the power is under study by considering, for example, the types of fibre and cleanliness of the fibre end faces.

5 Maximum transmissible optical power to keep eyes and skin safe

5.1 Maximum permissible exposure (MPE) on the surface of eye and skin

Definition 3.56 of IEC 60825-1 defines the MPE as follows:

MPE is "the level of laser radiation to which, under normal circumstances, persons may be exposed without suffering adverse effects. The MPE levels represent the maximum level to which the eye or skin can be exposed without consequential injury immediately or after a long time and are related to the wavelength of the laser radiation, the pulse duration or exposure duration, the tissue at risk and, for visible and near infra-red laser radiation in the range 400 nm to 1 400 nm, the size of the retinal image."

Here, the MPE values IEC uses have been specified in ANSI-Z136 based on animal experiments. Clause 4 of IEC 60825-14 gives more details of MPE.

Subclause 4.8.2 of IEC 60825-2 includes the following normative text in which it is requested that optical fibre communication systems be designed not to exceed the maximum permissible exposure (MPE), including the time period before an automatic power reduction (APR) system completes its job:

"Where the optical fibre communication system uses an automatic power reduction feature to meet the limits of a hazard level that is lower than that which would have to be assigned if no automatic power reduction feature would be present, the irradiance or radiation exposure during the maximum time to reach the lower hazard level shall not exceed the irradiance or radiant exposure limits (MPE). For controlled locations the measurement distance is 250 mm for this subclause only."

Here, the hazard levels of the laser products including OAs are determined based on the classification rule of IEC 60825-1. In the existing standards, automatic laser shutdown (ALS) could have the same meaning as automatic power reduction (APR).

5.2 Maximum permissible optical power in the fibre for the safety of eye and skin

Informative Annex D of IEC 60825-2 gives the following formula that calculates the maximum permissible optical power P in the fibre by using the maximum permissible exposure (MPE) to the eyes/skin after free-space propagation.

$$P = \frac{\pi d^2 MPE}{4t} \frac{1}{1 - \exp\left[-0{,}125\left(\frac{\pi \omega_0 d}{\lambda NOHD}\right)^2\right]}$$

where

P is the total power in fibre, in W;

MPE is the maximum permissible exposure, in Jm^{-2};

ω_0 is the mode field diameter ($1/e^2$ power density), in m;

d is the limiting aperture diameter, in m;

t is the shut down time, in s;

$NOHD$ is the nominal ocular hazard distance, in m;

λ is the wavelength, in m.

Based on the above formula, Table D.14 of IEC 60825-2 shows examples of power limits for optical fibre communication systems that have the APR to reduce the power to a lower hazard level. MPEs used in the calculation are shown in Tables 5, 6 and 7 of IEC 60825-14.

Table 3 reiterates the Table D.14 of IEC 60825-2. It must be noted that, however, the maximum permissible optical power in such OAs can be increased by reducing the power reduction time of the APR (the shut down time).

Table 3 – Examples of power limits for optical fibre communication systems having automatic power reduction to reduce emissions to a lower hazard level

Wavelength nm	Fibre mode field diameter µm	Maximum power output unrestricted mW	Maximum power output restricted mW	Maximum power output controlled mW	Shutdown times s	Measurement distance m
980	7	9,4	9,4	–	1	0,1
980	7	N/A	7,2	–	3	0,1
980	7	N/A	–	39	3	0,25
1 310	11	78	78	–	1	0,1
1 310	11	N/A	59	–	3	0,1
1 310	11	N/A	–	314	3	0,25
1 400 ... 1 500	11	1 598	1 598	–	0,3	0,1
1 400 ... 1 500	11	650	650	–	1	0,1
1 400 ... 1 500	11	N/A	389	–	2	0,1
1 400 ... 1 500	11	N/A	288	–	3	0,1
1 400 ... 1 500	11	N/A	–	2 403	2	0,25
1 400 ... 1 500	11	N/A	–	1 774	3	0,25
1 550	11	2 539	2 539	–	0,5	0,1
1 550	11	1 273	1 273	–	1	0,1
1 550	11	N/A	639	–	2	0,1
1 550	11	N/A	428	–	3	0,1
1 550	11	N/A	–	2 640	3	0,25

NOTE 1 The fibre parameters used are the most conservative case. Listed figures for λ = 1 310 nm ... 1 550 nm are calculated for a fibre of 11 microns mode field diameter (MFD) and those for λ = 980 nm are for 7 microns MFD.

Many systems operating at 1 550 nm with the use of erbium doped fibre amplifiers (EDFAs) pumped by 1 480 nm or 980 nm lasers use transmission fibres with smaller MFDs. For example, 1 550 nm dispersion shifted fibre cables have upper limit values of MFD of 9,1 microns. In this case, the maximum power outputs for unrestricted and restricted areas at 1 480 nm and 1 550 nm are 1,44 times the values in Table D.14 of IEC 60825-2, and those for controlled areas at 1 480 nm and 1 550 nm are 1,46 times the values in same table.

NOTE 2 Times given in the table are examples; shutdown at any shorter time than the maximum is permissible, and may permit the use of higher powers (the maximum times are 1 s for unrestricted locations and 3 s for restricted and controlled locations, respectively).

Here, it is assumed that the user does not employ any optical instrument or viewing optics within the beam. When optical instruments or viewing optics are not used, devices classified as 1M are considered safe under the conditions indicated in Clause 8 of IEC 60825-1. However, they may be hazardous if the user employs optical instruments or viewing optics within the beam.

5.2.1 Need for APR

ITU-T Recommendation G.664, Appendix II (*Considerations on APR mechanisms for systems employing Raman amplification*) states the following, suggesting that the APR is needed not only on the main optical signal sources but also on all pump-lasers employed:

"In particular Distributed Raman amplification systems will need specific care to ensure optically safe working conditions, because high pump powers (power levels above +30 dBm are not uncommon) may be injected in optical fibre cables."

"Therefore APR procedures are required in order to avoid hazards from laser radiation to human eye or skin and potential additional hazards such as temperature increase (or even fire) caused by local increased absorption due to connector pollution/damages or very tight fibre bends."

"In order to ensure that the power levels emitting from broken or open fibres connections are at safe levels, it is necessary to reduce the power not only on the main optical signal sources but also on all pump-lasers employed, in particular the backward pumping lasers."

5.2.2 Wavelengths

The safe limit of the optical amplifier power set by the MPE limit should include main optical signals, pump-laser powers and optical supervisory channel power, if used.

5.2.3 Locations

Table 4 shows location types within an optical fibre communication system and their typical installations. See IEC 60825-2.

Table 4 – Location types within an optical fibre communication system and their typical installations

Location type	Typical installation (informative)
Unrestricted access	Accessible by the public (e.g. domestic premises, premises open to the public)
Restricted access	Secured areas within business/commercial premises not open to the public (e.g. telephone PABX rooms, computer systems, etc.)
Controlled access	Cable duct, street cabinets, dedicated and delimited areas of distribution centres

5.2.4 Nominal ocular hazard distance (NOHD)

In controlled locations, NOHD at which the level of exposure should drop to the MPE for the eye is 25 cm, because personnel should be trained to keep the 25 cm distance. Otherwise the NOHD is 10 cm, because the minimum focal distance for the human eye is generally known as 10 cm.

5.2.5 Power reduction times

Power reduction time is the maximum time span after the incident before the APR completes its task. ITU-T Recommendation G.664 suggests as information the power reduction times for OAs in multi-vender systems. For systems without line amplifiers, the APR time suggested is less than 800 ms, and that for OAs in systems with line amplifiers is less than 3 s, as follows.

ITU-T Recommendation G.664, Appendix III states the following:

"After at least 500 ms of continuous presence of the LOS (loss of signal) defect, the actual shutdown command will be activated, which shall result in reduction of the optical output