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TECHNICAL REPORT

Reliability of devices used in fibre optic systems – General and guidance

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Reliability of devices used in fibre optic systems – General and guidance

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

RELIABILITY OF DEVICES USED IN FIBRE OPTIC SYSTEMS – GENERAL AND GUIDANCE

FOREWORD

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IEC 62721, which is a technical report, has been prepared by IEC technical committee 86: Fibre optics.

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

Enquiry draft	Report on voting
86/406/DTR	86/412/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- withdrawn,
- replaced by a revised edition, or
- amended.

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

INTRODUCTION

TC86 (Fibre optics) is a group that reviews and implements the standardization of optical fibres and optical cables, optical interconnecting devices, passive and active optical components and modules, and optical sub-systems. As these optical components and modules are used for telecommunications as well as data communications systems, the reliability required for these are extremely high. Since the 1980s, when fibre optic communication systems were first deployed for commercial use, the reliability of optical fibres, optical components and modules has been examined and checked. As a result, reliability theories are nearly completely established for optical fibre, optical connectors, optical passive components and optical active components.

How to check reliability differs depending on the type of optical device. For example, for optical fibres, it is measured by the probability of fibre breaks under the condition of constant stress. Optical passive components are generally tested using accelerated deterioration tests under high temperature and high humidity conditions. For the reliability of laser diodes (LD) (a typical optical active device), the primary failure mode is a decrease of optical output power and an increase of threshold electric current caused by the increase of the leakage of electrical current in the active layers of the LD chip. The lifetime has an inverse correlation with the drive current.

In addition, the industry has established and uses standard reliability evaluation tests developed for the purpose of commercialisation in addition to the approach of estimating the lifetime by failure mode analysis mentioned above.

Information on failure mode and lifetime estimates are discussed and summarised in many documents prepared by the Subcommittees (SC) and Working Groups (WG) of TC86. Test items and conditions for reliability qualification tests are described in documents prepared and set forth by each SC.

RELIABILITY OF DEVICES USED IN FIBRE OPTIC SYSTEMS – GENERAL AND GUIDANCE

1 Scope and objective

This technical report provides information on the IEC documents concerning reliability for optical fibres, optical connectors, optical passive components, optical active components, optical amplifiers, and optical dynamic modules used for optical fibre communications.

Documents on reliability include summaries of reliability theory and quality management methods, technical information on failure mode analysis and failure mechanisms, lifetime and fit-rate estimates using acceleration tests, test items, conditions, and pass/fail criteria in reliability qualification tests, and tests and measurement methods for optical fibres, optical components, and optical modules.

Each SC in TC86 has already created documents on reliability. This technical report provides this information in a user-friendly manner.

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 60068 (all parts), *Environmental testing*

IEC 60749 (all parts), *Semiconductor devices – Mechanical and climatic test methods*

IEC 60793-1 (all parts), *Optical fibres – Part 1: Measurement methods and test procedures*

IEC 60793-1-30, *Optical fibres – Part 1-30: Measurement methods and test procedures – Fibre proof test*

IEC 60794-1-2, *Optical fibre cables – Part 1-2: Generic specification – Basic optical cable test procedures*

IEC 61290 (all parts), *Optical amplifiers – Test methods*

IEC 61291-5-2, *Optical amplifiers – Part 5-2: Qualification specifications – Reliability qualification for optical fibre amplifiers*

IEC 61300 (all parts), *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures*

IEC 62005 (all parts), *Reliability of fibre optic interconnecting devices and passive components*

IEC 62007-2, *Semiconductor optoelectronic devices for fibre optic system applications – Part 2: Measuring methods*

IEC 62150 (all parts), *Fibre optic active components and devices – Test and measurement procedures*

IEC 62343-2, *Dynamic modules – Part 2: Reliability qualification*

IEC 62343-5-1, *Dynamic modules – Test methods – Part 5-1: Dynamic gain tilt equalizer – Response time measurement*

IEC 62572-3, *Fibre optic active components and devices – Reliability standards – Part 3: Laser modules used for telecommunication*

IEC/TR 62048, *Optical fibres – Reliability – Power law theory*

IEC/TR 62343-6-6, *Dynamic modules – Part 6-6: Failure mode effect analysis for optical units of dynamic modules*

IEC/TR 62572-2, *Fibre optic active components and devices – Reliability standards – Part 2: Laser module degradation*

IEC/TR 62627-03-01, *Fibre optic interconnecting devices and passive components – Part 03-01: Reliability – Design of an acceptance test for fibre pistoning failure of connectors during temperature and humidity cycling: demarcation analysis*

3 Generic information on reliability

Reliability generally means the characteristics of keeping the required performance over a long period of time and/or on repeated operation (driving). Components and modules degrade and finally fail after long term operation. Reliability is usually expressed in this case as failure rate per unit time (e.g. hours) or a time. The curve of the failure rate is called a bathtub curve, and is generally divided into three regions: initial failure region, random failure region, and wear-out failure region. Screening tests are sometimes applied to reduce the initial failure rate. In the random failure region, the failure rate is independent of the operating time. In the wear-out failure region, the failure rate increases as operating time extends. Generally, reliability is expressed by the failure-in-test (fit) rate in the random failure region, and in the wear-out failure region by the accumulated failure rate depending on the operating time of the product.

There are two types of reliability: design reliability and field reliability. Design reliability is generally estimated by accelerated test results and/or calculated by a cumulative total of fit rates of the parts and materials. Field reliability is generally calculated by the total failures and the total operating hour volume in the field.

The following shows the standard approach to design reliability:

- Conducting a failure mode analysis and analysing the performance of the parts which degrade and the factors that accelerate degradation;
- Determining the acceleration test conditions and the pass/fail criteria based on the results of failure analysis;
- Carrying out acceleration tests under different conditions and obtaining the appropriate functions to indicate the lifetime (i.e. the failure function (Weibull distribution, lognormal distribution)) and the acceleration factor;
- Carrying out lifetime tests under suitable conditions of the accelerated tests to obtain more accurate parameters for the lifetime distribution function and calculating the failure rate and the accumulated failure rate.

Besides the reliability estimate obtained in the procedures based on the failure mode analysis described above, conventional reliability qualification tests have been used for many types of optical components and modules that consider the component environment. In particular, merchantability is often determined by the result of reliability qualification tests for modules that are composed of several components and other functional components for which the failure mode is difficult to identify.

4 IEC documents on reliability in TC86

4.1 General

TC86 (Fibre optics) consists of three Subcommittees: SC86A (Fibres and cables), SC86B (Fibre optic interconnecting devices and passive optical components) and SC86C (Fibre optic systems and active devices).

There are different approaches to failure mode and reliability depending on the products handled by each Subcommittee.

It is generally known that a failure mode for silica-based optical fibres is where a small crack on the surface and/or inside the fibre grows by constant stress and leads to fibre breaks.

The degradation mode and degradation accelerating factors for optical connectors and optical passive components are very complex, as these optical components are fabricated by several types of parts made from different materials. Reliability is determined by failure mode analysis and based on the acceleration rate and reliability estimate result obtained by such analysis. Another approach to ensure reliability is to conduct a reliability qualification test in the user environment.

For a laser diode it is known that optical output power is decreased by the increase of electrical current leakage in the active layers in the LD chip. It is caused by dislocation growth and formation of dark spots and dark lines in the active area of the laser diode. This degradation mode is one of the typical wear-out failures and information on this failure has been sufficiently collected. In order to evaluate the reliability of the LD module, not the LD chip itself, the test methods for passive optical components are generally applied.

Optical fibre amplifiers and dynamic modules are typically modules or sub-systems composed of optical passive and active components. Reliability of these modules or sub-systems is reliant on the reliability of the parts of the modules or sub-systems. Reliability (fit rates) of modules is generally calculated by the cumulative sum of the fit rates of individual optical component parts. Besides the estimation of the failure fit rate, some types of aging (long-term operation) tests and mechanical tests are required to check the effect after mounting the component parts.

Information on reliability includes failure mode analysis, lifetime estimate by acceleration tests, and reliability qualification tests in addition to the general items on quality and reliability. TC86 SCs and WGs have developed and published various documents relating to quality and reliability in each product group.

Table 1 shows the TC86 classification mentioned above. Measuring methods are described in the table, as the application of these in each test is important to confirm the reliability and performance.

Failure and degradation relating to higher power is also of interest although different from the issue of long-term reliability. Annex A gives a list of documents relating to higher power that are published or in process within TC 86.

Table 1 – IEC documents on reliability of fibre optic devices

Types of contents	Optical fibre and cable	Optical passive components	Optical amplifiers	Optical active devices	Dynamic modules
Generic of reliability and quality	None	IEC 62005-1 IEC 62005-4 IEC 62005-5[a)] IEC 62005-7	IEC 61291-5-2	IEC 62572-3	IEC 62343-2
Failure mode and/or degradation analysis	TR 62048	IEC 62005-3	None	IEC/TR 62572-2	IEC/TR 62343-6-6
Lifetime estimation and/or fit rate calculation	TR 62048	IEC 62005-2 IEC/TR 62627-03-01	IEC 61291-5-2	IEC/TR 62572-2	IEC 62343-2
Reliability qualification test	60793-1-30	IEC 62005-9-1[a] IEC 62005-9-2 IEC 62005-9-4[a]	IEC 61291-5-2	IEC 62572-3	IEC 62343-2
Test and measurement	60793-1 series 60794-1-2	IEC 61300 series	IEC 61290 series	IEC 60068 series IEC 60749 series IEC 62007-2 IEC series	IEC 62343-5 series
[a] To be published.					

Details of reliability documents for each optical device are given in 4.2 to 4.6.

4.2 Reliability documents for optical fibres and cables

4.2.1 General

The reliability for silica optical fibre is described in IEC/TR 62048, which indicates how to estimate and calculate the reliability of optical fibre under constant stress.

Break modes are roughly classified into dynamic fatigue and static fatigue. Test methods of dynamic fatigue and static fatigue are defined by IEC 60793-1-33. The characteristics of dynamic fatigue can be obtained by measuring the stress rate dependency of the break stress. The characteristics of static fatigue are obtained by measuring the static stress dependency found during the time to break.

Lifetime is estimated from the static fatigue measurement. A Weibull distribution is generally applied to the lifetime distribution, and the failure rate and the estimated lifetime are expressed as the time to break per fibre length. Parameters are derived by plotting the accumulated failure rate for the break strength or the time to break on an approximate Weibull distribution chart to obtain the failure rate and the lifetime.

To ensure fibre strength, proof screening is commonly adopted. The detail of the proof screening method is defined in IEC 60793-1-30.

The documents noted above are reliability documents for silica fibres. The reliability of plastic optical fibre (POF) is for further study.

Various environmental tests for optical fibres and cables are defined in the IEC 60793-1 series and IEC 60794-1-2. These environmental tests are established for known environments during transportation, installation and on-site operation.

4.2.2 IEC 60793-1-30, *Optical fibres – Measurement methods and test procedures – Fibre proof test*

This international standard defines details of the screening test method. The proof screening method for optical fibres puts a tensile force on the whole length of fibre, so that the part of