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TECHNICAL REPORT

Fibre optic interconnecting devices and passive components – Part 03-04: Reliability – Guideline for high power reliability of passive optical components

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FOREWORD

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IEC/TR 62627-03-04, which is a technical report, has been prepared by subcommittee 86B: Fibre optic interconnecting devices and passive optical components, of IEC technical committee 86: Fibre optics.

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

Enquiry draft	Report on voting
86B/3641/DTR	86B/3676/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 the parts in the IEC 62627 series, published under the general title *Fibre optic interconnecting devices and passive components* 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- withdrawn,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.

INTRODUCTION

Since 2000, the optical power in transmission systems has increased in conjunction with the increase in the number of channels for DWDM systems, with the deployment of RAMAN amplifiers and the application of optical amplifiers.

Several technical reports have been published on failure mode analysis, life-time estimation by accelerated aging tests, and other issues for passive optical components.

The long-term reliability for passive optical components is generally evaluated by accelerated aging tests such as a high temperature test, a damp heat test and a temperature cycling test. These tests are standardized and are included in reliability qualification test documents.

Although the failure mode for passive optical components under high power conditions has not been clarified, one technical report was published for specific passive optical components (IEC/TR 62627-03-02), and a technical report on high power reliability testing for metal doped fibre plug-style optical attenuators was proposed.

This technical report is prepared based on the knowledge contained within these two technical reports.

FIBRE OPTIC INTERCONECTING DEVICES AND PASSIVE COMPONENTS –

Part 03-04: Reliability – Guideline for high power reliability of passive optical components

1 Scope

This part of IEC 62627, which is a technical report, is a guideline for a procedure to evaluate the reliability of passive optical components under high power conditions. This guideline is one example to which the test results of IEC/TR 62627-03-02 and IEC/TR 62627-03-03 may apply.

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

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

IEC 61300-3-35, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-35: Examinations and measurements – Fibre optic endface visual and automated inspection*

IEC/TR 62627-03-02, *Fibre optic interconnecting devices and passive components – Part 03-02: Reliability – Report of high power transmission test of specified passive optical components*

IEC/TR 62627-03-03, *Fibre optic interconnecting devices and passive components – Part 03-03: Reliability – Report on high-power reliability for metal-doped fibre optical plug-style optical attenuators*

3 Generic information

IEC/TR 62627-03-02 describes the return losses of metal doped fibre plug-style optical attenuators degraded under high optical input power at around 2 W, and the fibre in the ferrule of in-line optical isolators breaking and causing isolation failure. The thermal simulation estimated that the maximum temperature for metal doped fibre plug-style optical attenuators and in-line optical isolators could reach several hundred degrees Celsius. It was estimated that the return loss degradation for metal doped fibre plug-style optical attenuators was caused by fibre withdrawal from the ferrule surface due to the thermal stress following a rise in temperature. It was believed that the optical isolator fibre breaks were caused by the stress created by the differences in thermal expansion coefficients of the materials from which the parts were made.

Passive optical components are generally composed of several parts with different shapes and materials. The typical failure mode under long-term operation is generally related to a change of shape and optical path displacement due to the dislocation of fixing points for constituent parts. To confirm the reliability against these failure modes, passive optical components are tested under temperature cycling, high temperature and high humidity conditions, all of which are more severe than nominal operating conditions. These tests are called accelerated aging tests. The temperature acceleration factor is commonly calculated by using the Arrhenius formula. The test duration time for these accelerated aging tests is typically several months. It is based on the belief that normal operation over a long period of time, i.e. over ten or more years should be assured. Typical acceleration factors are several hundred times that of nominal operating conditions for high temperature, high humidity and temperature cycling. If the factor is greater than a thousand, the test conditions may be too severe and produce different failure modes than those found in actual service. A lower acceleration factor value requires longer test duration.

The failure mode and the failure mechanism under high power conditions described in IEC/TR 62627-03-02 comes from the thermal stress caused by heat that is generated by the absorption of input optical power. It may be effective to use an accelerated aging test to assure long term operation of passive optical components under high power conditions. However, no life-time estimation model was determined and little evaluation data has been reported on the high power accelerated aging test. IEC/TR 62627-03-03 describes the estimated maximum input power that will assure long term operation. A similar approach found in the study of high power reliability for passive optical components seems to be useful and effective.

4 Procedures for confirmation of high power reliability

The following describes the procedure for the estimation and confirmation of maximum input power to assure the long-term reliability for passive optical components:

a) develop a high power risk table to analyse the failure mode under the high power input condition for passive optical components;
b) estimate the failure mechanism using the high power risk table;
c) carry out a high power step-stress test for optical components or for the parts considered likely to fail;
d) identify the damage threshold power from the result of the high power step-stress test. Disassemble the components to analyse the failure mode, or carry out a thermal simulation, if needed. Identify the failure mechanism from the step-stress test result, the failure mode analysis and the risk analysis table. Estimate the maximum input power that can assure the long-term reliability based on the step-stress-test result and the thermal simulation;
e) carry out a long-term reliability test under high power conditions. Use the samples with the lowest performance to effectively find the failure mode and the failure mechanism.

5 Risk analysis under high power conditions

5.1 Example of risk under high power conditions

Generally, passive optical components consist of several types of parts and materials. There are some typical failure modes for some specific parts and materials under high power conditions. Table 1 shows the summary of the typical failure modes.

A typical failure mode for coating films on the crystals, prisms or lenses under high power conditions is the coating film damage due to increasing temperature caused by absorbing the light. The colour-centre is sometimes the trigger of absorption. The colour-centre may be produced by a lattice defect. It is known that the toughness of the coating film depends on the material of the film as well as the deposition method of the film.

An optical semiconductor such as PD (photo diode) under high power conditions fails due to the material change caused by the excess electrical current in a small region.

$LiNbO_3$ substrates fail due to the increase in propagating loss by photorefractive effect when the $LiNbO_3$ is irradiated by high power visible light.

The failure mode under high power conditions for other materials is a change in quality due to temperature increases caused by the absorption of light. For example materials such as adhesive resins can change in quality or soften at a relatively low temperature.

A rise of internal temperature of optical components induces a thermal stress among constituent parts having different thermal expansion coefficients. The thermal stress deforms the parts and degrades the performance of the components.

A temperature rise of specific parts can cause an unequal thermal distribution in components. Thermal stress induced deformation due to an unequal thermal distribution is a common failure mechanism for passive optical components under high power conditions.

Table 1 – Typical risks of materials on high power input condition

Materials	Components/modules	Failure modes
TFF coating (AR coating)	Almost all components and modules	Coating film damage due to increasing temperature by absorbing light
Semiconductor	LDs, PDs, APDs	Material change by excess current
LCD	VOAs, WSSs, WBs	Insertion loss increasing by absorption (Visible light, UV)
$LiNbO_3$	Modulators	Insertion loss increasing by photorefractive effect
Garnet	Isolators, circulators, VOAs	Damage due to increasing temperature by absorbing light
Metal doped fibre	Optical attenuators	Fibre withdrawal due to increasing temperature by absorbing light
Connector endface	Optical connectors	Damage of endface due to burnt contamination, etc. Insertion loss by scattering light at scratches
Adhesive	Waveguide devices, mechanical splices, etc.	Change in quality and softening due to increasing temperature by absorbing light
Silicone	BOSA for BIDIs, AWGs	Material changing due to increasing temperature by absorbing light
Refractive index matching liquid	Optical switches, AWGs, etc.	Material changing due to increasing temperature by absorbing light

5.2 Preparation of risk analysis table

To analyse the risk level under high power conditions for passive optical components, it is useful to summarize risk factors in a table for all optical parts and their supporting parts in the optical path of passive optical components. This analysis method is similar to FMEA (failure mode effect analysis) used to determine component reliability risks.

Table 2 shows an example of the format for a high power risk analysis table. It is usually recommended to summarize information about the parts in the optical path, materials, beam diameters, optical power densities, failure modes, influences on performance of optical components, severity levels, and the failure mechanism of components.

It is also necessary to consider the operating wavelength range of optical components. At this point, it should be verified that there are no input errors not only in the operating wavelength range but also in the neighbouring wavelength range.. Moreover, it should be considered that users may input wavelengths other than the specified operating wavelength range. In order to prepare a risk analysis table, all potential applications should be considered. When there are materials whose failure modes depend on wavelength, it is necessary to list specific wavelength(s) to have an accurate assessment of the risk of failure.

High power risk analysis tables for metal doped fibre plug-style optical attenuators, in-line optical isolators, and optical splitters are shown in Annex A, as examples.

Table 2 – Format of high power risk analysis table

Units	Parts	Materials	Beam diameters	Power densities	Failure modes	Influences to performance	Severity levels	Failure mechanisms

5.3 Estimation of failure modes and determination of test conditions

Risks and likely failure modes under high power conditions can be analysed using Tables 1 and 2. The risk factors should be summarized for different wavelength ranges and input/output ports, if necessary.

6 Step-stress test

6.1 General

A step-stress test should be carried out for the DUT (device under test), or for parts considered likely to fail. IEC 61300-2-14 describes the detail procedure of the step-stress test of high power damage threshold power characterization.

If it is likely that the failure modes are due to a quality change in some specific materials, the material itself should be tested before testing components to determine the beam density to be used.

6.2 Test set-up

The recommended test set-up for a high power test is shown in Figure 1. The laser safety should be confirmed to comply with IEC 60825-1 before the test is started. Fusion splices should be used to connect all of the optical components. Where connectorized components are utilized, connector interfaces should be inspected to be in compliance with IEC 61300-3-35. Any special optical components used to block the backward propagation of the fibre fuse phenomena, or long fibres used to detect the fibre fuse phenomena should be inserted between the high power light source and the first 20 dB coupler as shown in Figure 1. Fused fibre type optical branching devices should be used for power monitoring. The branching ratio of optical branching devices should be 20 dB or more. Individual 1×2 optical branching devices for input power monitoring (PM1) and for reflected power monitoring (PM3) should be used. This configuration can eliminate the influence of reflection from the optical connector fibre endface of input power monitor (PM1) to the reflected power monitoring (PM3). For safety purposes, at the end of the test setup, an optical termination such as metal doped fibre should be connected as shown in Figure 1.