Quality Assurance and Quality Control of Optical Fibres for CERN

Elisa GUILLERMAIN and Johannes TROLLER on behalf of the Cabling and Optical Fibre Section (EN-EL-CF)
Seminar Outline

Introduction
Optical Fibres

Part 1
Quality Control for Conventional Fibres and Cabling Components

Part 2
Quality Assurance Plan for the Supply of Special Optical Fibres
Introduction

Optical Fibres

Optical Fibre Network

Optical Fibre Types
Main characteristics:
- ~35000 km optical fibre length;
- ~100000 optical connectors.

Supplied and installed through an industrial support contract.
Optical Fibre Types

Single-mode

Multi-mode
Optical Fibre Types

- **Conventional optical fibres:**
  - Supplied and installed through an industrial support contract.

- **Special optical fibres:**
  - **Radiation resistant optical fibre:**
    - Procured through a specific supply contract.
EN Seminar - 15th May 2014

Part 1: Quality Control for Conventional Fibres and Cabling Components

Johannes Troller
on behalf of the Cabling and Optical Fibre Section (EN-EL-CF)
Part 1 Outline

Part 1
Quality Control for Conventional Fibres and Cabling Components

Technical Background → Quality Control Activities → Test Results, Examples & Achievements
Context & Technical Background

Part 1
Quality Control for Conventional Fibres and Cabling Components

Technical Background

Quality Control Activities

Test Results, Examples & Achievements
Single-Fibre Connectors

Ferrule (diameter: 2.5mm or 1.25mm)

Ferrule end face

Core (diameter: 9µm or 50µm)

Fibre

Ferrule 1

Ferrule 2
Multi-Fibre Connectors (MPO)

Ferrule
(6.4mm x 2.45mm)

Guide hole
(diameter 0.7mm)

Guide pin

Ferrule 1

Ferrule 2
Big variety of articles.
(≈2700 different articles in contract)
Complex supply chain.
Complex production processes.
Quality Control Activities

Part 1
Quality Control for Conventional Fibres and Cabling Components

Technical Background

Quality Control Activities

Test Results, Examples & Achievements
Assessment of product quality.

Ensure that all products are according to contract specification.

QC for all material orders.

I „Technical Specialist“.

(according to quality assurance plan of CF-section)
QC Activities

- Laboratory fully equipped with latest test equipment.
  (microscopes, interferometers, insertion loss/return loss meters, OTDR)
- Visits in the field.
- Visits at contractor’s premises.
  (stock, factory)
Working Method

1. QC Planning
2. Material Reception
3. Selection of Test Samples
4. Test Procedure + Documentation

Delivery to User

Result?

Pass

Fail

Material Rejection
QC Planning

Material Reception → Selection of Test Samples → Test Procedure + Documentation

Delivery to User

Pass

Result?

Fail

Material Rejection

Project A
Project B
Project C
Project D
Project E
Project ...  

Material reception
Material delivery to user

Weeks
Material Reception

- Correct material?
- Correct quantities?
Sample size variation:

- High sample size at contract startup;
- Decreased sample size for standard products with known good quality;
- Increased sample size for new developed products or when a non-conformity is detected.
Working according CF test procedures:

- Procedures developed for each product type;
- Procedures developed for each instrument.

<table>
<thead>
<tr>
<th>Product properties</th>
<th>Serial number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cable type</td>
<td>OM4</td>
</tr>
<tr>
<td>Fiber type</td>
<td>6x MPOM</td>
</tr>
<tr>
<td>Terminal A</td>
<td>6x MPOM</td>
</tr>
<tr>
<td>Length</td>
<td>36.6 m</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test name</th>
<th>Test passed</th>
<th>Not passed</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheath color</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Connector color</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cord labels</td>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
“Feedback loop“ to factory.
Part 1
Quality Control for Conventional Fibres and Cabling Components

Technical Background

Quality Control Activities

Test Results, Examples & Achievements
Poor quality cable sheath for one production batch:
- Risk for fibre breaks;
- 82 out of 110 tested articles rejected (75%) for one delivery.

Achieved improvements at factory:
- Improved QC during cable production at the factory;
- Improved QC of incoming goods at the assembly house.
Number of rejected articles in reference to tested articles (%).

- **Jan-13**: 0%
- **Feb-13**: 0%
- **Mar-13**: 0%
- **Apr-13**: 0%
- **May-13**: 2%
- **Jun-13**: 75%
- **Jul-13**: 0%
- **Aug-13**: 0%
- **Sep-13**: 4%
- **Oct-13**: 0%
- **Nov-13**: 0%
- **Dec-13**: 0%
- **Jan-14**: 33%
- **Feb-14**: 0%
- **Mar-14**: 0%
- **Apr-14**: 0%

Legend:
- **Others**
- **Missing parts**
- **Kinks**
- **Loose connector**
Example: Connector Loss too High

- Poor quality MPO connectors:
  - Application 40 & 100 Gigabit Ethernet links;
  - New developed product type.

100 Gigabit Ethernet link structure:

- Optical channel
- Transmitter
- MPO connector
- Multi-fibre cable
- Receiver
- MPO connector
IEEE 802.3ba standard for 40 & 100 Gigabit Ethernet.
(multi-mode at 850nm)

Loss (dB)

- Max. optical channel loss: 1.50dB
- Fibre loss (length ≤ 150m): 0.50dB
- Loss connection 1: 0.35dB
- Loss connection 2: 0.35dB

Margin: 0.30dB
Loss Test Results

Distribution of loss measurements

Threshold: 0.75dB

(Loss measurements include 2 connections and fibre loss.)
Example: Connector Loss too High

- Poor quality MPO connectors:
  - 20 out of 93 tested articles rejected (22%).

- Achieved improvements at factory:
  - Improved QC;
  - Purchase of new production equipment;
  - Improved production process;
  - Improved employee skills.
Number of rejected articles in reference to tested articles (%).

- Jan-13: 36%
- Feb-13: 32%
- Mar-13: 26%
- Apr-13: 0%
- May-13: 2%
- Jun-13: 33%
- Jul-13: 0%
- Aug-13: 4%
- Sep-13: 0%
- Oct-13: 0%
- Nov-13: 0%
- Dec-13: 0%
- Jan-14: 0%
- Feb-14: 0%
- Mar-14: 0%
- Apr-14: 0%
Impact on Projects

(Time is not true to scale in these diagrams.)
Impact on Projects

Preventive QC avoids systematically:
- Delayed project completion;
- Additional time and resources for cable removal and re-installation;
- Up to 3 times increased cable installation cost.

(Time is not true to scale in these diagrams.)
Example case: Non-conform fibres installed in radiation area due to factory mistake.

Consequences:
- Large replacement campaign organized during LS1;
- All LHC points concerned;
- 1 MCHF cost + legal issues.
Collaboration with user following special requirements on fibre length tolerance:

- Multi-fibre cables with 96 fibres each.
Fibre length measurements for 60 cables, 96 fibres each.

Difference = 0.25m
Conclusion

- QC was organized systematically for LS1 on received contract products
  - Non-conformities received despite expectations
  - QC avoided significant impact
- Non-conformities discovered during 1 year
  - 8680 articles were subject to QC
  - 25% of tested articles rejected, over a total number of 1770 tested articles
- With preventive QC we achieved
  - Identification of non-conformities before installation
  - Clear identification of responsibilities for non-conformities between CERN and contractor
- Feedback systematically given to the contractor during production process
  - Constant improvements of production process at the factory
- Essential to carry-on QC on products received in the future
Part 2: Quality Assurance Plan (QAP) for the Supply of Special Optical Fibres

Elisa Guillermaint on behalf of the Cabling and Optical Fibre Section (EN-EL-CF)
Outline

- **Context**
  - Attenuation in optical fibres
  - Optical fibres at CERN
  - Radiation sensitivity of optical fibres

- **Procurement of radiation resistant optical fibres**
  - Technical requirements
  - Optical fibre qualification
  - Quality Control

- **Conclusions**
Slope of OTDR trace shows optical fibre attenuation coefficient [dB/km].
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Optical fibres at CERN

- Accelerator and experimental areas: Zones subject to radiation.
  - Examples:
    - SPS, Sextant 1:
      - Up to 300 kGy / year.
    - LHC, Point 3 and point 7:
      - Up to 100 kGy / year.

- Optical fibre exposure depends on:
  - Installation zone;
  - Distance from beam line.

- In high dose areas, special optical fibres are installed.
Outline

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- Conclusions
Radiation Induced Attenuation (RIA):
- Radiation increases the attenuation of the optical fibre.

RIA of installed optical fibres must be known and understood.
Radiation sensitivity of optical fibres

- Optical fibres RIA: Laboratory measurements

![Graph showing radiation induced attenuation (RIA) vs. dose](image)
Optical fibres RIA: Laboratory measurements

RIA depends on:
- Environmental conditions:
  - Accumulated dose;
  - Dose rate;
  - Temperature.

Irradiation conditions:
- Dose rate: 0.2 Gy/s
- Temperature: 25°C
Radiation sensitivity of optical fibres

- Optical fibres RIA: Laboratory measurements

RIA depends on:
- Environmental conditions:
  - Accumulated dose;
  - Dose rate;
  - Temperature.
- Operational conditions:
  - Wavelength;
  - Light power.

**Irradiation conditions:**
- Dose rate: 0.2 Gy/s
- Temperature: 25°C

**Operational conditions**
- Light Power: 10 µW
  - 1310 nm
  - 1550 nm
Radiation sensitivity of optical fibres

Optical fibres RIA: Laboratory measurements

RIA depends on:

- Environmental conditions:
  - Accumulated dose;
  - Dose rate;
  - Temperature.

- Operational conditions:
  - Wavelength;
  - Light power.

- Optical fibre itself:
  - Optical fibre type (SM, MM);
  - Dopants and doping level;
  - Manufacturing process;
  - Drawing conditions.

Irradiation conditions:
- Dose rate: 0.2 Gy/s
- Temperature: 25°C

Operational conditions:
- Light Power: 10 µW
  - 1310 nm
  - 1550 nm

Standard Single-mode optical fibre, Doped with Germanium
Radiation sensitivity of optical fibres

- Radiation resistant optical fibres.

- Special dopant and special manufacturing process.

- Radiation Induced Attenuation is lowered compared to standard optical fibres.

![Graph showing Radiation Induced Attenuation (RIA) vs. Dose for different types of optical fibres with irradiation conditions: Dose rate 0.2 Gy/s, Temperature 25°C. The graph compares Standard SM optical fibre and Radiation Resistant SM optical fibre at 1310 nm and 1550 nm wavelengths.]
Outline

- Context
  - Attenuation in optical fibres
  - Optical fibres at CERN
  - Radiation sensitivity of optical fibres

- Procurement of radiation resistant optical fibres
  - Technical requirements
  - Optical fibre qualification
  - Quality Control

- Conclusions
Special Optical Fibres
Quality Assurance Plan

1. CERN Technical Requirements
2. Optical Fibres Qualification
3. Contract
4. Quality Control
5. Assembly Into Cables
6. Traceability
7. Installation Projects
Constraints:
- Minimum optical budget of machine systems is 6 dB;
- Machine areas most subject to radiation:
  - Dose rate is estimated to reach some hundred kGy/year.
- Optical fibres links are targeted to last at least for 10 years.

Requirements:
- Taking into account optical link lengths and other losses (splices, connectors, etc...), the radiation resistant optical fibres shall have a RIA of:
  - Maximum 7dB/km after exposure to 100 kGy.
Specific tests are performed in order to ascertain optical fibres performances:
- Selection of optical fibres types and manufacturers.

Qualified optical fibres:
- Meet CERN requirements;
- Are suitable for installation at CERN.
First procurement in 2006:

- 8 manufacturers contacted;
- 6 replied;
- 11 optical fibres types tested and compared;
- 2500 km procured for LHC construction.

Work realized with the valuable input of Thijs Wijnands (EN-MEF).

Irradiation tests performed at Fraunhofer institute.
Second procurement in 2012:
- Extensive tests performed on two most radiation resistant optical fibres;
- Variation in dose rate and in wavelength.
Special Optical Fibres Quality Assurance Plan

- Technical Specification;
- Contract awarding;
- Industrial production;
- Supply delivery.
2400 km ordered;
- Delivered from August 2012 until January 2014.

Delivery schedule:
- 150 km/month.
- Production rate slower than standard optical fibres
  (≈ 40’000 km/month).

65 batches produced;
- 267 spools in total.
Quality Control tests:
- Performed by the manufacturer;
- Performed by CERN.
Tests performed by the optical fibre manufacturer:

- Full series of tests required by CERN throughout the production;
- Full documentation requested;
- Compliance with International Standards and with CERN requirements.
Irradiation tests performed by CERN:

Each produced batch is tested:
- 250 m samples are required for each produced batch;
- 65 irradiation tests were performed.

Irradiation tests conditions:
- $^{60}$Co radiation source;
- Dose rate of 1 Gy/sec;
- Total dose of 100 kGy;
- 1310 nm and 1550 nm.

Irradiation tests performed at Fraunhofer institute.
Radiation Resistant Fibre Quality Control

Dose rate 1 Gy/sec
Temperature 25°C

Graph showing the relationship between dose [Gy] and RIA [dB/km] for different batches and wavelengths.
Special Optical Fibres Quality Assurance Plan

CERN Technical Requirements ➔ Optical Fibres Qualification ➔ Contract

Quality Control

Assembly Into Cables
Performed within the frame contract:
- Assembly in micro-cables for cable blowing;
- Contract was set-up in anticipation of special optical fibres cables assembly;
- Specific procedures were defined;
- Part of the QAP.

Spare optical fibre and spare cables available for further installation works.
Documentation required in the QAP allows full traceability:
- Traceability from the single optical fibre up to the installed cable;

Performed via CERN database (GESMAR):
- Traceability;
- Stock management;
- Installation follow up.
CERN Technical Requirements → Optical Fibres Qualification → Contract

Quality Control

Assembly Into Cables → Traceability

Installation Projects
Installation projects impose the quantities and delivery schedule of the radiation resistant optical fibre cables:
- All cables delivered on time;
- LS1 planning respected.

LS1 installation projects examples:
- SPS BPM upgrade (new BI system):
  - 33.5 km installed.

- Radiation sensitive fibres replacement campaign and consolidation in LHC:
  - 22.8 km installed.
Conclusion

- Special radiation resistant optical fibres were procured:
  - Procurement of 2400 km of special radiation resistant optical fibre;
  - 65 irradiation quality control tests;
  - Assembly into cables: 90 km produced so far.

- The Quality Assurance Plan enabled:
  - Full compliance of special optical fibres with CERN requirements;
  - Respect of LS1 planning;
  - Traceability of the installed optical links, up to the fibre level;
  - Full documentation of the whole process.

- Quality Assurance is a vital part of the installation process:
  - The failure of an optical fibre link in the accelerator or experimental areas can lead to the machine’s interruption.
Publications


Others


Fujikura news n°375 (http://www.fujikura.co.jp/eng/f-news/2036945_4207.html) and news release (http://www.fujikura.co.jp/eng/newsrelease/2036502_3501.html).

Thanks