SLOVENSKI STANDARD
SIST EN 4533-004:2009

01-junij-2009

Aeronavtika - Sistemi iz optiļ nih vlaken - Priroļ nik - 004. del: Popravila, vzdrģevanje in nadzor

Aerospace series - Fibre optic systems - Handbook - Part 004: Repair, maintenance and inspection

Luft- und Raumfahrt - Faseroptische Systemtechnik - Handbuch - Teil 004: Reparatur, Instandhaltung und Inspektion

Série aérospatiale - Systèmes des fibres optiques - Manuel d'utilisation - Partie 004 : Réparation, maintenance et contrôle

Ta slovenski standard je istoveten z: **EN 4533-004:2006**

ICS:

49.060	Letalska in vesoljska elektriļ na oprema in sistemi	Aerospace electric equipment and systems

SIST EN 4533-004:2009 **en,de**

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 4533-004

July 2006

ICS 49.060

English Version

Aerospace series - Fibre optic systems - Handbook - Part 004: Repair, maintenance and inspection

Série aérospatiale - Systèmes des fibres optiques - Manuel d'utilisation - Partie 004 : Réparation, maintenance et contrôle

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Ref. No. EN 4533-004:2006: E

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Foreword

This European Standard (EN 4533-004:2006) has been prepared by the European Association of Aerospace Manufacturers - Standardization (AECMA-STAN).

After enquiries and votes carried out in accordance with the rules of this Association, this Standard has received the approval of the National Associations and the Official Services of the member countries of AECMA, prior to its presentation to CEN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by January 2007, and conflicting national standards shall be withdrawn at the latest by January 2007.

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Introduction

a) The handbook

The handbook draws on the work of the Fibre-Optic Harness Study, part sponsored by the United Kingdom's Department of Trade and Industry, plus other relevant sources. It aims to provide general guidance for experts and non-experts alike in the area of designing, installing, and supporting multi-mode fibre-optic systems on aircraft. Where appropriate more detailed sources of information are referenced throughout the text.

It is arranged in 4 parts, which reflect key aspects of an optical harness life cycle, namely:

- Part 001: *Termination methods and tools*
- Part 002: *Test and measurement*
- Part 003: *Looming and installation practices*
- Part 004: *Repair, maintenance and inspection*

b) Background

It is widely accepted in the aerospace industry that photonic technology offers a number of significant advantages over conventional electrical hardware. These include massive signal bandwidth capacity, electrical safety, and immunity of passive fibre-optic components to the problems associated with electromagnetic interference (EMI). To date, the latter has been the critical driver for airborne fibre-optic communications systems because of the growing use of non-metallic aerostructures. However, future avionic requirements are driving bandwidth specifications from 10's of Mbits/s into the multi-Gbits/s regime in some cases, i.e. beyond the limits of electrical interconnect technology. The properties of photonic technology can potentially be exploited to advantage in many avionic applications, such as video/sensor multiplexing, flight control signalling, electronic warfare, and entertainment systems, as well as in sensing many of the physical phenomena on-board aircraft.

The basic optical interconnect fabric or `optical harness' is the key enabler for the successful introduction of optical technology onto commercial and military aircraft. Compared to the mature telecommunications applications, an aircraft fibre-optic system needs to operate in a hostile environment (e.g. temperature extremes, humidity, vibrations, and contamination) and accommodate additional physical restrictions imposed by the airframe (e.g. harness attachments, tight bend radii requirements, and bulkhead connections). Until recently, optical harnessing technology and associated practices were insufficiently developed to be applied without large safety margins. In addition, the international standards did not adequately cover many aspects of the life cycle. The lack of accepted standards thus lead to airframe specific hardware and support. These factors collectively carried a significant cost penalty (procurement and through-life costs), that often made an optical harness less competitive than an electrical equivalent.

c) The fibre-optic harness study

The Fibre-Optic Harness Study concentrated on developing techniques, guidelines, and standards associated with the through-life support of current generation fibre-optic harnesses applied in civil and military airframes (fixed and rotary wing). Some aspects of optical system design were also investigated. This programme has been largely successful. Guidelines and standards based primarily on harness study work are beginning to emerge through a number of standards bodies. Because of the aspects covered in the handbook, European prime contractors are in a much better position to utilise and support available fibre optic technology.

1 Scope

The original task headings in the Fibre Optic Harness Study were 'Inspection and Fault Analysis' and 'Repair and Maintenance'. However, to create a more coherent and readable handbook these have been re-arranged in this part of EN 4533 to make two new topic headings – 'Fault analysis and repair' and 'Scheduled maintenance and inspection'. The first deals with what to do when something goes wrong – how to go from a fault notification to locating the fault, and finally, repairing it. The second covers the recommended procedures for upkeep and maintaining harness health over the lifetime of its installation. It is beneficial to read both sections together as many of the practices and techniques are applicable to both situations.

Two supplemental sections consider designing a harness with repair and maintenance in mind and good practices when maintaining or repairing a harness.

To keep the handbook to a reasonable size, other Harness Study reports are called up where more detail is required. This handbook does not contain sufficient information, for example, to be the sole reference for harness fault finding but it should provide adequate background for somebody working in that field.

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.

EN 4533-002, *Aerospace series — Fibre optic systems — Handbook — Part 002: Test and measurement.*

3 Fault analysis and repair

3.1 From notification to repair

Once notified of a fault, choosing a repair strategy depends on a multitude of factors; accessibility of the fault, criticality of the system, availability of spares etc. These same issues already exist for electrical harnesses for which proven strategies are in place. What the Harness Study set out to provide were similar strategies taking into account the unique aspects of fibre optic harnesses. The result is the "Repair and Maintenance Strategy" which contains a comprehensive list of fibre optic harness faults, their symptoms and how to locate and repair them. Much of the information in this section is taken from that document.

3.2 Fault notification

A fault notification will arise from one or more of three sources; scheduled maintenance, Built-In-Test (BIT), or failure of equipment dependent upon the harness.

Ideally, scheduled maintenance should highlight all latent faults i.e. those which initially have no effect on the system performance but may lead to a problem sometime later during aircraft operation. It should also highlight faults of the gradual degradation type i.e. those which gradually deteriorate the system performance but have yet to cause a failure and any other faults that slipped through the BIT net.

BIT is the ability of the aircraft's systems to diagnose themselves. It should identify all faults that occur in the time between scheduled maintenance and, with the exception of sudden catastrophic faults, before a failure occurs. It should also be able to provide some help in locating the fault.

Failure is the worst case and should only be the result of a fault occurring which cannot be prepared for.

3.3 Symptoms

This is where differences between fibre optic and electrical harnesses become apparent. The most common symptom in a fibre optic harness is complete or partial loss of optical power. This occurs when light breaks its confinement from the fibre core and can be the result of damage to the fibre or connector. It can also be the result of contamination, excessive pressure on the cable or bending of the cable. Depending on the magnitude of the loss, the result may be a fault that is above or below the link threshold – a fault below the link threshold is a failure. Severe damage, such as a fibre break may induce a complete loss of optical power.

Intermittent optical signals are possible and may be the result of fibre movement e.g. vibration or bending of a fibre. An increase in optical power is also possible although this is more likely to be due to stability of the light source rather than the harness itself.

Gradual degradation of optical power is an important symptom to be able to detect as it could indicate the onset of a failure. Increasing contamination or proliferation of damage to the fibre could be responsible. Outside of the harness it could be due to degradation of an optical source.

Back reflection occurs at any interface with different refractive index, e.g. glass/air. Connectors are designed to minimise back reflection but a fault in this area can lead to an increase. Back reflection is of particular worry in laser-based systems where the returning light can damage the optical source.

A final category of symptoms are latent fault symptoms i.e. those which have no effect on the optical power of the system but could be the first stage of a fault that does. These are most likely to be noticed during inspection and include chafing of cables and poor stress relief on connectors.

3.4 Fault location

3.4.1 General

Fault finding techniques and strategies will play a key role in restoring and maintaining the integrity of aircraft fibre-optic systems. Unless appropriate solutions are available the aircraft operator could incur significant down time, cost, and inconvenience whilst the fault is being located. The problem is exasperated by the fact that the fibre-optic networks in question could be relatively complex, incorporating fan-out connection paths (enabled by passive couplers or active switches, for example) and may be harnessed into relatively inaccessible areas of the airframe.

Criteria considered when assessing potential fault finding techniques included:

- effectiveness of the technique for likely fault scenarios;
- skill level and time required to perform the technique;
- size, weight, power requirements, and robustness of equipment;
- safety issues.

The first factor that will influence the choice of fault location technique is the type of harness – inaccessible, embedded or open. Several of the techniques described below cannot be used on an embedded or inaccessible harness.

3.4.2 Inspection

This is the simplest fault location procedure and falls into two categories – inspection of the fibre end faces and inspection of the cables and connector housings (which requires no de-mating).

Visual inspection of the fibre end face with the naked eye or with the aid of a microscope is an important fault finding technique. A clean, undamaged end face is essential for optimum performance. Assuming the termination end face can be visually accessed, then inspection is, in most situations, entirely adequate for determining levels of contamination and damage. In terms of skill levels and equipment required, it is a technique suitable for all fault finding scenarios from manufacturing through to first line maintenance. An inspection microscope with a magnification of ×200 is sufficient for multimode fibres.

Inspection of multi-way connectors can be more complicated, especially if the end faces are recessed. Most inspection microscopes are designed solely for viewing single terminations but modified microscopes which are able to hold and view multi-way connectors are appearing. Some multi-way connectors can be partially de-assembled to provide better access to the end faces. This is beneficial for cleaning procedures as well as inspection. This is discussed further in the introduction to this Part.

Visual inspection of the harness construction is the same as for existing electrical harnesses. The only difference is that often fibre has a greater minimum bend radius than most electrical cabling so inspection for potentially fault inducing bends is an additional requirement. Inspection of harness components (if accessible) is the only viable way to control latent faults. Even then many latent faults are either not visible, e.g. sub-layer damage, or are too small to visualise even with a microscope, e.g. micro-cracking in silica components. The schedule for such inspections will have to be determined through in-service experience.

To summarise, inspection is a good technique for locating contamination, fibre end face damage, cable damage and connector housing/backshell damage in accessible areas of the harness. Its main advantages are ease and speed of use plus the low cost and mobility of test equipment. The benefits of this technique fit well with the likelihood of failure, which is much more likely to occur in areas of high maintenance and during maintenance actions.

Inspection is not a viable technique for locating faults in inaccessible areas of the harness or fibre damage within the cable / connector.

3.4.3 Visible fault locator

This technique is based on the injection of visible light into the fibre-optic system under test. Defects such as fibre breaks or cracks scatter this light. If the cable or connector housing allows, this results in flare being visible at, or close to, the location of the fault. Figure 1 and Figure 2 show a visible fault locator.

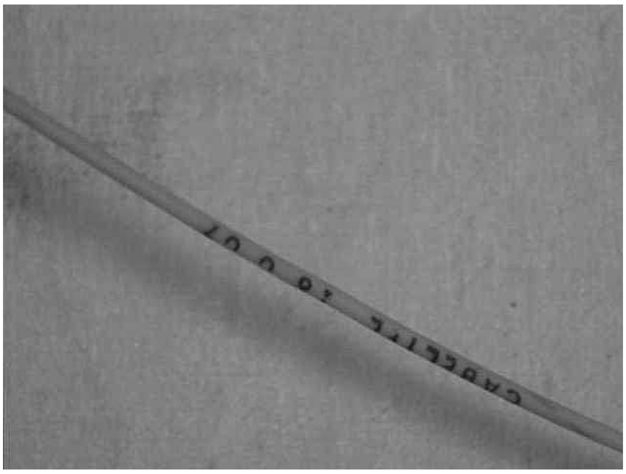

Figure 1 — Broken fibre under cable

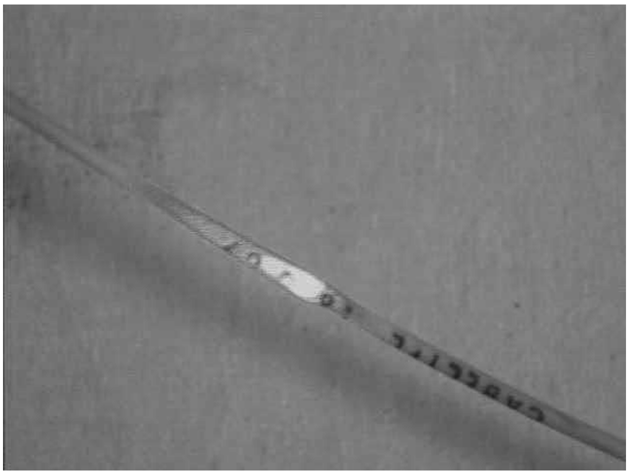

Figure 2 — Visible fault locator locates break

This is an appealing technique being easy to perform and requiring only the visible fault locator. A typical locator would be based on a red (635 nm) laser diode, housed in a torch type package with battery power. A white light or visible LED based device could just as easily be used. The only restriction on the source is that it is eye safe. By pulsing the source (~Hz) its ‘detectability’ to the eye can be enhanced. Also, by connectorising the source, efficient coupling into the harness can be achieved.

Visible fault locators are appropriate to use on fibre breaks combined with translucent cable constructions. They are also a quick and easy way to locate complete optical power loss faults by checking the continuity of point-to-point links.

Visible fault locators are limited to these types of fault and have the major drawback that most current avionic harness components are packaged in opaque materials and/or installed in conduit or visually inaccessible areas of the airframe.

3.4.4 OTDR

Optical Time-Domain Reflectometer (OTDR) technology has developed to satisfy the demand for fault finding and loss measurement in telecommunications, and latterly commercial data communication networks. They are specialist tools and certain ‘high performance’ OTDRs require training and a good knowledge of fibre-optic technology for effective use. Due to the fact that they were developed for relatively long distance links there are doubts over whether they have the necessary spatial resolution for use on avionics harnesses.

On top of the basic functionality discussed in the Test and Measurement chapter, OTDRs can be designed to automatically interpret information from multiple events and present them in user friendly form. Signal processing software can potentially: identify an event and locate it relative to a preceding event or the instrument bulkhead; identify the cause of the event; measure insertion loss increase from preceding event; measure total link loss; analyse only those events over a certain dB threshold; zoom in on sections of the network; *etc.* Many fault finding algorithms rely on comparison of the current OTDR record with a previously stored ‘footprint’. Automatic fault finding software is usually installed in the latest OTDRs largely de-skilling fault diagnostic operations.

The key performance parameters of OTDRs pertinent to avionic optical harness measurements are:

- Event Dead Zone – the ability to discriminate between closely spaced events, including the instrument’s bulkhead connector, defined as the distance in metres between the leading edge of a reflective event and the point on the trailing edge where the signal drops to 3 dB below its peak value;
- Attenuation Dead Zone (or Loss Measurement Resolution) – the ability to measure insertion loss of two closely spaced events, defined as the distance from the onset of a reflective pulse to the point where the event tail has recovered to within 0,5 dB (or more recently 0,1 dB) of the background noise floor;

As discussed in the Test & Measurement Chapter, the concept of ‘dead zone’ is specific to instruments such as OTDRs and is not well recognised or understood. Figure 3 shows part of an idealised OTDR trace. Event dead zone (EDZ) and attenuation dead zone (ADZ), as defined above, are depicted.

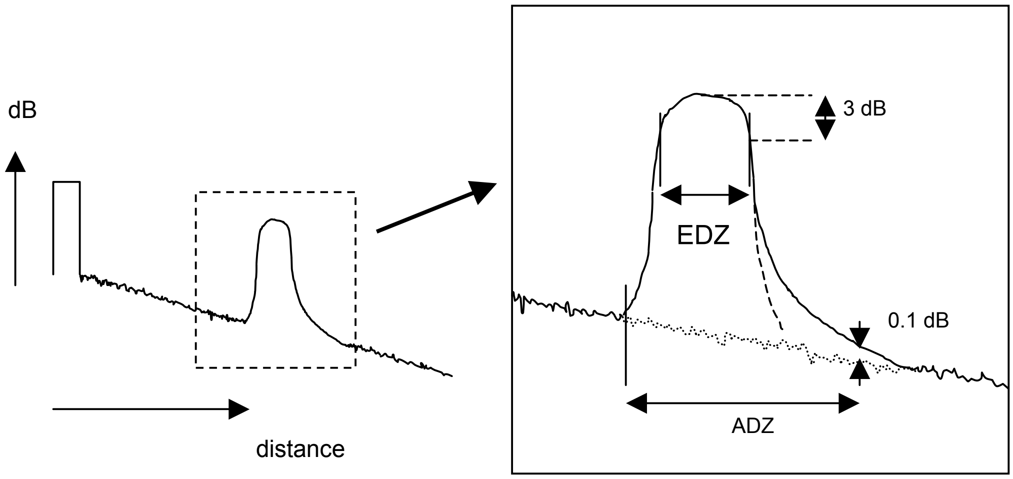

Figure 3 — Dead zone definitions for OTDRs

EDZ is the critical parameter for fault finding as in most cases accurate insertion loss measurement is unnecessary. However, current OTDRs struggle to meet the specific requirements of airborne optical harnesses in this respect. EDZs of less than one metre are of potential interest for basic fault finding in point-to-point avionic harnesses. EDZs and ADZs of ten centimetres for typical harness features would make OTDRs of more general use for both fault finding and insertion loss measurements.

Figure 4 shows actual OTDR results from a two metre EDZ commercial instrument interrogating a test installation. Note that the ‘extra’ peaks are due to multiple reflections. This demonstrates the importance of minimising any Fresnel reflections (e.g. from an airgap connector) which otherwise dominate the OTDR trace. This can be achieved through PC terminations. OTDRs may also struggle to interpret more complex avionic optical Local Area Networks (LANs) such as multi-way, star-coupled networks.

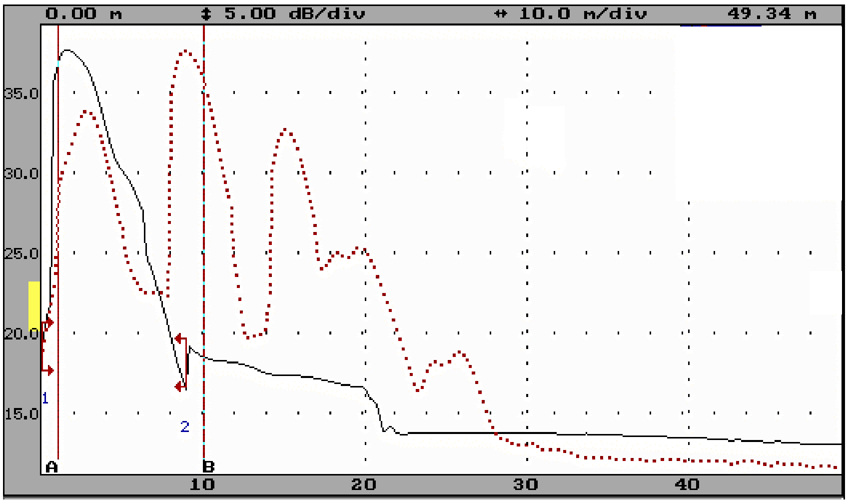

Figure 4 — Commercial OTDR trace from a point-to-point avionic link