A Dense Multi-Ribbon Cable For Installation in a Harsh Environment at CERN

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Abstract

The ribbon concept is proposed for a completely new application: an installation in a harsh environment at the European Laboratory for Particle Physics, CERN, in Switzerland. Two major experiments will be installed at the CERN Large Hadron Collider (LHC) called ATLAS and CMS. The experiments are planned to become operational by 2005. Optical links will be required to exchange data between the detector front ends and the control rooms. The ATLAS experiment will use approximately 25000 digital optical links based on 50µm-fiber and 850nm VCSEL emitters while the CMS experiment will operate about 150000 optical links.

A novel ribbon cable with 12-fiber ribbons has been designed and tested. The present study reports on the mechanical properties, radiation tolerance for the entire cable and the individual ribbons.

We also present the inline-technique for processing a 12-fiber ribbon, i.e. coloring and ribbonizing in one step.

1. Introduction

1.1 Particle Physics Experiments and Nuclear Radiation Effects

The European Organisation for Nuclear Research, CERN, is an Intergovernmental Organisation with 19 European member states.

CERN has its seat in the Canton of Geneva (Switzerland) but its laboratories are located on both sides of the Swiss-French border.

CERN is running a number of particle accelerators the largest being the Large Electron Positron Collider (LEP).

The Large Hadron Collider (LHC) project, a large proton-proton collider and superconducting accelerator of 27km in circumference, was approved in 1994. The LHC will be the next major research tool for world particle physics and it is expected to be commissioned in 2005.

Experiments to exploit the new physics expected from high energy proton-proton collisions produced by the Large Hadron Collider (LHC) are currently being prepared.

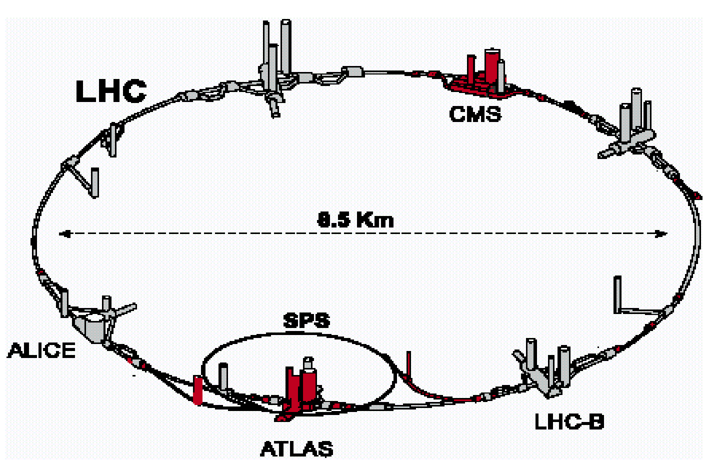

Figure 1. Sketch of the underground part of the Large Hadron Collider at CERN, and its four experiments: Alice, Atlas, LHC-B and CMS.

The main two experiments, ATLAS and CMS, (Fig. 1), will use a large number of optical links to transfer data off the experiments to remote data acquisition electronics, both projects being lead by independent development teams. For example, the ATLAS experiment will use approximately 25,000 digital optical links based on 50/125 multimode fibers and VCSEL emitters operating at 850nm [1].

The inner tracker of the CMS experiment alone has 50,000 analogue optical links using single-mode and edge emitting lasers operating at 1300nm [2-5]. To aid installation the fiber ribbon concept is being studied by both these experiments.

A non-standard feature for the data-links is the radiation environment in which they must operate. The integrated ionizing dose is expected to reach a few 100kGy in the central regions of the experiments after 10 years of running [2].

The CMS experiment has identified a standard un-shifted single-mode fiber, which incurs a loss of 0.04 to 0.06dB/m at such levels of radiation. The ATLAS experiment is studying a fluorine doped 50/60/125 step-index fiber and subsystems further from the central region are hoping to use standard phosphorous-free multimode fiber.

1.2 Ribbon Cable

Since both experiments will use fiber optic cables with similar environment and installation requirements, a new cable has been proposed for indoor use with an 80mm minimum bending radius and an outer diameter of 9mm with HFFR sheath material. Mechanical and environmental tests according to IEC-standards have been performed, as well as additional specific mechanical and radiation tests. The developed cable meets the required specifications, even after exposure to aggressive levels of nuclear and ionising radiation.

2. A Novel Ribbon Cable

A novel ribbon cable with eight 12-fiber ribbons has been designed and tested. The 12-fiber ribbon is of the encapsulated type with a thin outer layer, the ribbon matrix (Fig. 2).

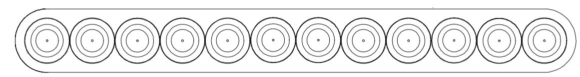

Figure 2. A 12-fiber ribbon

The same ribbon geometry is used for the CMS(single-mode) and ATLAS(multimode) detectors.

The ribbon has been processed with the inline-technique, i.e. coloring and ribbonizing in one step (Fig. 3). The ribbon process is mature and [6] with a professional maintenance program the risk is minimized to obtain a problem in the ribbonizing. It is, however, a complex unit. It is built from different modules (coloring and ribbonizing). It is also possible to extend this further to make ribbons with higher fiber counts or more than one ribbon at the same time.

The cable (Fig. 4) is for indoor use with, as already mentioned, an 80 mm minimum bending radius and an outer diameter of 9 mm with HFFR sheath material.

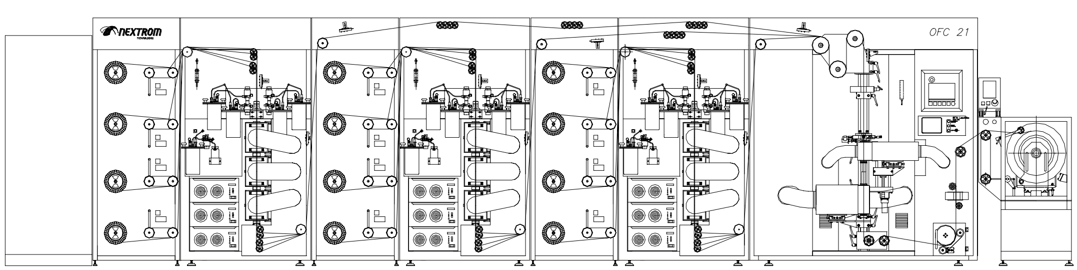

Figure 3. A 12 fiber in-line ribbon machine

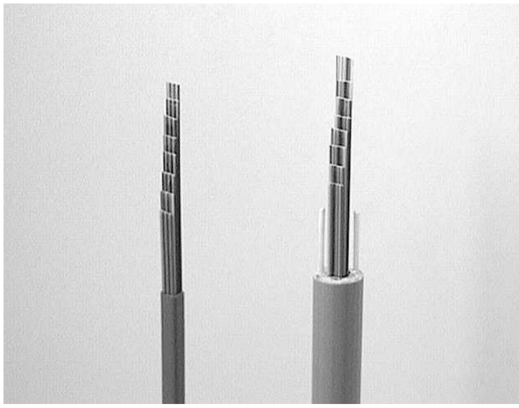

Figure 4. Both the ribbon bundle and the novel ribbon cable are shown above

In addition a simple ribbon bundle with eight 12-fiber ribbons has also been designed for short distances, maximum eight meters.

In Table 1 we give the single-mode ribbon cable characteristics.

Table 1. Cable Characteristics

Fiber Specifications		
Mode field diameter	μm	9.2 ± 0.4
Cladding diameter	μm	125 ± 1
Cladding non-circularity	%	≤ 1
Mode field concentricity error	μm	≤ 0.5
Coating diameter	μm	245 ± 5
Transmission Specifications (λ = 1310nm)		
Attenuation average in the cable	dB/km	≤ 0.37
Attenuation maximum, single fiber	dB/km	≤ 0.40
Zero-dispersion wavelength (dispersion un-shifted)	nm	1300 - 1324
Cut-off wavelength, cable, λ_{cc}	nm	1260
Cable Specifications and Construction		
Sheath diameter	mm	9.5
Bending radius, permanently and during installation (minimum)	mm	80
Tensile force permanent (maximum)	N	80
Pulling force during installation (maximum)	N	800
Crush resistance (maximum)	N	500
Cable net weight	kg/km	75

3. Cable Tests

3.1 Factory Tests

The present study reports on the mechanical properties, radiation tolerance and installation issues for the entire cable and the individual ribbons.

The cable has been tested according to the international standards IEC 60794-1 and EN 187 000.

The main factory test results are presented below.

3.1.1 Transmission performance

The attenuation in all fibers in both test cables was measured in the single fibre and in the completed cable.

The manufacturing process did not significantly change the fiber characteristics.

Fig. 5 shows typical results from the temperature test over the range –40 to +70 °C on the MM-cable.

The cable shows a satisfying behaviour down to –20°C, which is adequate to the functional needs in the detectors. The horizontal axis shows the temperature cycling order.

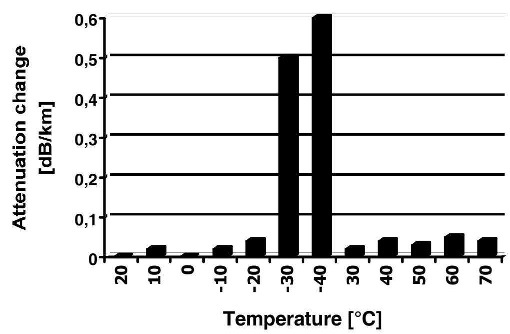

Figure 5. Temperature performance at the wavelength 850nm of the MM-cable to the Atlas project

3.1.2 Tensile performance

The cables were tested up to a tensile load of 2 kN. At this load no significant change in attenuation at neither of the measured wavelengths was noted, see Fig. 6, which shows the test result on the SM-cable.

The fiber strain reaches half of the proof test level at the load 1.1 kN. This is a strain that is commonly used as maximum allowed fiber strain in a cable or during manufacturing of a cable to guarantee the lifetime of the cable. Furthermore, no residual cable elongation was measured after the test.

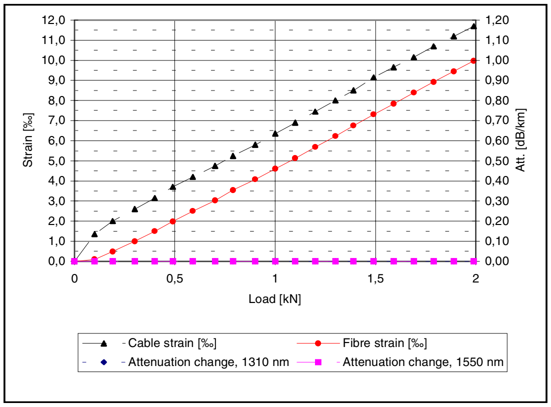

Figure 6. Tensile performance of the SM-cable to the CMS project. Since no attenuation increase can be seen at neither 1310 nor 1550nm, the values for both wavelengths follow the x-axis.

3.1.3 Crush performance

No significant change in attenuation can be seen in the crush test, using a plate with a diameter of 100 mm, when the cable is exposed to compressive loads up to 2 kN. The result from the crush test of the MM-cable is shown in Fig. 7 both 850 and 1300nm.

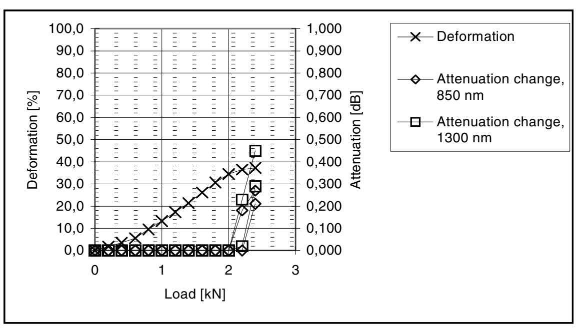

Figure 7. The result from the crush test on the MM-cable for the Atlas project

3.1.4 Flammability test

The test was carried out in accordance with IEC 332-3 category C.

Cable pieces were lashed to a ladder. The ladder was positioned vertically in a test chamber, see Fig. 8.

A flame was applied for 20 minutes. After the test the charred portion was 1.15 meters which means that the cable passed the test and is approved according to the standard.

The standard requires a charred portion less than or equal to 2.5 meters.

3.2 Tests at CERN and other facilities

As mentioned earlier there are two different projects at Cern interested in the 12-fiber ribbon concept. We will treat them here separately. The ATLAS tests will be presented first followed by the CMS-results.

3.2.1 ATLAS cable tests

Two types of experiment were performed:

1. Single and Multiple 360° turn put into cable in bending plane at various radii.
2. Routing of cable under simulated installation conditions within the ATLAS detector

During both types of test the light transmission of the fibers was monitored to assess excess loss caused by the bending of the cable.

Light was injected into the fiber from 840nm VCSEL sources and was monitored using low noise photodiode receivers.

The stability of the injected light was also monitored. The measurement set-up is shown in Fig. 9. An example of a multi-turn test is shown in Fig. 10. Routing along a simulated installed path containing the same number and type of bends as projected for the cable installed in the ATLAS detector is shown in Fig. 11. In addition to being routed inside ATLAS, it is foreseen that some services will require routing in cable chains to allow the end-caps to be withdrawn during assembly and maintenance. For this reason a test of this movement was also carried out as shown in Fig. 12. Qualitative assessment of the handleability of the cable was made during the loss tests.

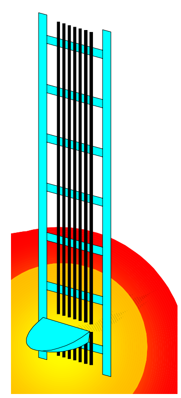

Figure 8. Flammability Test

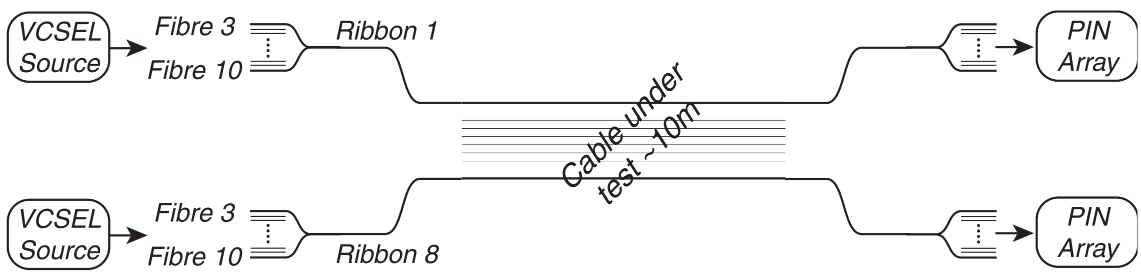

Figure 9. Test set-up

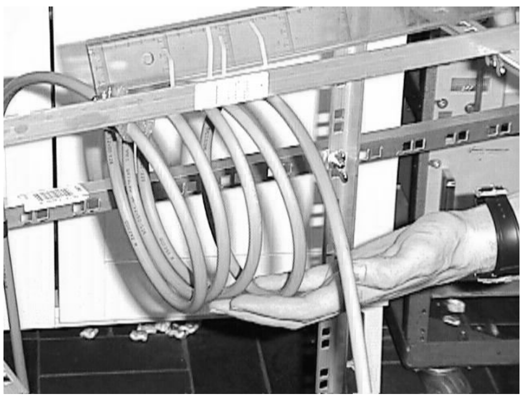

Figure 10. Example of cable bend testing

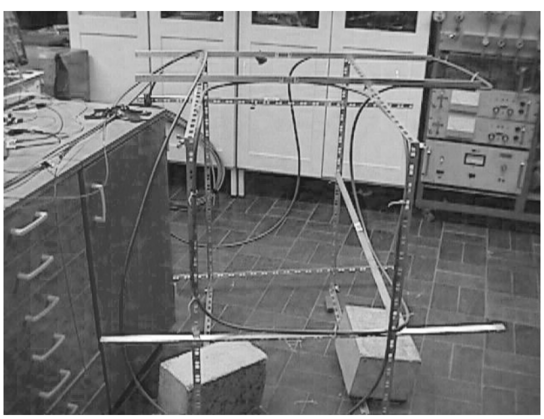

Figure 11. Cable being tested under simulated installed conditions

3.2.1.1 Single and Multiple turns

Complete 360° turns are not realistic in terms of the final installation, but rather provide a worst case for the cable. The results can be summarised for single turns as follows:

- ◊ No effect on loss if Bend Radius >100 mm
- ◊ 100 mm > Bend Radius > 80 mm: 0.2-0.4 dB loss
- ◊ Bend Radius < 80mm: 0.5-1.6 dB loss

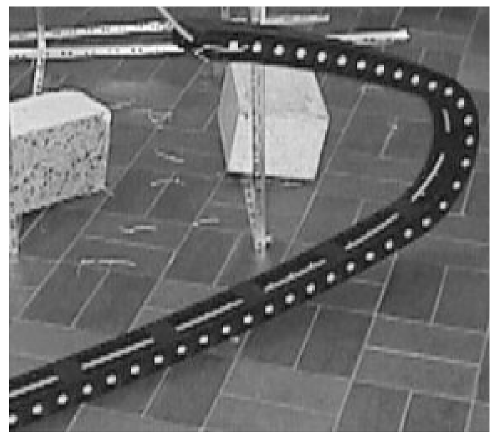

Figure 12. Cable routed in cable chain

Multiple turns caused increased losses:

- ◊ 2-5 turns at Bend Radius = 80mm: up to 4dB loss observed
- ◊ Over long term (12 hrs), bend radius 85 mm, steady loss @ 1.8dB

No loss was observed for turns <180°, the condition which will be encountered by cables installed within ATLAS.

3.2.1.2 Simulated routing

Mechanical drawings of the proposed cable routing within ATLAS were used to give both the number and nature of the bends foreseen in the current detector layout. This information was used to route the cable around a frame with successive bends in orthogonal planes, spaced more aggressively than the proposed ATLAS cable routing. This route had no bends >90°, and no losses were measured in the fibres. This is in agreement with the bend test results described in the section above. Futhermore, in the cable no losses were observed when the cable was mounted in the cable chain and the cable chain was allowed its full range of movement. Handling the cable for the purposes of these tests did not reveal any special precautions that need to be taken apart from making certain that the ribbon stack exited the cable in the correct orientation. This can be addressed by the proper termination of all ribbons at the cable exit, which will be carried out more carefully in the final system. No precautions were taken in this regard for these tests.

3.2.2 CMS cable tests

With this set of measurements, we wanted to better understand how the 96-fiber optical cable works under extreme bending conditions. The test set-up is similar to the ATLAS experiment, but we now work with single-mode fibers at 1310 nm. Moreover, the ribbons are spliced together at both ends of the cable under test so that light meanders through all ribbons before being measured.

Two types of experiments were performed. In a first step, the cable attenuation was measured under torsion, and bend conditions. No significant change of attenuation was observed when twisting the cable by as much as 4 turns/m, or winding it (1 turn, 8cm radius). In a second step, the cable was fixed and coiled around a 25cm size wooden cube to simulate successive bends in orthogonal planes. In the test illustrated in Fig. 13, 90° turns (with 8 cm bend radius) were imposed on the cable at neighbouring corners of the cube but on different faces, separated by 9 cm long straight sections where the cable was allowed to twist. The cable attenuation was measured after each quarter of a turn. No significant attenuation increase could be observed even after as many as 25, 90° turns in orthogonal planes.

The SM cable behaviour was thus found to be excellent at 1310nm.

3.2.3 Radiation tests

For the tests reported here the multimode fiber, 50 µm, originates from Plasma Optical Fibres and the un-shifted single-mode fiber from Corning.

It is well established that optical fiber production conditions [7], including the level of phosphorus doping, can strongly affect the radiation tolerance of a given fiber. Pure silica core fibers are generally found to be more radiation tolerant than doped silica examples. The level of optical absorption measured in an optical fiber exposed to radiation depends not only on the total ionising dose (or neutron fluence) but also on the dose rate (or neutron flux). The fiber types used in these tests are not pure silica core, but phosphorus free. The main reason for not using pure silica core in the single-mode case is that transmission is at 1310 nm and the only available pure silica core fiber operates at 1550 nm. Another reason is that the now qualified fiber is the most common one and therefore easy to supply for the CMS-experiment. In the multimode case some links operate at 1.6 Gb/s and therefore require graded-index fiber. For the inner detector links a pure silica core step-index fiber has been chosen. This fiber has not been part of the experiments reported here.

The evaluated multimode fiber exhibits an induced attenuation of ~0.1 dB/m at 800 Gy(Si) and 2×10^{13} n(1 MeV Si)/cm^2 [7]. In the single mode case, induced losses of 0.04 to 0.06 dB/m were measured at 100 kGy(Si) (720 Gy/hr dose rate) [2].

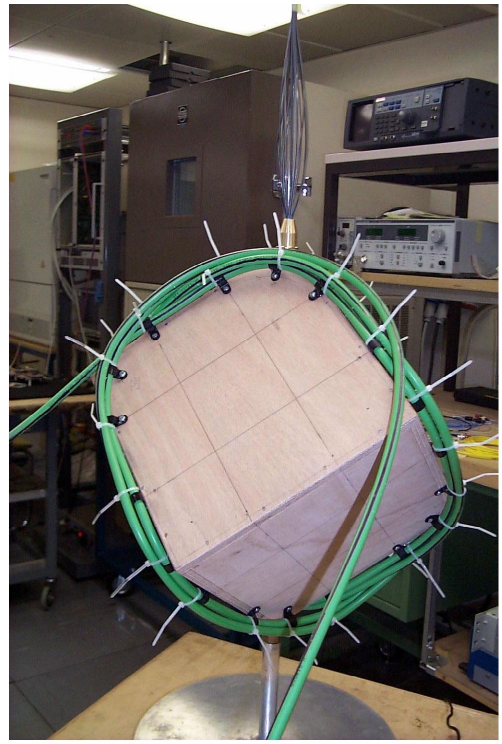

Figure. 13 "Worst case test" with 25 cm cube

The mechanical properties of the cable did not change after neutron and gamma irradiation.

The irradiation facilities have been various institutes and universities in Europe and USA.

4. Conclusion

We have discussed a novel ribbon concept for an application at CERN.

The most important environmental and mechanical properties of the cable:

- Cable diameter, 9.5 mm
- Minimum bending radius, 80mm (90° bend)
- Tensile strength, 1kN
- Fire resistance, according to IEC 332-3 cat 3.
- Radiation resistance

When exposed to standard cable tests and some worst case situations the cable responds well. The design is also very suitable for the extreme installation conditions that will be applicable at CERN.

5. Acknowledgements

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Before that, he worked inside the CERN R&D48 "ROSE" Collaboration in software developing and silicon detectors radiation hardness.